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Ministry of Economic Affairs, Agriculture and Innovation

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Jatropha Assessment

>> Focus on energy and climate change

Jatropha Assessment
Agronomy, socio-economic issues, and ecology

Facts from literature

Colofon

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Glossary

Jatropha: Jatropha curcas Linnaeus

Outgrower or contract farmer: a farmer (most often as smallholder) who has a contract with a processor to sell the produced Jatropha seeds. The input materials are sometimes provided for free, transport expenses might be arranged in the contract.

Smallholder: a small farmer who produces mainly for subsistence. He/she can be an outgrower/contract farmer or independent producer.

RSB: Roundtable on Sustainable Biofuels

Executive summary

Agronomy

Agronomy aspects of jatropha are merely reported for juvenile Jatropha curcas plants (seedlings) and relatively young production systems of less than 3 years old. Reports on germination, transplanting and propagation are quite complete, but mostly refer to (greenhouse) experiments and to a lesser extent to small-scale and industrial scale field production sites. The lack of well described methodologies for the response of Jatropha curcas to natural and additional resources such as radiation, temperature, water and nutrients is striking, but understandable, as the majority of Jatropha stakeholders are not equipped and not educated to produce scientifically sound reports on Jatropha curcas growth and production. Only limited experimental fertilization experiments have been presented so far. Recommendations on fertilization and irrigation strategies may still be lacking because recycling of nutrients is not well understood either. The toxic compounds (phorbol esters) of jatropha plant residues and press-cake degrade within 10 days when incorporated in the soil, and could not be traced in vegetable crops fertilized with jatropha press-cake.

Pruning methods (timing, frequency and technique) play a very important role in Jatropha curcas flowering rates, but are not well covered in the experimental and the small-scale and industrial production domains. This should be further investigated.

Productivity reports mostly refer to fresh seed weights on a per tree basis (g tree-1), instead of dry seed weights on a per area unit basis (kg ha-1). Productivity reports further lack important information on plant spacing (in-row and between-row distance), and other crucial information, such as the sample size (number of measured trees) that are required to provide the necessary insights in competition effects. Current jatropha seed productivity ranges between 500-2000 kg ha-1year-1. Sound reports on the productivity of intercropping and hedge row production systems are not well represented, although these production systems will become very important in small-scale jatropha production In general, the comparison between different Jatropha curcas genotypes is not available at all, although large plant breeding initiatives aim at productivity, oil quality, toxicity and tolerance to pests and diseases on the basis of Central American genotypes that are genetically more diverse than genotypes from other regions.

Recommendations on agronomic aspects:
- Scientifically sound methodologies (as detailed in Chapter 3) should be introduced for collecting observations on growth, production and development in new and in existing (older) Jatropha curcas production systems.
- Fruit coats, press-cake and pruning contain considerable amounts of nutrients. For environmental sustainable production, nutrients that are removed from the fields by harvests and pruning materials should be replenished.
- Jatropha curcas agronomy research should focus on the response of Jatropha (and intercrop) productivity to resources (fertilization and water) and pruning.

Social issues

Food security

Food security is influenced by a variety of factors; food availability, food access, food utilisation and food stability (UN 2008). None of the studies investigated all linkages. The most comprehensive study is a study by the FAO on biofuel crop production and food security in Tanzania. They found no significant negative impact (FAO 2010). They concluded that even a slight increase of current yields will offset any effect on food security. Food security can however be negatively impacted when the cultivation of food crops is replaced by Jatropha and the market for Jatropha seeds is not present. This happened so far in two known cases, one in Honduras and one in Brazil (Ariza-Montobbio and Lele 2010a; Finco and Doppler 2010). This also shows that converting current areas that are used for food production into Jatropha may have negative impacts and should therefore be avoided.

Local prosperity
Local prosperity is determined by the benefits the local population receives, either from the use of Jatropha products, or from the production (and selling) of seeds. Especially the availability of Jatropha oil for local communities and special equipment in which the oil can be used (leading to increased energy access), has a positive effect. However, there are socio-organisational issues that have to be taken into account. Furthermore the effects of Jatropha production on poverty levels (purchasing power), local employment, local economy and skills and attitude are analysed. Employment levels vary according to the business model used. Plantations normally generate more direct labour, while farmer centred models reach more people. The difficult financial situation of some Jatropha companies can have a negative impact on the attitude of the local communities. A gradual scaling up of the organisation could lead to a more sustainable operation.

Labour/working conditions
No child labour occurrence has been reported. Also most Jatropha companies and projects seem to give additional benefits to their employees.

Land rights
Land conflicts are very common in developing countries, especially Africa. Reoccurring issues when obtaining administrative land rights of large plots of land are; previous land use, compensation and transparency. Having a neutral broker who serves as a liason between investor and community can help in creating a good deal for the community and a clear understanding on both sides. In a smallholder model system, land issues have a less direct impact. It has been reported however, that in some cases the situation of vulnerable groups deteriorated. This was caused by land pressure (Salfrais 2010). It is important to check the situation of land pressure before promotion of Jatropha should take place. But, on a smaller scale, planting Jatropha as a fence can also help to reduce land boundary conflicts, especially when the neighbours are involved when the lines are delineated (Salfrais 2010).

Gender
Gender issues for Jatropha have not been looked at in great detail so far. Harvesting Jatropha is normally a women's task and often more technical tasks, such as driving tractors and processing, are executed by men. However, the impact of a labour force of e.g. 10,000 (mainly women) workers, is unclear. Women could as well be trained for higher skilled jobs. In one case in Mozambique, it was observed that favourable working hours at the plantation, enabled women to keep tending their household plots where they often cultivate food crops for their own consumption (Peters 2009). The availability of Jatropha oil for domestic use (cooking and lighting) could benefit especially women.

Recommendations on social aspects:

- All linkages and aspects that relate to food security should be analysed; base line studies are required to determine changes due to project interventions. Food security is a broad issue that should be dealt with in cooperation with local organisations and authorities. The use of complementary methodologies (e.g. primary interviews, secondary data, but also modelling & simulation) is advised to create a comprehensive overview. Furthermore, more research is required to establish increased understanding on food security impacts caused by plantations.
- Jatropha should not be planted on grounds where it replaces common property forest areas on which the local population collects fuelwood, fodder and so on. Quantitative analyses are required to gain better insights into the impact on local prosperity. Local purchasing (of food, drinks, construction materials and so on) should be encouraged in order to ensure that a large share of companies' investments stay within the region or country. Deliberate attempts have to be made to ensure that plantations create technology spill-overs, through training and education. Local populations need to be provided for in case companies stop their activities. Local communities should be involved in decision making processes. If rural areas are targeted for biofuels investments, incentives should be put in place to increase the attractiveness of this option.
- More research is required to be able to study the impacts of Jatropha investments on working and labour conditions.
- None of the plantation projects reviewed in this study have increased their employment up to the planned maximum; this is only expected to occur when harvesting begins in a few years' time. It is recommended to undertake studies that will monitor the impact on labour conditions as employment is being scaled up.
- A mediator should be involved with land acquisition processes, this person should serve as a liaison between the government, villagers and the company.
- Land pressure should be taken into consideration before activities in a certain village start
- Land administration systems should be improved. They should harmonize formal and customary land tenure systems.
- It is necessary to assess impacts for alternative business models, in which the community is a business partner.
- Specific aspects that relate to the participation of women should be included in projects, in smallholder outgrowers schemes as well as in plantation employment.
- Suitable work hours should be created so (female) workers can tend their plots after work.
- Attention should be paid to fair pay, the inclusion of gender in project design, and early involvement of women in projects.

Ecology

A critical analysis of published Life Cycle Assessments (LCA) for different Jatropha biofuel production systems found that the outcomes of individual studies are not comparable due to the large variety of systems, the wide range of different assumptions, the differences in local conditions as well as different methodologies applied (system boundaries, functional units, allocation and substitution, different impact categories etc.). Therefore, the focus lay on comparing the underlying data such as land use changes, seeds yields, fertiliser use and transport km overseas in order to identify the critical factors in the Jatropha production and usage chain, and gain insight into possible trade-off and directions for improvement.

The conclusion is that Jatropha Biofuels can contribute to GHG reduction when cultivated and processed in a sustainable manner. In this respect, critical issues are: land use changes and initial carbon debt, the use of by-products, energy use in transesterification, fertiliser use, transportation, and effect of nitrogen emissions on the Global Warming Potential. Based on the available data, the most promising option seems to be Jatropha cultivated on marginal land with limited inputs of artificial fertilisers and pesticides on a small scale for local use of pure plant oil for rural electrification.

Additional research is required to fill in the knowledge gaps by studying land use change as well as the initial carbon debt that may be caused by this, including above ground, below ground biomass and soil bound carbon and nitrogen. Clear methodological guidelines should be defined for how to include direct and indirect land use changes and nitrogen in LCA's on biofuels. Furthermore, additional research is needed to provide more reliable data to gain better insight into trade-offs and related impacts, for instance using marginal land with increased fertiliser application versus more fertile land; catering for distant markets involving long transport distances versus centralised production and local use; use of by-products for fertilisation versus energy use or as animal feed, etc.
Impacts differ across locations, especially with respect to land use changes. Therefore, in decision making processes a participatory LCA including all stakeholders will be best way to assure transparency on assumptions made and prioritising trade-offs according to the interest of all involved actors, reaching consensus on the outcome and decisions to be made.

Not many studies have analysed impacts on biodiversity. Biodiversity impact varies with the specific location of the Jatropha trees. Two determining factors are: previous land use and intensity of production, but the latter has hardly been studied at all. Smallholder cultivation of Jatropha tends to have minimal biodiversity impacts, in contrast with some large plantations. It is important that base line studies be undertaken, to enable impact determination at a later stage. So far, base line studies have not been done. Also long term impact studies have to be carried out.

Recommendations on ecological aspects:
- Additional research is required to fill in the knowledge gaps by studying land use change as well as the initial carbon debt, including above ground, below ground biomass and soil bound carbon and nitrogen. This should be folllowed by defining clear methodological guidelines how to include direct and indirect land use changes and nitrogen in biofuel LCAs.
- Additional research is also needed to provide more reliable data to gain better insight into trade-offs and related impacts, for instance, opting for marginal land with increased fertiliser use versus cultivation on more fertile land; long transport distances versus centralised production and local use; by-product for fertilisation versus energy use, etc.
- Due to limited ecological data available, Jatropha projects can still be categorised as experiments rather than main stream activities. Furthermore impacts differ per location, especially with respect to land use changes. Therefore, in decision making processes a participatory LCA including all stakeholders will be the best way to assure transparency on assumptions made and prioritising trade-offs according to the interest of all involved actors, reaching consensus on the outcome and decisions to be made.

- Base line studies have to be carried out so as to make it possible to determine biodiversity impact in a later stage. Also long term impact studies have to be carried out.

Economic issues

The available evidence about the expected economic viability of Jatropha-based activities is heavily concentrated on Eastern and Southern Africa and India. Two major problems were found to have major effects on the estimated results: (ii) estimates of seed yields have often been unrealistically optimistic in the light of the emerging body of evidence about Jatropha's agronomic performance; and (ii) land and labour resources have often not been costed at their full opportunity costs. Together, these problems have given rise to overestimations of expected profitability. Many methodological problems were also noted, which makes it hard to compare the results of the studies with one another.

A critical interpretative survey of the evidence suggests that the financial feasibility prospects for Jatropha cultivation under current conditions and with the current state of knowledge and experience are quite poor. On fertile lands and using irrigation and fertiliser, dry seed yields can be reasonable or even good, but under these conditions the same resources can produce far more profitable food crops. On true wastelands with zero opportunity costs, yields would be far too low to be of economic interest. On in-between scenarios with marginal & grazing lands, opportunity costs of key resources cannot be assumed to be zero, while yields will be modest unless substantial costly supplementary inputs are provided. These intermediate options are therefore also likely to be unviable.

The findings for oil processing are not much better than for cultivation. Jatropha biodiesel cannot currently compete with fossil fuel on domestic markets. For Jatropha to become a viable biofuel in those markets, its value chain as a whole needs to become more profitable, through finding higher-value uses for by-products (especially press cake), further increasing oil processing efficiency, developing seed varieties with higher and more reliable seed yields under semi-arid conditions, and optimizing cultivation practices. These challenges are, however, unlikely to be resolved within a few years.

Currently, the only possibly feasible local scenario that emerges from the studies is resource-extensive Jatropha hedge cultivation. This practice has very low opportunity costs and can yet be undertaken on fertile lands with good water access. The studies concur that Jatropha cultivation other than as hedge plantings should not be recommended for the time being. Furthermore, projects focused on local self-sufficiency that link seed production closely to local processing and oil use appear to have better potential for achieving financial viability than larger, non-local ones. The reasons are: the ability to return the seedcake to farmers as fertiliser, and the use of Jatropha SVO for local applications, instead of production of more expensive biodiesel.

Seed & oil production for export to the EU is currently unprofitable due to stiff competition from highly subsidized US bio-oils, but this is likely to change when niche markets with high sustainability requirements develop, such as bio kerosene feedstock for airlines, and when official biofuel sustainability criteria will be introduced in the coming years.

So far, feasibility studies that compare production of SVO and biodiesel in large plantation scenarios with a decentralized outgrower (predominantly hedge-based) model of similar total land size have not been undertaken. Our own preliminary estimates for a total production capacity of 80,000 ha, set in East African conditions, reveal remarkably similar profitability estimates for the two models – both have low Internal rates of Return of about 16-17% (base case estimates, including benefits from carbon credits). This would suggest that, in view of its superior social and environmental performance, the outgrower model has a distinct edge over the central plantation model.

Recommendations on economic feasibility:

- More information should be collected about the expected profitability of different cultivation and processing models – especially large plantations and decentralised outgrower-based systems – which could guide investors and government policy makers.
- It is also vital to keep reviewing the reliability of Jatropha CBA assessments in the light of more reliable observed yields in different conditions, which are now becoming available as Jatropha plantings begin to mature in different regions.
- Possibly adverse distributional effects on farmers of Jatropha cultivation should also be probed. Undertaking more research on this aspect will become highly important in the coming years, when Jatropha plantings mature and the full impacts from the crop's cultivation begin to materialize.
- Research should focus on improving profitability by finding higher-value uses for by-products, further increasing oil processing efficiency, developing seed varieties with higher and more reliable seed yields under semi-arid conditions, and optimizing cultivation practices.
- The energy-crop potential of alternative, indigenous trees and shrubs should be explored, especially those whose seedcake is non toxic, which allows its productive utilization as animal feed. This could make these alternatives financially more viable than Jatropha.

Selected technical, organisational and policy issues

These aspects were discussed only selectively in this report. Key issues included: oil pressing and biodiesel production technologies, application possibilities of the seed cake, alternative business models, market conditions, and policies to foster competitiveness.

Recommendations on technical, organisational and policy aspects:

- More experiments are needed with the application of seedcake as fertilizer, taking possible issues with adoption by the local population into account.
- Market analysis and economic feasibility assessment of different seed cake applications also need to be undertaken.
- More research on various processing aspects is required, both in lab setting and in pilot or experimental set ups.
- More research is required about adapting equipment to Jatropha oil in rural areas.
- Flexibility in the implementation of business models can improve sustainability.
- In choosing a particular business model, the local context should be taken into account.
- Participation of smallholders in business-model development is recommended.
- Biofuel policies are needed to open domestic markets in Jatropha-producing countries (e.g. with blending policies).
- At the global level, there is a need for coordination of biofuel development and an international food reserve system to protect the vulnerable poor.

Overall, we advise NL Agency to monitor carefully the inputs and outputs from all their Jatropha projects, to improve the data and come to a good and reliable data set. A format for such monitoring needs to be developed.

1 Introduction

Jatropha (*Jatropha curcas* L.) has been promoted as a potential renewable energy source for many of its advantageous properties in comparison to other biomass feedstock. As a tropical woody perennial tree species, Jatropha may survive under harsh climate and soil conditions, although agronomy, socio-economic and technical aspects of the Jatropha value chain and its implications on the sustainable livelihoods of people are still unknown. Despite these uncertainties, large numbers of projects at different scales and with varying objectives have been implemented to turn the species into a viable bioenergy crop. This has led to an increasing number of research publications, project results and experiences of different aspects of the Jatropha value chain, which have to be evaluated and screened against selected sustainability criteria to create a new reference that should facilitate policy makers and project implementation.

Such an overview is essential to formulate recommendations and policy guidelines (e.g. for the Corbey Committee), to stimulate best project practices and also help to avoid the promotion of unviable or unsustainable practices. It is also useful for policymakers and project developers involved in the programs that have been set up by the Dutch government to promote sustainable biomass; Sustainable Biomass Worldwide 'Duurzame Biomassa Mondiaal' (DBM), Sustainable Biomass Import 'Duurzame Biomassa Import (DBI) and the Daey Ouwens Fund (DOF). The goal of DBM is to enhance the sustainability of biomass production (connected to policy and indirect effects), DBI focuses on creating sustainable flows of biomass for the Dutch market and DOF is promoting small scale innovative energy projects with emphasis on poverty reduction in developing countries. Within these programmes, 13 projects have been approved that are related to Jatropha. Furthermore there are Jatropha projects executed and in progress in other Dutch programmes such as PSI/PSOM.

This report is written by authors from three research institutes. Wageningen University and Research centre – Plant Research International (Raymond Jongschaap) has focussed on the agronomy, the Copernicus Institute (UU) (Janske van Eijck and Edward Smeets) has focussed on the social aspects, technical aspects and other relevant aspects, and Eindhoven University of Technology (Henny Romijn and Annelies Balkema) has focussed on the economic and the GHG balance aspects.

2 Methodology

In this analysis we will identify the knowledge gaps by describing what aspects are covered so far in existing literature and what aspects are still missing. This can be used as a framework for ongoing and new Jatropha projects. We will focus on the agronomic aspects, the social and ecological aspects, the economic aspects and the technical aspects. The main focus will be on the agronomy, social, ecological and economic aspects and slightly less on the technical aspects. This is due to the overwhelming number of technical studies and the limited time available to review these.

We have focussed on studies published in recent years. We have covered a total of more than 200 studies for the analysis of the aspects. The review of each aspect concludes with tips for practitioners and conclusions & recommendations for policymakers and researchers. A preliminary version of the report was presented at the workshop 'Sustainable Access to Sustainable Energy' organised by NL Agency in Moshi, Tanzania, 27 Sept - 1 Oct 2010, where Jatropha practitioners provided feedback on the report. The issues that came up during the workshop have been incorporated in the final version of the report.

We describe the analysis framework for each socio economic aspect. For some aspects we were able to work with our own methodology and/or analytical model for the analysis, other aspects were analysed and grouped according to methodologies/models found in the studies themselves. Two business models that we expected to yield very different results were distinguished throughout the analysis as much as possible. These are: a smallholder model and a plantation model. Smallholders are farmers who produce independently or in a contract farming model. A plantation is a large piece of land that is planted with Jatropha, employees are paid to harvest the seeds

An introduction to the studies included in this review is provided in section 3. The agronomic issues are discussed in section 4. Section 5 describes the social aspects; we considered: food security, local prosperity, labour or working conditions, land ownership and land rights, and finally gender. Ecological aspects (GHG and biodiversity) are discussed in section 6. The financial feasibility is reviewed in section 7, while technical aspects are discussed in section 8. Other aspects, described in section 9, consist of market prospects, organisational issues and finally policy issues.

3 Overview of reviewed studies

An enormous number of studies on Jatropha are available. Many are peer reviewed articles, published in internationally renowned journals but there is also more 'grey' literature like field reports, NGO reports etc. We have attempted to create a comprehensive and state-of-the-art overview. We have focused predominantly on literature from the period 2007-2010 in order to avoid the presentation of outdated information. We have only considered English literature; this means that studies in Portuguese or Spanish have not been taken into account. We have analysed the region on which the literature was based, Sub Saharan Africa (SSA), Latin America (LA) or Asia (A), see Table 3.1 and ANNEX II.

Table 3.1: Geographic spread of studies

Region or country of focus	Number of studies identified for agronomic aspects	Number of studies identified for socio economic aspects
Sub Saharan Africa	18	61
Asia	49	27
Latin America	13	4
General	26	
Tanzania		26
Mozambique		13
India		13
Kenya		4
Mali		4
Honduras		2

3.1 Agronomic aspects

From the 200 consulted scientific publications from 2007-2010 on Jatropha, more than 100 of them clearly dealt with agronomic aspects. From these studies, 26 could not be geographically specified, 18 concerned Africa, 49 concerned Asia, 7 concerned Central America and 6 concerned South America. See Annex I for the overview of the publications with their specific agronomy themes.

3.2 Socio economic and ecological aspects

In total we have identified 128 studies that cover social, economic, ecological or technical Aspects. In Annex II, the overview table shows the specific themes for the socio economic and ecology themes. This table also indicates the nature of the publication (MSc. or PhD. thesis, journal article, NGO report, research institute report or industry report) and when possible the source of the data (e.g. based on 45 interviews, based on literature, etc.).

Nature of studies
The table included 59 scientific journal articles, 16 MSc. theses, 4 PhD theses, 31 research institute reports (such as FAO, ICRAF etc), 17 NGO reports and 8 reports from industry (including consultants). In total 77 reports where found to include one or more social aspects, while 32 studies covered other aspects (market prospects, policy or business models).

Regions
From Table 3.1 we can conclude that the majority of studies cover Sub Saharan Africa (Tanzania and Mozambique) and Asia (India). This is partly due to the fact that no Spanish or Portuguese studies have been taken into account which limits the coverage of Latin America.

If we look at the countries that the studies were focused on, out of 89 studies that were country specific, Tanzania is overrepresented with 26 studies. Furthermore Mozambique is the focus of 13 studies, similar to the number focused on India; 4 studies were focused on Mali, and also 4 on Kenya. Lastly, 2 were about Honduras while the remaining studies focused on other countries or did not have a specific country focus.

Source of data
The sources on which the reports are based vary from primary data collected through fieldwork done by the author to review studies that synthesize existing literature. Around 34 studies are based on field data or interviews with stakeholders in the country of study. However, for some studies it was difficult to find the source of data. Around 25 studies are only based on secondary sources.

4 Agronomy

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Much has been written about agronomy measures that should be applied to jatropha production systems in order to increase its seed productivity, but still very little of it has been scientifically sustained. However, many of very valuable experiences with jatropha over the last few decades have been collected and systematically described, for instance in 'The Jatropha Handbook' (FACT 2010) and in the recent FAO-IFAD publication on pro-poor development of jatropha (Brittaine and Lutaladio 2010b). A number of applied agronomy measures in jatropha production systems have resulted in more and/or less satisfactorily results, but these are difficult to translate to other production systems in different production environments. The major problems for the interpretation of these experiences are the unscientific reports in which the environmental setting, definitions, methodologies and results are not clearly described.

As an introduction to this chapter, we state some important reasons for the lack of scientific evidence for general agronomy measures for jatropha oil seed production.

Jatropha curcas:

- …still is a relatively unknown species which has had many other functions than the now favored oil seed production, so there still is little experience with jatropha in more intensive oil seed production systems;
- …still is a wild species, with no registered varieties for selected traits that are optimized for specific growth conditions and production systems;
- …is a perennial species, so that agronomy measures do not directly provide results in the short term and effects on the long term are not known at all;
- …is a pan-tropical species occurring in many different environments that require different agronomy measures with different results that are difficult to interpret for other production systems in different environments.

One of the most striking problems while reading through any reports on the effect of agronomy measures on productivity is the way results are presented. Jatropha productivity should be reported on a large enough sample size (the number of observation trees is often not provided) and should be presented on an area basis (g m-2 or kg ha-1), and not on a per tree basis (g tree-1), as competition effects are easily hidden if productivity is expressed on a per tree basis. Preferably tree density or tree spacing should always be provided. Furthermore, seed yields should refer to dry seed weights, and not to fresh seed weights, as this introduces unsolicited variability in the results, as moisture content of the fresh seeds may range 5-10% and treatment effects may easily be hidden.

In general, agronomy measures aim at optimizing resource use efficiency for crop production, i.e. making the best out of local environmental conditions (climate and soil), by the selection of an optimized set of genetic resources and management options, and of course in the most sustainable way! It is obvious that socio-economic conditions set limits to the intensity agronomy measures can be taken. This affects the production potentials, as will become clear in Chapters 5, 6 and 7.

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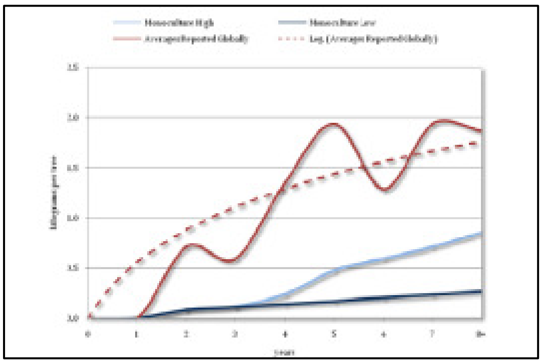
It is generally assumed and often stated, that the age of the jatropha trees is the major factor that affects the productivity level of a jatropha production system, but that has little to do with the agronomic productivity level. Indeed, older trees that surpass the juvenile stage may be taller, occupy more space, have more branches and therefore may generate more flowers per unit area, which after fertilization result in the required fruits and seeds, but the same amount of flowers on an area base can be the result of a larger number of younger and smaller trees that may be more easy to manage.

In Figure 4.1 various reports on jatropha productivity (on a kg per tree basis) are presented per age class for different locations (For references see (GTZ 2010)). Although the graph states that these values are valid for mono-cropping situations, it is absolutely not clear under what spacing these trees were grown and what management was applied, and therefore provides little valuable information.

Figure 4.1: Reported jatropha productivity on a per tree basis from global literature research (GTZ, 2010)

Country	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8+
Burkina Faso								0.96
Cape Verde								0.32
Cape Verde								0.81
Guatemala		0.81						
India		1.12						
India			0.20					
India			0.76					
India		0.82						
Indonesia								2.91
Mali		0.22						
Mali								1.94
Mali								1.71
Mali								5.18
Nicaragua		1.50	1.80	2.25				
Nicaragua					3.24			
Paraguay			0.06	0.45	0.65	1.29	1.94	2.59
Tanzania	0.00	0.00	0.23					
Tanzania			0.50					
Thailand		0.51						
Zimbabwe								0.40



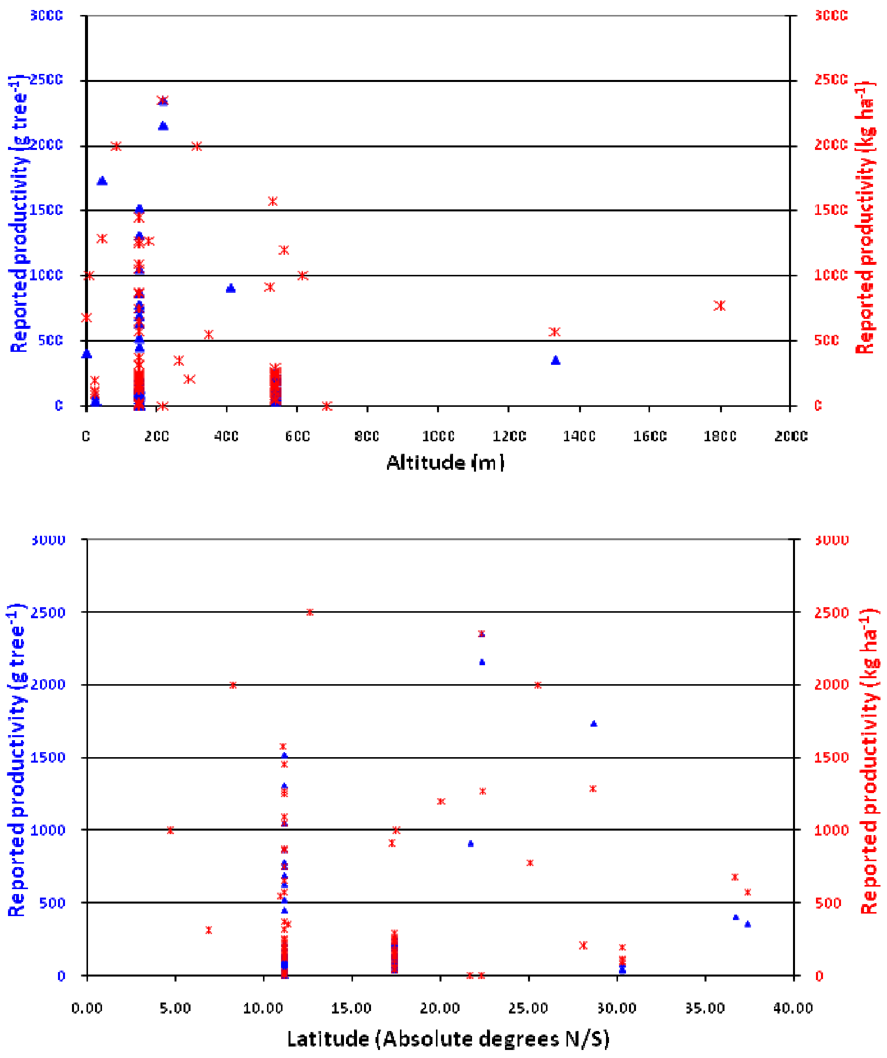
A great number of the values (in red in the Table included in Figure 4.1) that are used for the creation of the table and graph are predictions and extrapolations and do not apply to observed values in production systems. In further analyses outlying productivity reports that could not be backed up by sound measurements are removed.

In a number of reported jatropha productivity figures (tree age between 1 and 5 years) are presented both on a 'per tree basis' (g tree-1) and on a 'per unit area basis' (kg ha-1), and show the relation between seed yield with altitude and latitude, which both affect the length of the growing season, temperature conditions and precipitation rates.

Although not every productivity observation point in could be expressed on a per tree basis and on a per unit area basis, the first conclusion that can be drawn is that there is absolutely no relation between them. Secondly, it can be concluded that differences in crop management (i.e. soil conditions and agronomy measures) largely determine the productivity level in current production systems, indicated by the vertical range of productivity levels at a similar altitude or latitude. Thirdly it becomes clear that the current range of jatropha seed productivity lays around the 1000 kg ha-1 in field experiments and under (mostly small-holder) field conditions.

Producers are waiting for plant breeders to develop in the long-term the improved (pest and disease tolerant and high yielding) jatropha varieties with selected traits that fit local production systems for producing the required quantities of jatropha products (oil, (non-detectable phorbol ester) press-cake and other crop residues). In the short-term, producers will have to rely on appropriate agronomy measures for their specific conditions that will make the most optimal use of their available resources. The most appealing agronomy measures for jatropha production systems will be highlighted in the following sections of this Chapter.

Figure 4.2: Reported jatropha productivity on a 'per tree basis' (blue triangles; g tree-1) and on a 'per unit area basis' (red asteroids; kg ha-1), in dependence of altitude (top; m) and latitude (bottom; absolute degrees N/S) of the observations



4.1 From germinating seeds to transplanting seedlings

Natural jatropha plant growth, like any other plant species, starts from seeds that germinate under favorable conditions. Favorable temperatures are required to stimulate the activity of the embryo, using the oil rich endosperm in the seeds as a source to grow roots and expand 2 green cotyledons (Figure 4.3).

The maturity stage of the fruits (DAA; days after anthesis), being green (30-45 DAA), yellow (mature; 45-60 DAA) or brown (ripened; >60 DAA) favors seed weight and thereby germination rate, root and shoot length (Kaushik 2003). Lower temperatures and prolonged seed storage unfavorably affect these characteristics, although seed storage up to 2 years have been reported to give satisfactory germination results (Deng et al. 2005). Temperatures of 30 °C favor germination rates significantly over temperatures of 25 °C (Kaushik 2003).

Figure 4.3: Start of jatropha growth cycle: from seed to seedling (© 2010 Plant Research International)

Jatropha fruit with 3 seeds | Jatropha seed hull and kernel | Jatropha germinating seed | Jatropha expanding cotyledons

Beside temperature, moisture conditions are important for the embryo to burst more easily through to the barrier of the seed hull. Pre-soaking seeds for 12-24 hours in water enhances the germination rate of jatropha seeds considerably; longer soaking (up to 72 hours) decreased germination rate (Sharma 2007a). Seed inoculation with rhizobacteria and other supplements results in significant growth promotion in the seedling stage ((Desai et al. 2007); (Elefan 2008)). Seedling containers with a volume less than 2 liters negatively affect root development (de Lourdes Silva de Lima et al. 2007).

To reduce evapotranspiration from the seedling transplanting bags (thereby reducing irrigation requirements), the shading of seedling nurseries is often promoted. Shading is not required to reduce the radiation intensity, which is often the case as jatropha is a sun loving C3-species that responds well to full sunlight (Yong et al. 2010). Jatropha seedlings and adult jatropha trees adapt their physiology (osmotic adjustment of roots and leaves by inorganic and organic solutes) and physical status (stomata closure and reduction of stomata in new leaves) to reduce transpiration losses ((Maes et al. 2009b); (Silva et al. 2010)). Shading seedlings leads to reduced stoma density, reduced leaf chlorophyll α/β content, thicker leaves, reduced maximum net photosynthetic rate, but at low radiation intensities, radiation is more efficiently used (Lingfeng 2008).
The germinating and seedling period should be timed carefully, so that transplanting after 2-3 months occurs in the wet season, to prevent drying out of seedlings (especially the roots) and to minimize the transplanting shocks.

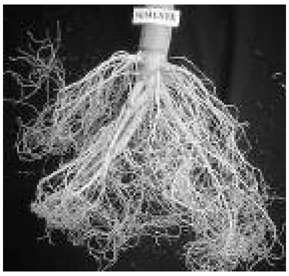
Tips: Jatropha seed selection and germination strategies

- Use local seeds, or test seeds from foreign origin before using them at production system scale
- Use seeds from mature (yellow) fruits that are stored as shortly as possible
- Select germination and seedling period carefully to assure transplanting in the wet season
- Pre-soak seeds up to 24 hours in water to soften the seed hull (and remove floating seeds)
- In poor soil media, supplements and rhizobacteria increase germination rate and seedling vigor

4.2 Direct seeding, transplanting seedlings and cuttings

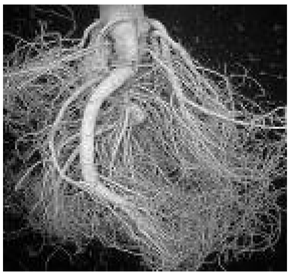
Direct seeding can be applied successfully under humid conditions with high soil moisture contents and high temperatures that favor germination (>20 °C; see paragraph 4.1). Other conditions will negatively affect germination rate and introduce variability in the production stand as a result of later resowing. With direct seeding, multiple seeds per seed hole are required (2-4) and a soil cover of about 4-7 cm should be applied ((Ye et al. 2009); (Brittaine and Lutaladio 2010b)). Emerging plants should be thinned to 1 per position.
Planting cuttings introduces uniformity in a stand, as cuttings may come from the same tree, which means that they are genetically identical. Cuttings contain carbohydrates in their stem reservoirs that make leaves and additional branches come out earlier than seedlings have reached this stage.

Figure 4.4: Different seedling root development patterns (© 2007(Soares Severino et al. 2007a))

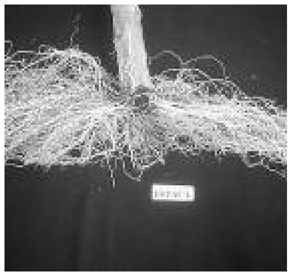


Jatropha seedling roots after direct seeding in the field

Jatropha seedling roots grown in an open polyethylene tube



Jatropha seedling roots grown in a closed polyethylene bag



Jatropha roots of a planted cutting

Direct seeding or (trans-) planting methods affect rooting patterns. Using small soil containers or polyethylene bags (<2 L) hamper root growth, not by lack of nutrients but by growth restrictions leading to circling roots and root nodes (de Lourdes Silva de Lima et al. 2007). Direct seeding and seedlings raised in polyethylene open tubes or closed bags or containers secure the growth of tap roots and deeper rooting, whereas cuttings result in the development of superficial roots (Figure 4.4).

A less developed root system at the seedling stage delays the growth of plants after transplanting, thereby enabling weeds to compete for light, water and nutrients in the unused space.

In order to decide whether to transplant seedlings or use cuttings, the following argumentation can be used: the function of the roots are the anchoring of the plant and the uptake of water and nutrients. If jatropha has to explore deeper soil layers for water and nutrients, if it has to catch the nutrients that are lost from intercropping fertilization, and to firmly fix the trees in the soil (e.g. on slopes and in other areas that may (shortly) experience a flood or areas that are confronted with strong winds, transplanting seedlings is preferred. If water and soil fertility is available or if it is provided in the topsoil layer, and if such events (strong winds, flooding, run-off) are not like to happen, planting cuttings may not necessarily negatively impact the performance of jatropha.

Tips: Direct seeding, transplanting seedlings and cuttings

- Preferred system for nurseries of 2-3 months
- Direct seeding only under good soil moisture and high temperature conditions; use 2-4 seeds per planting hole of 4-7 cm deep, and thin to 1 tree per hole after establishment
- Seedlings should be raised in spacious (>2 L) containers to prevent reduction in root development

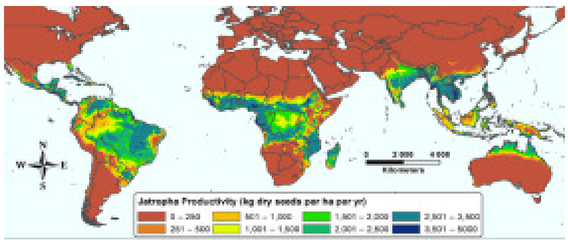
4.3 In-vitro propagation

In-vitro propagation is a technique that enables the vegetative reproduction from small tissue samples taken from preferably young and vigorous plant parts. Tissue from buds, leaves, stems and roots may be used. A sterile working environment is required. Interspecific and intergeneric crosses and other techniques in tissue culture such as in-vitro fertilization and somatic hybridization can be employed in Jatropha curcas. Sujatha et al. (2005) have established protocols for in vitro propagation of ‘non detectable phorbol ester’ accessions of jatropha through axillary bud proliferation and direct adventitious shoot bud regeneration from leaf segments ((Sujatha et al. 2005)). Propagation on an initial basal Murashige and Skoog (MS) salt medium supplemented with different concentrations of benzyladenine (BA), kinetin and thidiazuron (TDZ) resulted in an increased number of shoots per nodal explant (Sujatha et al. 2005). Earlier studies with different medium treatments led to an unsatisfactory 6% shoot regeneration frequency from leaf segments (Sujatha and Prabakaran 2003). Tissue culture can induce variability in plant tissues through somaclonal variation, and micro-propagation can be useful for the multiplication and distribution of suitable planting material (Sharma et al. 2009a). The propagation process may take quite some time, as new plants should grow from a relatively small plant part that does not have a reservoir such as the seed, and thus need to feed on growth media.

Tips:
- In-vitro propagation is an advanced laboratory technique to produce a large number of plants under well controlled conditions.
- In-vitro propagation is not common practice for as seed reproduction and cuttings may give similar results.

Figure 4.5: Jatropha curcas belt and estimated annual dry seed productivity on the basis of temperature and precipitation variables and scaled between 0 and 5000 kg ha-1 y-1 (Trabucco et al., 2010)

Rough representation of the *Jatropha curcas* and oil palm belt (Jongschaap et al. 2007)



Estimated *Jatropha curcas* dry seed productivity (kg ha^{-1} y^{-1}) for average climatic conditions (1950-2000)

4.4 Production systems and plant spacing

As jatropha is a pan-tropical species that can roughly be found between the Northern Tropic (Cancer) and the Southern Tropic (Capricorn) , there is a large range of environmental circumstances in which it grows and a great variability of its performance is observed ((Heller 1996); (Henning 2007); (Jongschaap et al. 2007); (Maes et al. 2009c); (Trabucco et al. 2010b); Figure 4.5).

Production systems with jatropha may consist of singular trees, hedges or living fences, intercropping systems and monocultures. In this order, the production systems show decreasing space per tree and increasing competition with neighboring plants for available resources (Figure 4.6). Apart from the acreage and the quality of land that is available for jatropha production, socio-economic resources such as labor availability and opportunities for management investments eventually determine which production system prevails and how it performs (See Chapter 5, 6 and 7). Historically, the use of jatropha has served different objectives than oil seed production, and as a result jatropha performance in terms of quantity and quality of the oil differs greatly.

From an agronomy point of view, optimized plant production systems are efficient in resource use. These resources include solar radiation, soil water and soil fertility, which all differ from location to location and which set the attainable production potential. From a sustainable point of view, these resources should be renewable and/or replenished, so that the original status is regained, or may be enhanced and subsequent production is secured for the future.

Figure 4.6: Different Jatropha curcas production systems with decreasing space and increasing competition per tree: single trees, hedges or living fences, intercropping and monocultures. Photos www.jatropha.org.za; www.jatropha.de; www.projectrwanda.org; www.jatropha.wur.nl

Jatropha single trees in South Africa and in Indonesia

Jatropha hedges in Guatemala and Mali

Jatropha intercropping with onions and a jatropha nursery

Jatropha monoculture in Guatemala and in China

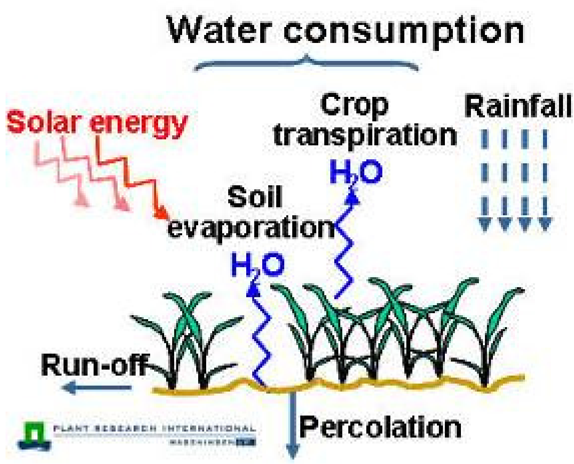
Radiation, temperature and precipitation are natural phenomena that cannot be influenced directly, but production system design, plant spacing and possible mulching affect the rate in which these resources are used on an area base (Figure 4.7).

Intercrops should be compatible with jatropha, i.e. use the resources that jatropha is not using, for instance: grow an intercrop when jatropha has no leaves (at the start/end of the growing season), or when the canopy is not covering the soil, or grow an intercrop that is shade tolerant or shade-loving (in contrast to jatropha which is a sun-loving species (Yong et al. 2010). If jatropha has deep roots, use an intercrop with short roots, etc. Advantageous effects can be expected from intercrops that fix nitrogen (from the air) (legumes) of which plant residues after harvest are left in the field. Please note in this example that nitrogen fixing by legumes is hampered by nitrogen fertilization: then the intercrop prefers taking up fertilizer N instead of fixing it from the air.

Of course intercropping should be evaluated on the Land Equivalent Ratio = (Yield intercrop with jatropha) / (Yield intercrop without jatropha) + (Yield intercrop with jatropha) / (Yield jatropha without intercrop). If this Land Equivalent Ratio (LER) value exceeds 1, the intercropping is advantageous. If not, there is too much competitions between the crops.

Temperature, wind speed and incoming solar energy that is intercepted by the canopy affect water use by the plant (transpiration), whereas radiation that reaches the soil surface affects water use by the soil (evaporation).

Figure 4.7: Temperature, wind speed and solar energy interception affect water resource



For an optimal use of incoming radiation, the jatropha canopy should be closed with effective green leaves as soon as possible, which calls for high planting densities, or jatropha trees with a large number of branches. The use of an intercrop in the open space between jatropha trees also is an effective way to prevent radiation losses to the soil, where it is unavailable for plant growth and increases water loss by evaporation. Radiation intercepted by intercrops does not contribute to the performance of jatropha, unless they are nitrogen fixing leguminous species, or if losses from intercrop management (such as irrigation and/or fertilization) are used by jatropha as an agroforestry option (Achten et al. 2010c).

Tips: Plant production systems and plant spacing

- The selected jatropha production system affects the area requirements per tree (singular trees > hedges > intercropping > mono-cropping), and thereby the competition for available resources for plant growth

- In locations with fewer resources (water, nutrients), plant spacing should be wider in order not to reduce competition effects and avoid running out of resources before the end of the growing season
- Reduced plant spacing result in higher density cropping systems, which may be more susceptible to the spread of pests and diseases

4.5 Response to radiation, temperature, water and nutrients

In the initial growth phase after establishment of a plantation, if there is no competition for radiation, water and nutrients between plants, nutrient content in mature leaves is not significantly affected by crop density.

Jatropha trees of 3 years old in India at 2x2 and 3x3 m spacing in control treatments and treatments with different irrigation treatments at 7, 15 and 30 days intervals significantly affected plant height, stem diameter increments, the number of lateral branches and plant canopy increment. Among the intervals no significant differences were found, so that 30 day irrigation intervals would be most cost effective (Behera et al. 2010).

In the competition phase, in a range from 1,667-10,000 plants ha-1, nutrient (N, P) content in leaves and nutrient (N, P) uptake from the soil was negatively correlated with plant density ((Chaudharry et al. 2007);). In this situation, fertilization of J. curcas increased seed yield by 100%, either by inorganic or organic fertilizer (Patolia et al., 2007a; Patolia et al., 2007b). Fertilization with J. curcas seedcake, the remaining bulk after oil pressing significantly increased seed yield (Ghosh et al., 2007). Spacing experiments (1,667-10,000 plants ha-1) with 1-1.5 year old jatropha trees in India showed a negative correlation between plant density and number of fruits (68-24 per tree) and seed yield (94-32 g tree-1), but a positive correlation with seed yield on an area basis (157-319 kg ha-1) (Chikara et al. 2007).

Jatropha trees of 3 years old in India at 2x2 and 3x3 m spacing in control treatments and treatments with different organic and mineral fertilization types and rates. These significantly affected plant height, stem diameter increments, the number of lateral branches and plant canopy increment (Behera et al. 2010). No quantitative data was provided on nutrient content of the various organic fertilizer types.

Table 4.1: Average predicted Jatropha curcas dry seed productivity within Köppen climate zones (Trabucco et al. 2010b)

Climate zone	Code	Description	Productivity (kg ha^{-1} y^{-1})
Tropical humid	Af	Wet – no dry season	1150
	Am	Monsoonal – short dry season, heavy rains in wet season	2200
	Aw	Savannah – winter dry season	2300
Sub-tropical dry	BSh	Steppe – low latitude	750
Sub-tropical	Cw	Humid – dry winter	1950
Temperate	Cf	Humid – marine without dry season, hot or warm summers	1550

According to recent analyses of the suitability of Köppen climate zones in which annual average temperature, minimum temperature, annual precipitation and precipitation seasonality were the principal responsible factors that were used for the most significant prediction of global seed productivity (Table 4.1; Trabucco et al., 2010b). Despite their intentions, the authors have not been able to integrate more mechanistic relations in their modelling approach, that could have prevented the overestimation of productivity (as they range their seed productivity values up to 5 tons ha-1, which has not been reported on a sound scientific basis), and underestimation, as large parts of known production areas such as South Africa are missing in their maps (Figure 4.5).

Tips: Radiation, temperature, water and nutrients

- Jatropha is a sun loving species, well adapted to high radiation and temperature levels and does not need to be shaded
- Water stress affects the plant's constitution, as leaves appearing under water stress have less stomata to prevent transpiration losses
- Irrigation requirements for surviving drought periods and for extending the growing season should be accompanied by additional fertilization

4.6 Fertilization requirements

The objective of fertilization is to provide the required nutrients for optimal plant growth. These nutrients are the building blocks for structural tissue (standing biomass) and for functional plant tissue to perform specific plant processes, such photosynthesis in the green parts of jatropha. Roots, stems, branches, leaves and fruits (including the seeds) require different concentrations of macro nutrients N, P and K (and others) in their tissue in order to function properly (See Table 4.2).

Table 4.2: Jatropha curcas Dry Matter Fractions (DMF) with observed Nitrogen (N), Phosphorous (P) and Potassium (K) concentrations (%) from various sources (Jongschaap et al. 2007)

	DMF	N	P	K
	(-)	(%)	(%)	(%)
Roots	0.08	2.2%	0.1%	2.2%
Stems	0.23	3.3%	0.1%	2.9%
Leaves	0.23	5.0%	0.2%	2.0%
Fruit coat	0.14	0.9%	0.1%	3.3%
Seed shell	0.11	0.4%	0.0%	0.5%
Seed kernel	0.21	2.5%	0.5%	1.0%
Sum	1.00			

Additionally, micro elements may be required which generally occur naturally in most soils, but they might not be available in specific cases and should be applied for an unrestricted growth if they are missing.

Passive nutrient uptake occurs through the uptake of water with dissolved nutrients by the plant to maintain cell pressure (turgor) and through transpiration of water for the photosynthesis process and for cooling the plant. Nutrient uptake can also be an active process in which the required nutrients are withdrawn from the soil medium. Both nutrient uptake processes can only take place when nutrients are dissolved in the soil medium (water).

The required levels of nutrients for the build-up of the standing biomass may be provided by the soil, as nutrients may become available for uptake by decomposition of organic materials and the mineralization of the soil, after which they dissolve in the soil moisture. However, for most soils (and specifically for those soils that are propagated for jatropha production, often marked as 'marginal' or 'unfertile' soils), the appropriate amounts may not be readily available and should be provided by additional fertilizer inputs.

In order to manage jatropha production systems in a sustainable manner, additional fertilization should replenish the nutrients if these are removed from the field through harvest products (fruits and seeds) and by pruning (branches).

Table 4.3: Jatropha curcas seed dry matter (SDM) production of 500, 1000 and 1500 kg ha-1, required nutrient uptake (NU, PU, KU) to support standing biomass and consequences of 2 Dry Matter Removal (DMR) scenarios on nutrient removal (left) and fertilizer requirements. (right)

TDM (kg ha-1)	ADM (kg ha-1)	SDM (kg ha-1)	ODM (kg ha-1)	OP (l ha-1)	NU (kg ha-1)	PU (kg ha-1)	KU (kg ha-1)
1698	1563	500	149	162	47	3	34
3397	3125	1000	298	323	94	7	69
5095	4688	1500	446	485	142	10	103

DMR 1 (kg ha-1)	DMR 2 (kg ha-1)
879	543
1758	1087
2637	1630

			Seed productivity level (kg ha-1)		
DMR1			500	1000	1500
Removed (kg ha-1) & req nutrients	N		15	30	45
	P		2	4	6
	K		15	30	45
DMR2			500	1000	1500
Removed (kg ha-1) & req nutrients	N		1	1	2
	P		0	0	0
	K		1	2	3
Difference DMR1-DMR2			500	1000	1500
Removed (kg ha-1) & req nutrients	N		14	28	43
	P		2	4	6
	K		14	28	42

		Min. Fert. recovery	Seed productivity level (kg ha-1)		
DMR1			500	1000	1500
Removed (kg ha-1) & req fertilizer	N	50%	30	60	90
	P	10%	20	41	61
	K	40%	38	75	113
DMR2			500	1000	1500
Removed (kg ha-1) & req fertilizer	N	50%	1	3	4
	P	10%	0	1	1
	K	40%	2	5	7
Difference DMR1-DMR2			500	1000	1500
Removed (kg ha-1) & req fertilizer	N	50%	28	57	85
	P	10%	20	40	60
	K	40%	35	71	106

ADM	Aboveground Dry Matter (kg ha-1)
DMR	Dry Matter Removed (kg ha-1)
DMR 1	Dry Matter Removal Scenario 1: 25% of the pruned stems and branches and all fruits and seeds are removed
DMR 2	Dry Matter Removal Scenario 2: pruned stems and branches are left in the field for decomposition, and fruit coats and press-cake after mechanical oil extraction (85% efficiency) is returned to the soil
KU	Potassium (K) Uptake (kg ha-1)
MFR	Mineral Fertilizer Recovery (%); percentage of applied fertilizer that is uptaken by the crop
NU	Nitrogen (N) Uptake (kg ha-1)
ODM	Oil Dry Matter (kg ha-1) at an assumed 35% of SDM
OP	Oil production (liter ha-1) with an Oil Density of 0.92 kg liter-1
PU	Phosphorous (P) Uptake (kg ha-1)
SDM	Seed Dry Matter (kg ha-1)
TDM	Total Dry Matter (kg ha-1); ADM and roots

In Table 4.3 the consequences of 2 scenarios for dry matter removal (DMR) on nutrient requirements are shown. In scenario DMR1, 25% of the stems and branches are pruned and removed together with all fruits and seeds. In scenario DMR2, all pruned stems and branches are left in the field for decomposition and fruit coats and press-cake after mechanical oil extraction are returned to the soil.

From Table 4.3 it can be observed that for the production of 1.5 ton dry seeds ha-1, a total crop biomass of 5.1 ton ha-1 should be supported, for which about 140 kg nitrogen (N), 10 kg phosphorous (P) and 100 kg potassium (K) is required. Soil analyses may reveal how much N, P and K are available and can be provided by the soil, and how much additional fertilizer should be applied. Note that in order to avail 140 kg of nitrogen with a fertilizer type like urea (46% N), 300 kg urea per hectare should be applied, assuming 100% recovery of the applied fertilizer. However, normal N fertilizer recovery percentages are 50%, which makes that 600 kg of N fertilizer would be required. Fertilizer recovery percentage depends on application technique (split dose is preferred), soil type, climate conditions (high precipitation rates result in nutrient leaching, i.e. loss by superficial or deep drainage) and uptake rate by the crop.

Depending on the Dry Matter Removal scenario, additional fertilization is required to replenish the removed nutrients in subsequent years. In the DMR1 scenario with the removal of all fruit coats and press cake from 1 ha, 45 kg N, 6 kg P and 45 kg K should be replenished. In the DMR2 scenario, i.e. returning pruned stems and branches, fruit coats and press-cake to the soil, only 2 kg N, 0 kg P and 3 kg K are required, in other words this saves 43 kg N, 6 kg P and 42 kg K on a hectare base!
Both examples assume a 100% recovery of the returned plant residues and the selected fertilizer type. With the normal recovery percentages of 50% for N, 10% for P and 40% for K, returning press-cake and pruning saves 85 kg N fertilizer ha-1., 60 kg P fertilizer ha-1 and 106 kg K fertilizer ha-1.

The toxic compounds (phorbol esters; PE) of jatropha press cake degrade within 10 days when applied to the soil (Devappa et al. 2010). Increase in temperature and moisture increased rate of PEs degradation. Using the snail (Physa fontinalis) bioassay, mortality by PE-amended soil extracts decreased with the decrease in PE concentration in soil. Another study by D1 Oils concluded that no toxic compounds could be traced in chemical analysis of food crops fertilized with jatropha seedcake (Ab van Peer, personal communication).

Tips: Fertilization requirements

- Nutrients coming from mineral or from organic fertilizers are essentially the same and therefore .
- In case of high temperatures and high precipitation rates, organic fertilizers may be preferred as they have a slow release during the growing season, and are less susceptible to losses (lateral losses, volatisation and leaching)
- Under the above conditions, mineral fertilizers should be applied in split dose (more times during the growing season) to avoid losses (lateral losses, volatisation and leaching)
- Nutrient requirements should be calculated on the basis of growth of the standing biomass for the growing season, with additional inputs for removed nutrients by the pruned stems and branches, fruit coats, and seeds
- Soil analyses provide the availability of nutrients that will become available during the growing season by mineralization and decomposition of organic materials
- Fertilization recovery rates determine how much fertilizer should be applied to obtain the required plant nutrient uptake

4.7 Water requirements and irrigation

Several studies calculated water use efficiency (WUE) by dividing photosynthetic rate (A) and transpiration rate (E) at the leaf level. Under field conditions in India, A-values ranged between 22.5-35.4 μmol m-2 s-1 and E-values ranged between 5.1-6.1 μmol m-2 s-1, resulting in WUE of 3.8-7.0 μmol μmol-1. Other authors (Yong et al. 2010) have found the same range of 7-27 μmol CO_2 m-2 s-1 under greenhouse pot and field conditions. Nitrogen fertilization favored photosynthetic rates, which were higher in mature leaves and reached saturation levels above 800 μmol (quanta) m-2 s-1. (Yong et al. 2010). Under controlled greenhouse conditions A-values ranged between 28.2-37.3 and E-values ranged between 7.0-7.9 μmol m-2 s-1, resulting in WUE of 3.6-4.8 μmol μmol-1 (Popluechai et al. 2009). Greenhouse pot experiments in Brazil at ambient CO_2 concentration resulted in water use efficiencies of 2.5-5.0 µmol µmol-1 for non-stressed situations, whereas stress treatments dropped WUE to 0-1 µmol µmol-1 over water stress periods of 8 and 18 days (Pompelli et al. 2010). Greenhouse pot experiments in Belgium with seedlings grown at increased CO2 levels of 500-600 ppm and applying severe, medium and no water stress, resulted in average daily transpiration rates of 10, 100 and 250 mm H20 d-1, leading to WUE of 6.5-8.7 mg g-1 for the wet and medium water stress treatment (Maes et al. 2009b). The high CO2 levels of 500-600 ppm may easily have doubled the photosynthesis rates as shown in other jatropha species ((Fernández et al. 2000); (Tezara et al. 2005)), resulting in an apparent more efficient water use than other authors have found.

Jatropha trees of 3 years old in India at 2x2 and 3x3 m spacing in control treatments and treatments with different irrigation treatments at 7, 15 and 30 days intervals significantly affected plant height, stem diameter increments, the number of lateral branches and plant canopy increment. Among the intervals no significant differences were found, so that 30 day irrigation intervals would be most cost effective (Behera et al. 2010).

In a recent study, the water footprint (WF in m3 water per GJ or m3 of water per liter ethanol / biodiesel) of a range of bioenergy crops was calculated by dividing yearly average precipitation and additional crop irrigation requirements by the eventual production (Gerbens-Leenes et al. 2009b). Jatropha was not coming out very well (Table 4.4), but as various authors have observed ((Jongschaap et al. 2009a); (Maes et al. 2009a)), the applied methodology was not fair for jatropha with its low yields in the 1st years of establishment and under severe drought conditions. In the original publication by Gerbens-Leenes et al. (2009) this was wrongly interpreted as acknowledged by the authors (Hoekstra et al. 2009).

Table 4.4: Total weighted-global average WF for 10 crops providing ethanol and 3 crops providing biodiesel (m3 GJ-1), as well as their blue and green WF (Gerbens-Leenes et al. 2009b)

Crop	Total WF	Blue WF	Green WF	Total water	Blue water	Green water
Ethanol		m^3 per GJ ethanol			L of water per L of ethanol	
Sugar beet	59	35	24	1,388	822	566
Potato	103	46	56	2,399	1,078	1,321
Sugar cane	108	58	49	2,516	1,364	1,152
Maize	110	43	67	2,570	1,013	1,557
Cassava	125	18	107	2,926	420	2,506
Barley	159	89	70	3,727	2,083	1,644
Rye	171	79	92	3,990	1,846	2,143
Paddy rice	191	70	121	4,476	1,641	2,835
Wheat	211	123	89	4,946	2,873	2,073
Sorghum	419	182	238	9,812	4,254	5,558
Biodiesel		m^3 per GJ biodiesel			L of water per L of biodiesel	
Soybean	394	217	177	13,676	7,521	6,155
Rapeseed	409	245	165	14,201	8,487	5,714
Jatropha*	574	335	239	19,924	11,636	8,288

The table also shows the amount of water needed for a specific crop to produce 1 L of ethanol or 1 L of biodiesel.
*Average figures for 5 countries (India, Indonesia, Nicaragua, Brazil, and Guatemala).

In an example from South Africa (Jongschaap et al. 2009a), non-irrigated unfertilized 4-year-old jatropha trees (at 4.5 x 3.0 m or 741 trees ha^{-1}) yielded 1,286 kg ha^{-1} dry seeds in a growing season of 8.5 months with 652 mm rainfall. With 35% oil, this represents 450 kg ha^{-1} oil (or 489 Liter ha^{-1} oil at 0.92 kg $liter^{-1}$) and 836 kg ha^{-1} press cake, delivering 31.6 GJ ha^{-1}. Over the growing season, the water-balance model simulated total transpiration and soil evaporation of 4,052 m^3 ha^{-1}, well in agreement with field observations. The concurrent WF is 8,281 L of water per L of oil and 128 m3 of water per GJ; not even 1/3 of the WF of soybean, comparable to the WF of cassava, and only 1/5 of the WF obtained by using potential crop water requirements.

Tips:
- Irrigation requirements for surviving drought periods and for extending the growing season should be accompanied by additional fertilization.

4.8 Pruning

The pruning of *Jatropha curcas* serves two objectives. There is Formative Pruning (FP) that shapes the tree in the desired shape and forces it into branching patterns, and Maintenance Pruning (MP) that is required to keep jatropha plantation accessible and remove excess biomass for other purposes. Formative pruning can be carried out when transplanted seedlings reach 30-60 cm height to reduce the apical dominance and induce branching (Behera et al. 2010). Additional FP can be carried out at the end of the 1st growing season and of later seasons, to arrive at a desired number of 35-40 branches at 1.20 meter height ((Sharma and Sarraf 2007a)). In the new growing season, branches will grow from the reserves that are available in the older branches and stems, and will flower more quickly at increased heights. Formative pruning can be replaced by foliar application of plant growth regulators, which has been proven effective for increasing the number of branches, even more in comparison to manual pruning ((Abdelgadir et al. 2009a); Figure 4.8 in Section 4.9).

Maintenance Pruning should be carried out periodically depending on the vegetative state of the plantation and pruning should be carried out to get a minimum height of 1.20 m observed at the start of the growing season. Pruning lower than that will result in a loss of energy, as the pruned plants will first invest in branches and have too little reserves to start flowering.

Both FP as MP remove plant parts from the living biomass with nutrients at optimal concentrations, which can be returned to the soil, or should be replenished by fertilization if used for other purposes.

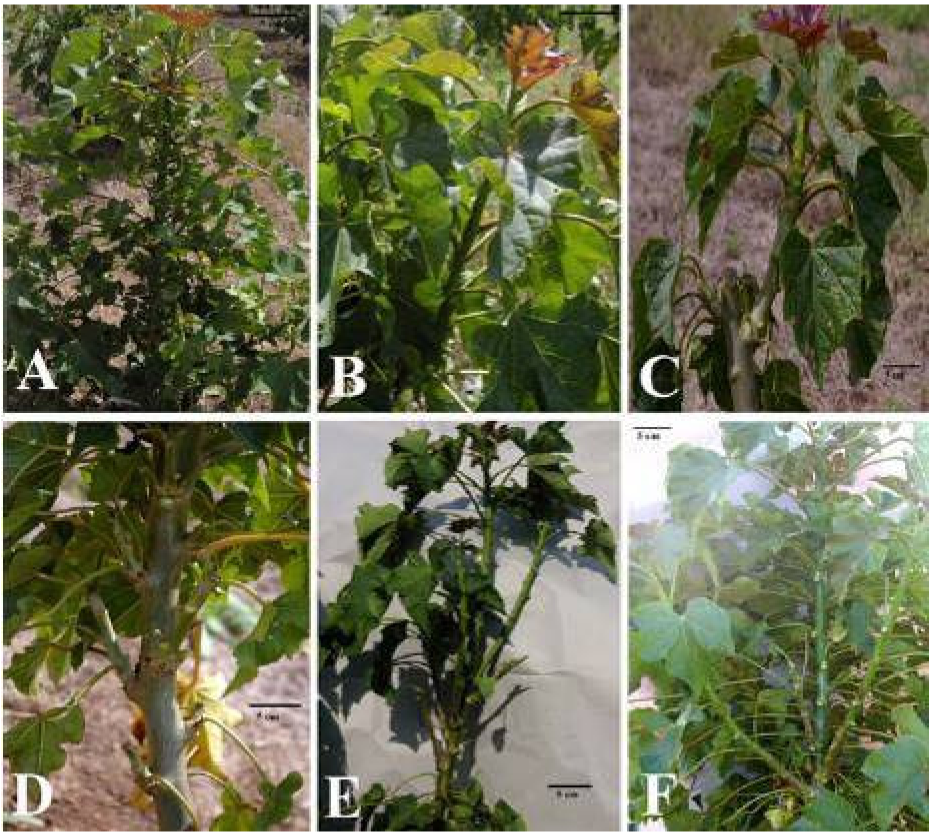
Tips:
- Formative Pruning (FP) can be carried out when transplanted seedlings reach 30-60 cm height to reduce the apical dominance and induce branching
- Additional FP can be carried out at the end of the 1st growing season and later seasons to arrive at a desired 30-35 branches at 1.20 meter height
- Maintenance Pruning should be performed when the trees shed leaves and enter the dormancy period at the end of the growing season. MP should prune back maximally to the desired height of 1.20 m observed at the start of the growing season

4.9 Hormones / PGR (Plant Growth Regulators)

Rooting and sprouting behaviour of stem cuttings of biofuel plant *Jatropha curcas* and their performance under field conditions have been studied in relation to auxin applications. Pre-treatment with indole-3-butyric acid (IBA) and 1-naphthalene acetic acid (NAA) increased both the rooting and sprouting ((Kochhar et al. 2008)). Indole acetic acid oxidase (IAA-oxidase) seems to be involved for triggering and initiating the roots/root primordia, whereas peroxidase is involved in both root initiation and the elongation processes as supported by the peroxidase and IAA-oxidase isoenzyme analysis in the cuttings ((Kochhar et al. 2008)). After hormonal treatments, clonally propagated plants (cutting-raised plants) performed better in the field as compared to those raised from the seeds ((Kochhar et al. 2008)).

The application of hormones (auxines NAA and IAA) favored plant growth and biomass yield in comparison to the control treatment. Application of the hormone GA3 improved flowering in the plant. The application of growth regulators not only improved the flowering and fruiting but it also improved the oil yield ((Kumari and Kumar 2007)). Small flowers and abortion of flowers and fruits may be as large as 60% or more, depending on soil water and nutrient availability. If carbohydrates are insufficiently available and photosynthesis rates are not sufficient shortly after flowering, flower and fruit abortion is common.

Figure 4.8: Influence of foliar application of plant growth regulators on lateral branching of Jatropha. curcas (one-year old) after 7 months under field conditions. (a) Control. (b) Manual pruning. (c) 12.0 mM N6-benzyladenine (BA) 12 mM. (d) 1.0 mM 2,3,5-triiodobenzoic acid (TIBA). (e) 2.0 mM Dikegulac (2,3:4,6-di-O-isopropylidene-2-keto-Lgulonic acid; DK). Bar scale = 5 cm (Abdelgadir et al. 2009a)



If manual formative pruning is too laborious, good results have been observed with the applications of plant growth regulators. Under field conditions, *J. curcas* plants responded better to the plant growth regulators (DK \ TIBA \ BA \ MH) when treated once, with insignificant variations in other growth parameters (See Figure 4.84.8). This study indicates that a single foliar application of plat growth regulators under field conditions can be an alternative method to MP for increasing the number of lateral branches of *J. curcas* (Abdelgadir et al. 2009a). evaluated. The number of flowers per plant, number of fruits per bunch, fruit- and seed characteristics and seed oil content were significantly affected by the different treatments in the subsequent years (Abdelgadir et al. 2010). A single foliar application of N^6-benzyladenine produced more flowers per plant, more fruits per bunch, heavier and bigger fruits and seeds with more oil compared to manual pruning. Treatment with 2,3,5-triiodobenzoic acid yielded more flowers per plant and heavier fruits with a higher oil content than the control and manually pruned plants. Treatment with 2,3:4,6-di-O-isopropylidene-2-keto-L-gulonic acid yielded similar results. More fruits per bunch and more seeds per fruit were also produced. Maleic hydrazine treatment yielded more flowers per plant, heavier and bigger fruits with more, heavier, oil rich seeds compared to the control and manual pruning. This study indicates that foliar application of PGRs as chemical pruners in *J. curcas* may have a sequential effect in boosting seed production, seed oil content and improves fruit quality (Abdelgadir et al. 2010).

Tips:

- Plant Growth Regulators may replace Formative Pruning
- Plant Growth Regulators may induce flowering, but if photosynthesis rates are insufficient, flower and fruit abortion is likely to occur

4.10 Conclusions and recommendations

Conclusions:

- The agronomy aspects of jatropha production are merely reported for juvenile jatropha plants (seedlings) and relatively young production systems of less than 3 years old
- Reports on germination, transplanting and propagation are quite complete, but mostly refer to (greenhouse) experiments, and to a lesser extend to small-scale and industrial scale field production sites
- The lack of well described methodologies for the response of *Jatropha curcas* to natural and additional resources such as radiation, temperature, water and nutrients is striking, but understandable, as the majority of jatropha stakeholders are not equipped and not educated to produce scientifically sound reports on *Jatropha curcas* growth and production
- Only limited experimental fertilization experiments have been presented so far, and recommendations on fertilization and irrigation strategies are still lacking because of that, and because recycling of nutrients is not well understood
- Jatropha plant residues, including press-cake are biodegradable and phorbol esters could not be traced in subsequent crops when applied as organic fertilizer
- Pruning methods (timing, frequency and technique) play a very important role in *Jatropha curcas* flowering rates, but are not well covered in the experimental and the small-scale and industrial production domains
- Productivity reports mostly refer to fresh seed weights on a per tree basis (g $tree^{-1}$), instead of dry seed weights on a per area unit basis (kg ha^{-1}). Productivity reports further lack important information on plant spacing (in-row and between-row distance), and other crucial information, such as the sample size (number of measured trees) that are required to provide the necessary insights in competition effects
- Sound reports on the productivity of intercropping and hedge row production systems are not well represented, but these production systems will become very important in small-scale jatropha production
- In general, the comparison between different *Jatropha curcas* genotypes is not available

Recommendations:

- Introduce scientifically sound methodologies for observations on growth, production and development in new and in existing (older) *Jatropha curcas* production systems (See text box below for recommendations on productivity observations)

- Fruit coats, press-cake and pruning contain considerable amounts of nutrients. For environmental sustainable production, nutrients that are removed from the fields by harvests and pruning materials should be replenished
- *Jatropha curcas* agronomy research should focus on the response of jatropha (and intercrop) productivity to resources (fertilization and water) and pruning

Recommendations on productivity observations:

- Record Longitude, Latitude and Altitude, Age, seed origin and size of the plantation
- Mark at least monitoring 6 trees per treatment inside a plantation (not in border rows, unless a hedge of course, then do not use the head and tail of the hedge)
- If possible, assign 3 replicates in the same treatment
- Record Phenological development dates: 1^{st} leaf/branch growth, 1^{st} flowering, last flowering, 1^{st} harvest, last harvest and last green leaves
- Record between-row and in-row distance of the plantation (in meters) to relate per tree observations to observations on a hectare basis: Average value for 6 trees * 10,000 (m2 ha-1) / (between-row (m) * in-row (m))
- Record all management actions that could influence the natural resource base: irrigation (date, rate, type) and fertilization (date, rate, type).
- For productivity observations: at each harvest cycle, weigh the fresh seeds from each tree or treatment (); dry a subsample of about 100 g fresh seeds at 70° or 100° Celsius to determine dry seed weight. Sun drying for 5 days is another option.

5 Social aspects

By J. van Eijck (UU)

The social aspects that we considered consist of food security (5.1), local prosperity (rural and social development) (5.2), labour or working conditions (human/labour rights) (5.3), land ownership and land rights (5.4), and finally gender(5.5).

5.1 Food security

Methodology
Food security is a broad concept that covers more aspects than only the production of food. The latest FAO definition describes it as "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2009). There are four factors that influence food security according to a study by the UN, see Figure 5.1.

Availability of food relates to agricultural production of food crops. This is influenced by factors such as the crop selection, farming techniques, agricultural yields and the development of new technologies

Stability of food refers to events that may lead to populations losing access to food such as conflict, loss of resources, market failure, environmental degradation and disasters.

Access to food primarily refers to people's ability to afford and overcome barriers such as remoteness and social marginalization. Food prices and income level are the main fact related to access.

Utilization of food refers to people's ability to absorb the nutrients within the food.

Figure 5.1: Factors that influence food security (UN 2008)

Food availability is seasonally influenced but can also differ annually (for example differences across years due to droughts, floods and so on). Furthermore, food insecurity may be chronic or temporary (FAO 2008b).

5.1.1 General issues
Jatropha is mostly grown in regions with an abundance of land, but with significant food insecurity problems. Yet, none of reviewed studies investigates the direct and indirect impact of Jatropha production and use on all four dimensions of food security. Most studies stress the potential positive impact of Jatropha on employment, income generation, poverty alleviation and local prosperity, as lack of these are considered the most important causes of food insecurity. The most comprehensive study on food security is carried out by the FAO and studied Tanzania (see box). In this study (Bioenergy and Food Security (BEFS)) the FAO concluded that food insecurity is primarily driven by low food crop yields. An

increase in these yields will offset any decrease in food security. They found no national level trade-off between food production and biofuel production. But they indicated the importance of changes in food prices, which can have a significant impact on households' food security (FAO 2010). This is also acknowledged by Habib-Mintz, who found that subsistence farmers in Tanzania often face food insecurity due to a lack of household income. In seasons in which a surplus is produced, they often sell this surplus to pay off pre-existing debts for seeds, fertilizer, medicines, clothing, schools, etc. As a result, rural farmers do not have crops to eat or cash to purchase food from the market during 6-8 months of the year. This problem often peaks during the rainy season, when prices rise (Habib-Mintz 2010). Food utilization is touched upon by another FAO report, though not specifically for Jatropha. Its authors state that traditional systems may also influence utilization, e.g. in rural settings very often family members eat from the same pot, which has a negative effect on the nutrient intake of the members who eat more slowly than the rest, for instance children. And in some communities food is distributed according to gender norms; men sometimes eat first till they are satisfied, what is left over goes to the women and children (FAO 2008b).

FAO study: Bioenergy and Food Security (BEFS) (FAO 2010)

In this study, 5 modules are analysed and combined to assess the situation for Tanzania when biofuel production would have been increased. The first module; biomass potential, showed that land suitability can be improved by using more sustainable agricultural practises (medium-term) and by increasing the level of inputs (longer term). These two changes will improve the whole agricultural sector. In the second module, the biofuel chain production costs were assessed leading to the conclusion that the technological capability of Tanzania is limited and new investments are required to support the development of biofuels. For Tanzania they therefore recommend to produce biodiesel by a conventional (first) level technology (or first generation biofuels). Jatropha biodiesel competes favourably on production costs, compared to other crops, but has uncertainties in processing as well. In the third module, Agriculture markets outlook, the focus is on domestic food production and the influence by international markets. The conclusion is that new lands should be brought into production to offset a slightly negative impact on food security. Furthermore, if cultivated lands and yields for biofuel feedstock are slightly increased, it will offset any impact on food security. The economy wide effects are discussed in module 4. They indicate that there is no national level trade-off between biofuels and food production in Tanzania. Due to changes in the real exchange rate it is expected that the amount of land that is displaced by biofuel feedstock, is smaller than the lands released by declining traditional export crops. This results in a slight increase of food production for most biofuel investment scenarios. For all biofuel scenarios welfare gains (GDP increase, employment opportunities) are improved. Small-scale outgrowers schemes (esp. for cassava and Jatropha) are found to be most effective in raising poorer households' incomes (compared to plantations). Lastly, in module 5, the household level food security is assessed. It is concluded that changes in food prices will affect household incomes, but they were not able to draw country level conclusions. Food prices have risen over time, but it is unclear whether this has benefited the poor.

Other studies typically focus on land availability, whereby there are large differences between a plantation model and an outgrower model or smallholder model. The impact on food security for smallholders and plantation models is analysed separately.

5.1.2 *Impact of a smallholder system on food security (availability and access)*

The areas where Jatropha production takes place are often associated with already low levels of food security. However, most studies found no additional impact due to the Jatropha projects. One report even analysed 15 case studies on bioenergy initiatives on 3 continents and found no links between the initiatives and food production, price or security (Practical Action Consulting 2009). In Honduras (Gota

Verde), where Jatropha is only promoted as living fences and in intercropping plantations, projects do not support the dedication of farmers' entire land to Jatropha. This helps to minimize substitution of food crops (Puente-Rodríguez 2009). Since living fences are popular in that region, this promotion is well received. The same promotion strategy is also seen in Tanzania (van Eijck 2009). In Tanzania the company Diligent promotes the planting of Jatropha as a fence, thereby not posing a threat to food security (because no food crop has to be substituted). The local population has been used to this mode of planting since many years. Diligent also promotes intercropping on a small scale, and makes records of its farmers with photographs, visits, GPS location etc (Gordon-Maclean et al. 2008). Also Mitchell (2008) concluded that domestic food security is currently not at risk. She interviewed farmers cultivating Jatropha for Diligent and concluded that smallholders, or subsistence oriented households were reluctant to adopt Jatropha in plantation form. They prioritised food crops when allocating labour (Mitchell 2008). In another study on Tanzania, Loos conducted surveys amongst 248 households (131 Jatropha farmers) close to the company Prokon. Loos (2008) was able to conclude that there were no significant differences in food security between Jatropha outgrowers and non-Jatropha farmers, though more than 50% reports food shortages. Furthermore he found that the difference in land size between Jatropha farmers and non-Jatropha farmers was close to the area cultivated with Jatropha. This indicates that Jatropha seems to be planted in addition to already cultivated areas.

However, some studies observed negative impacts. For example, in India Ariza-Montobbio (2009) identified a loss of food for subsistence (and fodder for cattle). Fourty-six farmers were interviewed but underlying information is not revealed so the context is unclear. Also in India, a loss of food for subsistence was observed. In a sample of 45 Jatropha growers, 82% was previously cultivating foodcrops on the plot in which they were cultivating Jatropha. Furthermore, also half the sample cultivated Jatropha on 50% or more of their land, leading to a relatively large reduction of food crop area (Ariza-Montobbio and Lele 2010a). In this particular case in Tamil Nadu, groundnuts were cultivated as main crop, a reduction of this crop also led to a reduced availability of groundnut oil for the family. Where Jatropha replaced pigeon peas or cotton, a source of firewood was lost. This is because these crops are suitable to be used as firewood, while Jatropha is not (Ariza-Montobbio and Lele 2010a). At the same time, Altenburg et al did not find any proof of loss of food security in the government centred plantations in India, nor of a significant negative impact on smallholders, although a few farmers in Chattisgarh switched from millet to Jatropha. However, this did not occur on a large scale (Altenburg et al. 2009).

A negative impact was also found in Northern Brazil. In this region a considerable part of the local population has to purchase food. Out of interviews conducted with a group of 27 Jatropha growers, 65% had to buy rice, 88% beans and 29% cassava. This demonstrates that families in the region can be considered net food buyers. Fifteen families in the Jatropha 'group' (56%) responded that they have changed the land use from other feedstock cultivation (maize, rice, etc) to Jatropha. This corresponds to to 47% of the area. As a result of the land conversion, 37% less cassava and 34% less maize was produced . Furthermore 26% of the Jatropha group reported food shortage during the year (compared to 57% in the group cultivating Castor) (Finco and Doppler 2010). However, there is no control group without Jatropha plants. The author focuses only on land that has been converted to Jatropha cultivation, but food access (related to income) is not taken into account. It would be important to repeat this research. Because if there is an increase of household income, it may be possible to offset the loss of food production which means food security does not decline.

So both the studies by Ariza-Montobbio and Lele and Finco and Doppler and to some extent Altenburg et al. (2009) observed negative impacts because land was converted from food crops to Jatropha.

In Honduras the limiting factor for increased food production was credit. A project in Gota Verde achieved that small farmers gained access to credit for food crops, because of their increased income from the intercropping scheme. This resulted even in an *increase* of the planted area as well as increased productivity (Moers 2010). In Gorongosa, Mozambique, a smallholder community was interviewed by Bos et al. (2010). Jatropha was planted as experiment in the field and as border plants and the farmers did not stop growing food crops. In the community only farmers with access to many resources were willing to start planting Jatropha, whereas subsistence farmers wanted to wait and see how the plant was doing in other fields (Bos et al. 2010).

Competition for labour

Ribeiro and Matavel mention that subsistence farming in Mozambique is very labor intensive, this makes each crop a direct competitor for food production. Additional problems that are faced in this respect are the lack of infrastructure which makes it complicated to get farmer surplus production (if any) to local markets (Ribeiro and Matavel 2009). However the claim that Jatropha is a direct food competitor is countered by a review of this study by the Jatropha Alliance (Jatropha Alliance 2009), which states that the amount of labour reduces in the years after planting, and if Jatropha is planted as hedges it can be an addition to food crops. The authors further emphasize that Jatropha can strengthen food production by increasing farmers' income and protecting the fields from animals. The claim by Ribeiro and Matavel is also contradicted by Nielsen and de Jongh (2009), who observed in Mozambique that Jatropha offers a compatible labour scheme to other crops (sesame) because Jatropha seeds can be left on the plants for several weeks before harvesting. This makes it possible to choose a time of low agricultural activity (Nielsen and de Jongh 2009). Mitchell concluded from her study in Tanzania that only the weeding of Jatropha competes for labour with the weeding of other crops. This activity however becomes unnecessary when the plants grow bigger. Harvesting was found to have less impact on labour availability (Mitchell 2008). In Zimbabwe the Jatropha harvest season in Mutoka Ward is from May to August, this is an off peak period for food production and hence there is no bottleneck for agricultural labour demand (Tigere et al. 2006).

Table 5.1: Impact on food security by smallholders (see also table in annex II)

Study	Positive	No effect	Negative	Source of data
(FAO 2010)		X		Tanzania (Tz) Country data
(Practical Action Consulting 2009)		X		15 case studies, 3continents
(Puente-Rodríguez 2009)		X		Honduras, 8 month fieldwork, lit., interviews (60) and observ.
(Gordon-Maclean et al. 2008)		X		Tz, 1.5 months study, interv. with key stakeholders and case studies on companies
(van Eijck 2009)		X		Tz, 3 yr experience
(Mitchell 2008)		X		Tz, 74 Jatropha farmers
(Loos 2008)		X		Tz, 248 households
(Ariza-Montobbio 2009) (Ariza-Montobbio and Lele 2010)			X	India, 49 plots
(Altenburg et al. 2009)		X	X	India, 13 case studies
(Finco and Doppler 2010)			X	Brazil, 17 Jatropha farmers
(Moers 2010)	X			Honduras, experience
(Bos et al. 2010)		X		Mozambique, fieldreport
Effects specifically through labour competition:				
(Ribeiro and Matavel 2009)			X	Moz. field visit, 7 plantations, 27 questionnaires and 50 interviews
(Jatropha Alliance 2009)		X		Mozambique, review
(Nielsen and de Jongh 2009)		X		Moz, field data, 3 yrs old project
(Mitchell 2008)		X	(weeding)	Tanzania (see above)
(Tigere et al. 2006)		X		Zimbabwe, Field interviews (60 jatropha growers)

In Table 5.1 the studies are summarised, 3 studies (in India and Brazil) mention a food security reduction, while 9 studies did not find a negative impact on food security, including the comprehensive report of the FAO (one study is double counted). One study finds a positive effect (Honduras). Corresponding to labour competition, one study finds a negative effect (though not based on observations) and 4 studies find no effect.

5.1.3 *Impact of a plantation model on food security (availability and access)*

For plantations no studies were found for the factor food availability. Jatropha plantations are often situated in food insecure areas. Tanzania for example has only 5 regions that have regular food surpluses (out of 20). The region where the plantation company Bioshape was active (Kilwa) belongs to the regions which produce just enough to be sufficient for three or four months after harvest (FAO 2008b). During the remaining months people have to buy their products on the market. However the company Bioshape has established a school vegetable garden in Mavuji village in Tanzania (Gordon-Maclean et al. 2008). Local children can learn about agricultural practices which could increase food production.

From among the visited projects in Mozambique by Schut et al. (Schut et al. 2010b) only a few initiated food-security projects. They concluded that on the short-term the current scale will probably not endanger food security, the long term effects are unclear (Schut et al. 2010b). Farmers who were employed as labourers at plantations seemed to spend less time on their own farm, this resulted in decreased food self-sufficiency (Peters 2009) cited by (Schut et al. 2010b). Also, the amount of household labour on their farm has decreased since the arrival of the plantation, leading to a lower household food production (Peters 2009). However, the workers have favourable hours (e.g. until 16:00) to enable them to continue working on their household farm.

Table 5.2: Impact on food security by plantations

Study	Positive	No effect	Negative	Source of data
(Gordon-Maclean et al. 2008)	X			Tz. 1.5 months study, interviews with key stakeholders from all levels, case studies on companies
(Schut et al. 2010b)		X		Mz. Literature review, field visits, interviews
(Peters 2009)			X	Mz. Field work, household survey (84) in 3 villages

In summary, food security is increased by plantation models according to one report (Tanzania) and decreased according to another (Mozambique). In total 3 reports discussed food security impacts for plantations.

Tips to increase food security:

- Promote agricultural knowledge by supporting a school vegetable garden or other extension services that provide knowledge to the population.
- Don’t convert (or promote to convert) land under food crops into Jatropha plantings.
- Promote the planting of Jatropha as an additional crop for farmers, at low opportunity costs for the population (see Section 7.2 for an explanation of the concept of ‘opportunity costs’); planting as a fence helps to protect the field; prioritise labour for food crops, since the harvesting of jatropha seeds can be postponed.
- Don’t support farmers to dedicate their entire fields to Jatropha (monoculture).
- On plantations, create favourable working hours to enable workers to keep working on their own fields.
- Increase the income of the local population by paying sufficiently high wages.
- Focus on land-abundant regions, and marginal and degraded lands.

5.1.4 *Conclusions and recommendations*

Conclusions

- Food security is a major concern in many regions in which Jatropha is produced, especially in Sub Saharan Africa (SSA).
- Food security is a four dimensional phenomenon: the availability, stability, access and utilisation of food together determine food security.
- In none of the studies all four dimensions are taken into account. Food access is analysed in a few cases, but food stability and utilisation have not been analysed so far. Most studies focus on the availability of food in terms of the direct impact of Jatropha production on the availability of land or labour for food production. None of the studies investigated the impact of Jatropha production on food prices (e.g., through economic modelling or through monitoring), while this can affect food security.
- There are only two observed cases (in India and Brazil) of loss of food production when smallholders switched from food crops to Jatropha. There is no evidence that this occurs on a large scale at the moment. There seems to be a consensus that when cultivating Jatropha does not lower food production (e.g. Jatropha planted as fences, on degraded land or in an intercropping model) there is no negative impact on food security.

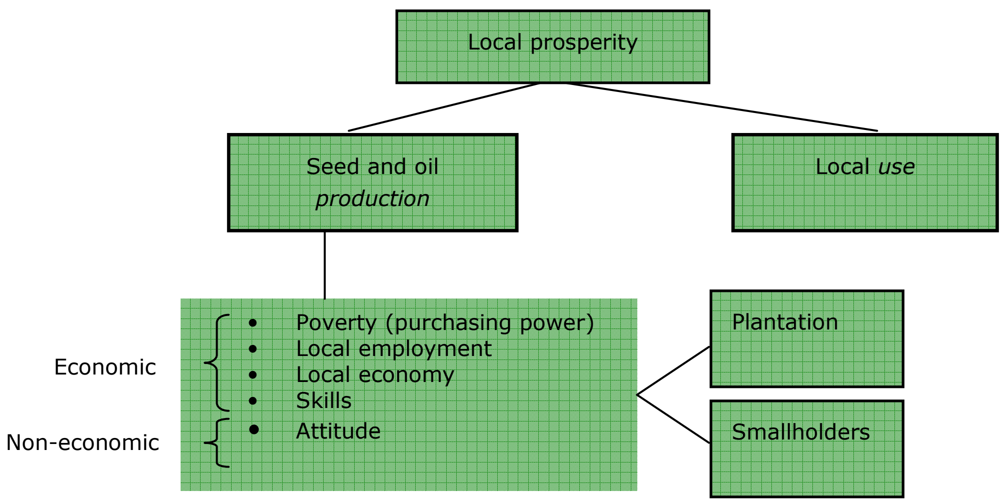
- The impact on food security from large plantations is unclear, since in one study it is increased (due to a school vegetable garden) and in another study it was decreased (due to reduction of time available for household farming).
- Competition for labour on Jatropha production in smallholder systems is minimal, only weeding might overlap with other agricultural activities during the initial few years after planting.
- Many studies stress the positive impacts of Jatropha production on poverty and employment reduction, which are crucial food security factors.

Recommendations:
All linkages and aspects that relate to food security should be analysed, base line studies are required to determine changes due to project interventions. Food security is a broad issue that should be dealt with in cooperation with local organisations and authorities. The use of complementary methodologies (e.g. primary interviews, secondary data, but also modelling & simulation) is advised to create a comprehensive overview. Furthermore, more research is required to establish increased understanding on food security impacts caused by plantations.

5.2 Local prosperity (rural and social development)

Methodology
Local prosperity relates to the welfare of the local population. It is a term that is mentioned in many sustainability criteria, for example those formulated by the Cramer Committee (criteria 8) and the NTA 8080 which is a Dutch technical standard for the use of biomass-based energy that contains more specified criteria. The RSB principles (RSB 2009) mention rural and social development (principle 5) which is a related concept. However, a clear definition is lacking. Therefore, we created a model, see Figure 5.1, to analyse local prosperity.

Figure 5.1: Model used to analyse local prosperity



We made a distinction between the *use* of Jatropha products (Section 5.2.A), and the *production* of Jatropha seeds and oil (Section 5.2.B). Local use of Jatropha products, e.g. oil, seedcake and soap, relates to energy access. This is mainly energy for cooking, lighting and transportation. We used economic and non-economic factors to determine changes in local prosperity at the production side. We thereby made a distinction between a plantation production model and a smallholder production model. The direct economic factors are;

Poverty or (lack of) purchasing power relates to the household situation in the region. It includes the income that can be made from selling seeds.

Local employment relates to the chances for the local population to earn an income; this can be either from working on a plantation or in a processing unit.

The *local economy* can be of influence on local prosperity as well. A whole region can potentially benefit if money is spend in the region, e.g. increase of trade at local shops and at other small and medium enterprises.
and the non-economic factors;

Skills relates to the possibility of capacity building, e.g. by increased agricultural knowledge which stimulates local prosperity.

Attitude is a social factor that relates to a change in attitude (personal beliefs and motivations) of the local population which can increase or reduce local prosperity. For example the level of expectations; according to Mitchell (2008), if high expectations of a household are not met, farmers may become less receptive to advice and development interventions in future. This reduces local prosperity.

5.2.1 Local use of Jatropha products, impact on local prosperity

Especially important for local prosperity is the local use of Jatropha products. The Jatropha tree itself can be used as a fence. Fencing with Jatropha reduces fencing costs and deforestation since no fencing posts are needed anymore. Farmers in Zimbabwe like Jatropha for this use and also for its fast growth from cut branches (Tigere et al. 2006). Other uses are medicinal (the Luo tribe in Kenya amongst others), especially the milky substance that comes from the stem or leaves can be used for this purpose, and lastly the tree is used as support for vanilla trees (GTZ 2010).

Jatropha wood cannot be used as source for firewood because the wood is very light and humid and the amount of wood per tree is not significant (Wani et al. 2006; Rajagopal 2008; Ariza-Montobbio and Lele 2010a). This is also recognised in Zimbabwe by Tigere et al. (2006), they further observed that it is also sensitive to ground frost, and its toxicity to humans and livestock were perceived as limitations. Leaves are not eaten by animals so there is also no use as fodder. Rajagopal therefore points out that if Jatropha is planted on common property resources (such as community lands with trees) a wide variety of commodities like fuel wood, fodder, timber and thatching material for home roofing etc. will be lost (Rajagopal 2008). (see also Section 7.4) The same is mentioned by Ariza-Montobbio and Lele (2010a) who also stated that in Tamil Nadu, India, a loss of fodder was reported by half of the 45 interviewed farmers where Jatropha replaced paddy or groundnuts. This is because previously, paddy straw or groundnut cake was used as feed for bulls.

In rural areas demand for transportation fuel is minimal (often only tractors and occasionally cars/trucks). The major demand in rural areas is energy for cooking and lighting. This is confirmed by Bos et al. who observed that only smallholders who have access to average or above-average resources have equipment that use diesel or kerosene. One farmer in Nhambita community, Mozambique, for example has two lanterns working on diesel (Bos et al. 2010). Furthermore, in Tanzania, Jatropha SVO is currently sold for a price higher than diesel making it only a market for high-end users or for the international market (van Eijck 2009). Local use of the oil would require equipment that is adapted to the relatively high viscosity of Jatropha. Two cooking stoves for vegetable oil were tested in Arusha region. According to a report by GTZ: "The so-called "Kakute stove" does not function at all. The "protos" developed by the Bosch and Siemens Home Appliances Group (BSH) does work but did not prove to be a competitive alternative to existing systems" (GTZ 2007) (van Eijck 2009; Wahl et al. 2009).

Positive impacts on the availability of energy in rural areas include the following:

- In India a rural electrification project made the villagers switch from kerosene lamps to electricity from the project, for 4 hours per night (Gmünder et al. 2010).
- In Honduras there was often a lack of diesel at the beginning of the crucial rainy season. Due to the availability of locally produced biodiesel, the people in the project area were able to start their activities on time (plowing), while famers elsewhere had to postpone their activities (Puente-Rodríguez 2009).
- Establishment of Multi Functional Platforms that provide agricultural services like milling or dehulling, save time and can provide electricity for lighting. They can potentially have a positive impact on health, education and income (see box)(Nygaard 2010).
- In Garalo, Mali, Jatropha farmers produce seeds for a village generator; 247 households are connected, 30 $ has to be paid as a one-off contribution to the connection costs, and a user charge of 5, 12 or 24 $ per month, depending on the electricity consumption (50, 150, 300 W). Subscribers with higher power demand are charged according to the metered consumption. The access to modern energy services in rural areas led to an increase in the access to information, health and education services. The availability of electricity made possible light for studying at night, vaccine refrigeration and communications and it also improved confidence (Practical Action Consulting 2009).

But there are also barriers that have to be overcome before these positive impacts can be created. The barriers are described by Ewing and Msangi (2009): technical know-how, capital availability, private sector capacity and support, and market development (Ewing and Msangi 2009). It is also recommended to pay attention to socio-organisational issues and to use existing structures rather than imposing new ones on the rural population (Nygaard 2010). Another issue is identified by Schut et al. (2010a), the authors found that for Mozambique, most biofuel projects have been targeting the international market so far, rather than the domestic market. So they conclude that for targeting rural areas, incentives should be put in place to increase the attractiveness of this option.

Multi Functional Platforms

A Multi Functional Platform (MFP) provides energy to a rural community by placing a small diesel engine that turns e.g. a milling machine and a generator for the production of electricity. The MFP can be expanded with a Jatropha press, the Jatropha oil can then be used to run the diesel engine. Nygaard (2010) has explored the concept of the MFP.

The potential benefits of the energy services for rural people include health, education and income. Health centers now have light, light can be used to study, and increased income generation can occur due to saved time for women on dehulling, milling etc. This last benefit can only occur when the service (e.g. milling) did not already exist, when local income generating activities are possible and when the potential income generating activities outweigh the cost of milling (Nygaard 2010).

But by the end of 2005 about 35% of the 515 MFPs that were installed in West Africa were not in operation. And in 2007 none of them was running on Jatropha (Nygaard cites Dembele et al. 2007). However, because the concept is so appealing, the programmes still continue. The concept of an MFP is that it should be owned and maintained by community-based organisations, members should be women and the engine should preferably be driven by biofuel. Some of the problems that made implementation on the ground so difficult are analysed: 60 % of the non-functioning units were due to socio-organisational problems (internal conflicts in the management committee, rivalry between the women's groups and other village structures etc.); 26% of the problems was due to technical problems; and 14% due to economic problems. Often the (supposed) profitable activities stopped when donors withdrew. Many platforms did not provide a 'multifunctional service,' either because they had only one piece of equipment connected (often a service that was already available in the village such as milling) or because of technical or organisational problems. A sequential multifunctionality only has moderate benefits over investing in two diesel engines with single purpose equipment attached. Furthermore having one engine for multiple devices reduces flexibility. In Mali the electricity part and the milling part of the MFPs are now separated (Nygaard 2010).

5.2.2 Seed and oil production, impact on local prosperity

5.2.2.1 Poverty, (lack of) purchasing power

In none of the investigated studies the aspects related to poverty (purchasing power) were quantitatively considered.

A model to calculate the impact of large-scale investments in biofuels on growth and income distribution was developed by Arndt et al. (2009). They compared an outgrower approach to a plantation approach and concluded that an outgrower (smallholder) approach is more pro-poor. This is due to the differences in labour- and capital intensity. An outgrower approach is more labour intensive and can also result in technology spillovers. This is also concluded by the FAO who found in their model that all biofuel production scenarios improve household welfare, but small-scale outgrower schemes especially for cassava and Jatropha are most effective at raising poorer households' incomes (FAO 2010). Also (Ewing and Msangi 2009) point out that the welfare gains for small-scale production models are higher, based on literature and case study reviews.

Smallholders

Smallholders can grow Jatropha and sell seeds; the cash income constitutes an improvement of their local prosperity. In Mali, selling Jatropha seeds (via a co-operative) is considered an important economic and social safety net. The seed price is fixed, so when fossil oil prices decrease the Jatropha oil market might be difficult. But on the other hand, higher fossil oil prices will enable the co-operative to negotiate higher seed prices (Practical Action Consulting 2009). It is also possible to collect seeds from communal areas and sell them, Messemaker (2008) observed an increased income for these gatherers, often the poorest of all stakeholders. Also Altenburg et al. (2009) mention that landless labourers benefit from collecting seeds. Prices paid for seeds determine the returns on labour. But whether a farmer cultivates Jatropha and then picks the seeds or only picks the seeds (e.g. from communal owned Jatropha trees) only matters in their labour requirement, not in the price they receive. (Struijs 2008). See Table 5.3.

Table 5.3: Prices paid for Jatropha seeds in various studies

Country	Type of project	Price per kg ($)	Transaction details	Study
Thailand	Small scale	0.20 (and 0.01 hulls or leaves)	Guaranteed fixed price to farmer	(Practical Action Consulting 2009)
Tanzania	Outgrowers, Diligent in May 2008	0.07 (80 TZS)	Guaranteed price to farmer	(Struijs 2008)
Tanzania	Outgrowers, Diligent in 2009	0.08-0.17 (100-200 TZS)	0.08 $ is guaranteed	(van Eijck 2009)
India Tamil Nadu	Government centered	0.06 and 0.14 (6.5 or 3 Rs)	Guaranteed minimum support price	(Altenburg et al. 2009)
Mozambique	FACT-ADPP	0.08-0.18 (2.5-5 MZN)	5 MZN is paid to participating farmers, 2.5 MZN to other farmers	(Nielsen and de Jongh 2009)

Current prices paid for seeds vary from 0.06-0.20 $/kg. In Section 7.5, where we present our own profitability estimates of Jatropha cultivation for smallholders, an average of 0.14 $/kg is used in the calculations.

Mitchell (2008) indicated a social structure in which the poorer households may not benefit from Jatropha when prices increase. This was observed in one village, where family members from poor households were initially collecting seeds from hedgerows with approval of the owners of the hedgerow. When seed prices increased the owners wanted to collect the seeds themselves. The poorer households were not able to cultivate their own Jatropha due to e.g. the relatively long distance from an irrigation source.

The case study on Nhambita community, Mozambique, indicated that for a successful Jatropha outgrowers project it is essential to create an enabling environment which provides access to knowledge, training and technology and establish a guaranteed market for the produce. Furthermore, paying an annual remuneration for planting and maintenance helps to target the people with access to very little resources Also Ribeiro and Matavel (2009) mention that a lack of market is the reason that many farmers who started to grow Jatropha in 2007 in Mozambique abandoned it. Lack of information is a problem as well. In Zimbabwe a survey among 43 Jatropha smallholders identified that the wealth category is important, the poorer a household, the more likely it is that Jatropha activities will be started (though Schut et al. (2010b) conclude that farmers with access to many resources are more likely to experiment and therefore to plant Jatropha). It is assumed that this is because there are (almost) no capital requirements to start growing, picking and selling Jatropha. When the selling price was considered unattractive, farmers were unlikely to start Jatropha growing (Mujeyi 2009). A sales agreement that guarantees a market for seeds is very helpful to stimulate production (van Eijck 2009; Bos et al. 2010). Also paying an annual remuneration for planting and maintaining the plants would be helpful to target the people with access to little resources (Bos et al. 2010).

We identified several studies that mentioned a change in purchasing power:

- In India a project is described whereby women earn carbon credits for planting Pongamia (a tree) and Jatropha. The World Bank sponsored this project. Most seedlings were sold to the forest department but some were planted on field boundaries and communityowned lands. The women earned 645 $ for planting 4500 trees (Wani et al. 2006).
- In Thailand in the first year smallholders are allowed to grow only 200 plants, to gain experience. Each farmer receives a loan of 60 $ which has to be paid back within the year (5-6% interest) (Practical Action Consulting 2009).
- In Honduras the Gota Verde project has set up a separate enterprise for the production of Jatropha oil that will be used for local purposes. Feedstock is sourced from smallholder farmers and they own 49 % of the shares, growing to a 100% over time. It is not allowed for one farmer to own more than 5% of the total shares, to avoid voices of resource-rich farmers to become dominant (Puente-Rodríguez 2009; Moers 2010). By the end of 2009, a total of 196 Jatropha farmers where shareholders, with a total owned capital of 7500 euro. This project also created a local currency to ensure that the purchasing power is spent locally. By the end of January 2009, 26 businesses accepted the new currency (vouchers), a total of 107,646 units where emitted. It is unclear at what exchange rate this currency relates to 'real' monetary units. The project also set up a financing system for Jatropha investments that consists of loans to farmers. 30% of the farmer's harvest is used for repayment so the risk is shared between farmer and the foundation (Moers 2010). It does take a rather long time however, before there would be a return on investment.
- In Tamil Nadu, interviews among 45 Jatropha farmers revealed that the (mostly landless (without official land administrative rights), small and marginal) farmers increased their off-farm activities. Especially from the second and third year onwards they migrated to nearby cities for longer periods than before since they did not need to guard and irrigate the crops anymore (Jatropha needs less management). This could result potentially in increased income, but Ariza-Montobbio and Lele (2010a) indicate that this probably only compensates for the potential loss of food or fodder on their plots due to the shift to Jatropha (Ariza-Montobbio and Lele 2010a).

<u>Plantation</u>
The prime influence of the plantation model on poverty works through the wages that are paid to local employees. This has a very positive effect on poverty levels, though none of the studies has analysed this aspect.

In Mozambique almost 80% of the proposed biofuel projects are located in the most populated and developed regions of the country which cover only 39% of the available land. Schut et al. mention a relationship between the presence of biofuel projects and the availability of (skilled) labour, access to inputs, and the availability and quality of infrastructure (roads and ports) in these areas. In general they found a high concentration of biofuel projects. However, even though the projects are not located in the most remote rural areas, they do generate employment, income and indirect spin-offs (Schut et al. 2010a).

5.2.2.2 Local employment

Arndt et al. (2009) created a model for biofuel impacts in Mozambique. With this model calculated that the investments in biofuel lead to an increased annual economic growth of 0.6 percentage point, and reduces poverty with about 6 percentage points over 12 years in Mozambique.

<u>Smallholder</u>
In Tanzania, the company Diligent uses a system with collectors that buy seeds from seed pickers. This enables the local community to benefit, and collectors have access to other benefits as well. The longer a collector delivers seeds to Diligent the larger will be the cash advance they can get from Diligent, and other benefits like acquiring mobile phones on credit from Diligent can also be obtained. The collector repays the phone with seeds. There is a risk of middlemen taking larger shares, but transparency about the price will limit this. A guaranteed minimum price (of 100 TZS per kg) is communicated to all farmers with flyers, so that middlemen are forced to pay at least these prices (van Eijck 2009). The occurrence of middlemen who take a large share of the profit is reduced in the Indian state of Uttarakhand. The state government does not allow seeds to be sold outside the state, the forest development corporation is the sole purchaser and the price is fixed (Altenburg et al. 2009). Arndt et al. have calculated that for Mozambique, outgrowers schemes create more employment for unskilled labor than plantation estates (Arndt et al. 2009) (also cited by (Ewing and Msangi 2009)).

<u>Plantation</u>
Arndt et al. (2009) calculated that on average 49 farm worker jobs are created per 100 ha Jatropha cultivation and processing (compared to 34 for sugarcane). While large-scale production will create jobs in rural areas, these will be mainly low-skilled and seasonal (IFAD/FAO 2010). In Mozambique many of the projects that have been visited by Schut et al. (Schut et al. 2010b) (9 in total) provided direct employment opportunities for nearby communities. However, the absence of local skilled labour force is identified as a problem.

An analysis of investment data on 17 biofuel investment proposals revealed an estimated employment potential between 0.14 and 0.17 jobs per ha. The proposals included Jatropha and sugar cane. The estimate for one already approved Jatropha project (Enerterra SA) is slightly higher, 0.27 jobs per ha (Schut et al. 2010a).

The company East Africa BioDiesel (EABD) in Tanzania intends to employ 606,000 people to cultivate 6000 ha, though the author wonders whether this figure is realistic. The company is located in a very poor district, Bahia (Habib-Mintz 2010). The labour force within this district numbers only 85,000 people, indicating that migration of labour would be necessary. However, the estimate for the required number of labourers is questionable, since operations have not started yet. The project would require medium-skilled manpower. A company in Mozambique (Energem) generated around 500 jobs (permanent and seasonal). The average worker salary is around US$ 60 per month. A working day starts and ends early, leaving daylight hours to tend personal fields (Ribeiro and Matavel 2009). Peters conducted a household survey among 84 households to analyze the impact of this plantation. The $60 average wage for permanent jobs (Mtc 1650 /month) is lower than the wage level in the tourism sector (Mtc 2275 /month) but higher than a guard’s wage (Mtc 1500 /month) (Peters 2009). At ESV, also in Mozambique, permanent workers earned US$ 72 and seasonal ones US$ 46 per month on average, and 1350 jobs were created. ESV also constructed new water supply points and supported the community with small expenses e.g. for funerals. However, due to financial problems salaries were not paid for 9 months which caused social unrest. Ribeiro and Matavel explained that the wage income is lower than farming revenue in a good year, but higher than in a bad year. The wages also fluctuate less between seasons than farm income. A combination of both wages and income from continued farm work seemed a good mix in principle. However, since the company did not pay for 9 months, the area that the workers could cultivate independently was actually reduced. Two other companies in Mozambique also had to stop all activities due to financial problems (CHEMC agri and Bachir Jatropha). The company MocamGalp was still in early stages in 2009 and had generated 34 jobs (Ribeiro and Matavel 2009). Another company, Sun Biofuels, generated 430 jobs and observed on average 9 hour' working days (45 hours per week) (Ribeiro and Matavel, 2009). A move to mechanical harvesting could have a significant impact on the number of workers (ProForestLtd. 2008). In India, the Forest Department created employment for 3.2 to 3.7 labourers per ha for 25 days for the establishment of a Jatropha plantation in Chahattisgarh (Altenburg et al. 2009), but most employment will be generated during harvesting periods. If the land was not used before, which is the case here, the employment and income effects are positive. This would be different in cases where the land was not previously used.

5.2.2.3 Local economy

<u>Smallholder</u>
In Tanzania the company EABD intends to generate additional income for the local population by creating a market to sell food crops. But this company has not started operations (Habib-Mintz 2010).

In Tanzania the company Diligent has set up collection points where seed pickers can sell their seeds. This creates a local economy around the collection point. The more seeds a collection point sells to Diligent the more benefits the collector will get. Wahl et al. (2009) have indicated that market access for local people is good where a collection point has already been set up by Diligent. These collection points are always situated at strategic points, e.g. market places. But market access is found to be difficult for villages that have not (yet) been provided with a collection point and where there is also no local demand from a soap-producing women group. Although people could bring seeds directly to the factory in Arusha town, Wahl et al. mention that this is a rather unlikely option for poor small-scale farmers living in remote areas (Wahl et al. 2009).

The transportation sector in Tanzania is very inefficient, transport costs for maize can constitute up to 49-60% of the retail price (Habib-Mintz 2010). This is a barrier for small farmers who want to enter the agricultural market by selling Jatropha.

<u>Plantation</u>
In Mozambique the projects that were visited by Schut et al. (2010b) had quite a positive impact on the region, creating direct employment as well as indirect employment (housekeepers, guards and cooks) and access to infrastructure, and leading to opening of shops along the newly created roads. The contribution to the local economy is expected to increase when the projects expand (Schut et al. 2010b). Growing purchases of locally made food, drinks, construction materials and other goods are also likely to boost local prosperity (Schut et al. 2010b)p 80.

However, machinery and materials for biofuel investments are mainly imported (Schut et al. 2010b).

Peters, who analysed villages surrounding the plantation of Energem in Mozambique, found three impact indicators: wage income, (non)food expenditure, and leisure time available. After the plantation was established the total number of households in the villages had increased between 7% and 18%. This is due to in-migration of people looking for work. In the villages surrounding the plantation, an increase in available household cash income was noticed. This resulted in a decrease in other cashgenerating activities (e.g. cash crop sales, microenterprise activities, etc.). Food and non-food expenditures had increased. These changes lead to the conclusion that households working on the plantation are better off (in socio-economic terms) than households not working on the plantation. However, the amount of leisure time had decreased for the households working on the plantation due to increased wage work. The amount of household labour working on the farm had also decreased in these households since the arrival of the plantation, leading to lower household food production (Peters 2009).

The company ESV in Mozambique improved a school and hospital, but they stopped these activities prematurely (Ribeiro and Matavel 2009).

5.2.2.4 Skills

<u>Smallholder</u>
In Honduras, technical advisors have to attend up to 80 farmers. This makes intensive technical assistance difficult, while this is also observed as an important factor to keep motivation high (Moers 2010). Small farmers that received regular attention perform better than large farmers that receive the same amount of attention. The performance of small farmers was improved by:
compensating good performing farmers for assisting other farmers in their area
offering the sowing of food crops between the Jatropha rows (intercropping)
allowing technical advisors to give more time to small farmers (thus reducing the amount of land that they supervise)
increasing coordination with other institutions that also give technical assistance or credit
Small farmers need short term incentives since it is not realistic to expect them to maintain their plantations without further support (Moers 2010). This can be done by providing support for intercropping. The project in Honduras showed that it takes at least 4 to 5 years to set up a value chain for Jatropha.

In Thailand farmers have learned new technologies to improve yield, which could be utilised for other crops as well (Practical Action Consulting 2009). Farmers received agricultural extension from the Prokon extension workers. Farmers who cultivated Jatropha were visited regularly, though the knowledge on Jatropha cultivation was not always good (Loos 2008).

<u>Plantation</u>
EADB in Tanzania has planned to set up local refinery stations as explained by Habib-Mintz (2010), however these plans have (as far as we know) not (yet) materialised. Bioshape plans to export the raw material for processing in the Netherlands and Belgium during the first five years of operation (Gordon-Maclean et al. 2008). Processing in the country would create more benefits for Tanzania (such as training etc.). In India a corporation will employ 100 workers in a certain village, but these will be mainly already skilled employees,not landless labourers who could benefit from training (Altenburg et al. 2009). And a study in

Mozambique revealed that engineers and technicians were mostly non-Mozambican workers. Some on the job training is provided, but no formal training or education programme (Schut et al. 2010b). In sum, we could not identify any study mentioning a significant improvement in skills.

5.2.2.5 Attitude

Smallholder
In Mali farmers adopt live fences rather easily, it helps to avoid property conflicts with the neighbours (Spaan et al. 2004). But traditional cultures (e.g. Masaai) might perceive cultivating Jatropha as an intrusive practice that is different from their traditional pastoralist lifestyle (Laltaika 2008). In Mozambique it is found that It is socially acceptable and compatible with the local farming system to cultivate Jatropha (Nielsen and de Jongh 2009).

(Bos et al. 2010). In a study on the Nhambita community in Mozambique, smallholder famers stopped growing Jatropha due to the absence of a market for their seeds. They would be willing to start again if others would start to grow. However, the subsistence farmers will probably not experiment with Jatropha (a crop with uncertain yield and market) as they normally pursue a low-risk strategy. In Nhambita, Mozambique, only 1 farmer from among 250 interested farmers started to grow Jatropha (Schut et al. 2010b) p .82, (Bos et al. 2010). But also other reasons are found, a study on Zimbabwe for example identified household size and the extant Jatropha tree population on the farm as significant indicators (Mujeyi 2009).

We found 2 studies that mentioned cases whereby the level of trust was reduced, in Kenya and India:

- In Kenya at one company (Energy Africa limited) only 75 out of 200 farmers continued to grow Jatropha. Reasons as given by the GTZ study have to do with trust of the farmers. Initially the farmers received cash payments to plant but these payments ceased and the information they got at the start was not correct, leading to a deterioration of trust between the farmers and the company (GTZ 2010). The misinformation is being corrected by the current staff but the perceptions among farmers remain apparently somewhat confused. Also at another project, the Vanilla Jatropha Development Foundation, despite an enthusiastic staff the GTZ study reports that some farmers were de-motivated because they felt they did not receive adequate support. Furtermore they identified that some buyers that buy occasionally for testing can distort the market, creating high expectations by the farmers.
- In India (Ariza-Montobbio and Lele 2010a) identified plantations where the expectations of e.g. yield of Jatropha were not met and companies have abandoned the buyback contracts they signed with the Jatropha farmers. This leads to tensions and conflicts, within households but also between farmers and local promoters and between farmers and the company. In one case a key individual in a village was hired to promote Jatropha and he got social recognition for that. However when Jatropha failed in the particular village, he was held responsible for the loss in livelihood (Alattur village). And one conflict is described between farmers and D1 Mohan Bio Oils ltd., where farmers lodged a collective protest due to not receiving promised special loans and prices (Ariza-Montobbio and Lele 2010a).

Plantation
Some of the projects in Mozambique and Tanzania experienced difficulties financing their activities due to cash-flow problems, this could have huge negative side-effects on the area in which they are based (Schut et al. 2010b). Companies that had to halt their operations are e.g. ESV, Energem, CHEMC agri and Bachir Jatropha, all located in Mozambique (Ribeiro and Matavel 2009). In Tanzania

similar problems have arisen, the Dutch holding of the company Bioshape Tanzania Ltd. went bankrupt in 2010. In some cases former employees were not paid for months, this reduces the level of trust of the (former) employees, even when these companies could restart.

Community consultation (e.g. on land acquisition) mainly takes place through the local leaders, in some cases local leaders are compensated in products or services that do not benefit the communities as a whole (Schut et al. 2010b). This also negatively affects the level of trust of the local community.

5.2.3 *Summary*

We have classified the literature used in this section on local prosperity into different categories according to their focus, see Table 5.4.

Table 5.4: Studies that mention aspects of local prosperity

(Sub) aspects	Studies that mention aspects	
Local use	(Tigere et al. 2006; GTZ 2009a; Practical Action Consulting 2009; Puente-Rodríguez 2009; Gmünder et al. 2010; Nygaard 2010) (van Eijck 2009; Bos et al. 2010) (Wani et al. 2006; Rajagopal 2008; Ewing and Msangi 2009; Ariza-Montobbio and Lele 2010a; Nygaard 2010)	
production	**smallholder**	**plantation**
Poverty	(Wani et al. 2006; Messemaker 2008; Altenburg et al. 2009; Arndt et al. 2009; Practical Action Consulting 2009; Puente-Rodríguez 2009; FAO 2010; Moers 2010) (Mitchell 2008; Ariza-Montobbio and Lele 2010a)	(Schut et al. 2010b)
Local employment	(Arndt et al. 2009; van Eijck 2009)	(Peters 2009; Habib-Mintz 2010; Schut et al. 2010b) (Ribeiro and Matavel 2009)
Local economy	(Wahl et al. 2009) (Habib-Mintz 2010) Habib-Mintz 2010)	(Peters 2009; Schut et al. 2010b) (Ribeiro and Matavel 2009)
Skills	(Loos 2008; Moers 2010)	(Gordon-Maclean et al. 2008; Altenburg et al. 2009; Schut et al. 2010b)
Attitude	(Spaan et al. 2004) (Nielsen and de Jongh(Nielsen and de Jongh 2009) (Laltaika 2008) (GTZ 2009a; Ariza-Montobbio and Lele 2010a)	(Schut et al. 2010b)

<u>Smallholder</u>

In summary, around 6 reports mention positive impacts for smallholders on poverty. Only one report indicated that the poorest households might not be targeted when the owners of the Jatropha trees do not allow them to pick seeds. The effects on the local economy and local employment are positive as well. And the effects on skills are improved when technical assistance is given to smallholders, though only one study provided some information on that (Moers 2010). The attitude in general is ok, though unmet expectations and initial misinformation can lead to decrease of trust (2 cases, Kenya and India).

<u>Plantation</u>

Summarising the reported prosperity effects of plantations, only the (presumably positive) impact on local employment has been quantified by 3 studies. The impacts on local economy, skills and attitudes are less clear.

Tips to increase local prosperity:

- Try to stimulate the local use of Jatropha oil (for cooking and lighting), along with sufficient technical know-how

outgrower

- Ensure a reliable market for seeds for a prolonged period of time
- Stimulate local spending of money, e.g. by creating a local currency
- Avoid the appropriation of large shares of profits by middlemen through transparency and/or fixed prices
- Plan sufficient time to gain experience, start with a limited number of farmers and upscale only after proven results
- Try to enhance the performance of small farmers by:
  - compensating good performing farmers for assisting other farmers in their area.
  - offering the sowing of food crops between the Jatropha rows (intercropping).
  - allowing technical advisors to give more time to small farmers (reducing the land area they have to cover).
  - increasing coordination with other institutions that also give technical assistance or credit.
- Avoid creating too high expectations among farmers.

plantation

- Pay higher than minimum wages.
- Try to minimize imports, purchase equipment and materials locally or nationally as much as possible.
- Contribute to infrastructure development.
- Provide training and education to employees to improve capacity building; higher skilled jobs for the local population contribute more to local prosperity.
- Think of an exit strategy in advance, in order to avoid problems with trust of the local population.

5.2.4 Conclusions and recommendations

Conclusions:

- Local prosperity comprises a large number of factors. Most studies emphasize the direct and indirect effects of Jatropha on employment, while only one study investigates the impact on purchasing power and leisure time.
- Large differences are discernable in the number of jobs created between the two Jatropha production systems. In addition mechanisation can have a large effect on the labour requirements of plantations. Outgrower schemes in Mozambique are shown to generate more employment for unskilled labour than plantations.
- Prices paid for seeds vary from US$ 0.07-0.20 /kg.
- Employment effects of large scale plantations are positive if the land was not used before.
- The poorest among the local population can increase their income by selling seeds, in an outgrower/smallholder setting. This has not (yet) been observed in a plantation model.
- The influence of Jatropha projects on poverty (purchasing power) and the local economy of the surrounding villages has been investigated in one large scale plantation in Mozambique. Households were found to be financially better off but experienced a reduction in leisure time.
- Several studies mention that if Jatropha replaces forests on common property grounds, this can lead to a loss of fuelwood, fodder and so on, but none of the studies actually recorded negative impacts. There is a general agreement that

the impact is minimal if Jatropha is established as fences and on degraded land.
- A multi functional platform (MFP) can potentially yield multiple benefits, especially through the availability of electricity, but socio-organisational problems are a major challenge.
- Jatropha can possibly contribute to increasing the availability of energy in rural areas, which can have many positive benefits on rural households, e.g. through increased incomes, improved health, and so on. Most demand is for light and cooking, rather than transport fuels.
- Financial difficulties of the company that invests in the area can have a large impact on local prosperity (especially on attitudes, trust etc.).

Recommendations:
Jatropha should not be planted on grounds where it replaces common property forest areas on which the local population collects fuelwood, fodder and so on. Quantitative analyses are required to gain better insights into the impact on local prosperity. Local purchasing (of food, drinks, construction materials and so on) should be encouraged in order to ensure that a large share of companies' investments stay within the region or country. Deliberate attempts have to be made to ensure that plantations create technology spill-overs, through training and education. Local populations need to be provided for in case companies stop their activities. Local communities should be involved in decision making processes. If rural areas are targeted for biofuels investments, incentives should be put in place to increase the attractiveness of this option.

5.3 Labour/working conditions (human/labour rights)

This aspect also relates to local prosperity. Whereas the section on local employment analysed the economic impact, the aspect of labour/working conditions is concerned with the human conditions faced by hired workers and smallholders. This aspect relates to the principle of 'human and labour rights', addressed by the RSB. In the following analysis we made a distinction between smallholders and employees. Smallholders are own-account workers who produce Jatropha seeds on their family ground. They can be contracted via an outgrowers scheme or grow Jatropha independently, but they are not employed by an external entity, like hired plantation workers are.

The following topics can be distinguished (adapted from Hooijkaas 2010):

Topics:	Potential impact on:
Legal issues	employees/smallholders
Wages and other benefits	employees/smallholders
Child labour	employees/smallholders
Discrimination	employees
Slavery (forced and compulsory labour)	employees
Disciplinary practices	employees
Safety	employees/smallholders (health)
Freedom of trade union organisation	employees/smallholders
Education	employees/smallholders
Rights of indigenous people	employees

For only four aspects we found information: legal issues; wages and other benefits; child labour; and safety.

5.3.1 *Legal issues*

A study by WWF analysed biofuel companies in Tanzania. Its authors observed that most of the companies were planning on following labour laws. They had also signed contracts with all their permanent employees and short term contracts with their short term workers (Gordon-Maclean et al. 2008).

A study by IFAD/FAO identified the weak legal position of smallholders. Outgrowers under contract to supply large processors may face unfair business practice with lack of legal redress in the event of reneged contracts (IFAD/FAO 2010). However, the same could be said for corporate plantation models. Overall the legal institutions in developing countries are often weak. Small farmers will have little negotiating power for settling sales terms and conditions with large private concerns unless they form effective cooperatives and producer organizations (IFAD/FAO 2010).

Two examples were found in the studies:

- In Mozambique one contract was voided after the initial businessplan was not followed (Schut et al. 2010b).
- In Myanman, Sheng Goh and Teong Lee (2010) mention that in Myanmar, a report from the World Rainforest Movement indicated that farmers were forced to switch from their usual crops to Jatropha and were ‘bound to production quotas enforced by strict laws’. These claims could not be verified. http://www.wrm.org.uy/bulletin/137/Burma.html

Large scale contract farming (e.g., as practiced by Diligent in Tanzania) can reduce the risk of a price fall when a minimum price is guaranteed for several years (ProForestLtd. 2008) citing (Caniëls et al. 2007).

Different work ethics were observed in Mozambique between the (foreign) investor and local workers. This occurs both on plantations and in contract farming arrangements. Labourers did not show up for work after payday, and farmers reneged because they were not used to working on a contract basis (Schut et al. 2010b).

5.3.2 *Wages/remuneration and other benefits*

Parts of this aspect have already been discussed in Section 5.2 on local prosperity. Here we only list the evidence that is additional to the points raised there.

Smallholders
Farmers interviewed by Loos (Loos 2008) in Tanzania, indicated that they would like to be provided with loans to be able to bridge the gap between investment and returns. However, no actual practices of this nature have been reported so far.

Employees
The WWF study on companies in Tanzania found that in addition to wages some companies provided: lunches for day staff, payments into the National Social Security Fund (NSSF – the retirement benefit) to all staff, medical support to workers and their families and costs of funeral services in case of accidents whilst on duty (Gordon-Maclean et al. 2008). Other benefits consist of contributions to a Saving and Credit Society (van Eijck 2009).
Normal working hours are 45 hours per week, spread over 5 or 6 days. At least the official minimum wage was offered. In more remote areas of Mozambique there were some concerns about labour availability when plantations would

expand, in future the provision of housing or daily transport for non-local workers could overcome this issue (Schut et al. 2010b).

5.3.3 *Child labour*

Child labour:
There are two conventions from the International Labour Office (ILO) on child labour:

Elimination of child labour and protection of children and young persons	
138	Minimum Age Convention (1973)
182	Worst forms of Child Labour Convention (1999)

In 2000, ILO Convention No. 182 on the elimination of the worst forms of child labour came into force (ILO 2010). Child labour includes employment of children and children's involvement in hazardous unpaid household services. The latter refers to working for long hours, in an unhealthy environment, involving unsafe equipment or heavy loads, in dangerous locations and so on (ILO 2010). Three forms of working children are identified:

- Children in employment
  This refers to the economic activity of children both in the formal and informal economy, inside and outside family settings. Working for the child's own household is not includedin this form of child labour.
- Children in child labour
  This is a stricter subset of children in employment. It includes the worst form of child labour and children in employment below the minimum age.
- Children in hazardous work

This refers to any activity that has or leads to 'adverse effects on the child's safety, health and moral development'. For example, night work, exposure to physical, psychological or sexual abuse, work with dangerous machinery, and so on.

Smallholders
Mitchell (2008) indicates that older children generally help with farm tasks after school, during weekends and holidays. Also in the Nhambita community in Mozambique, it is normal that the children help on the farm (Bos et al. 2010). The company Diligent in Tanzania buys Jatropha seeds from collectors. These collectors buy their seeds from seed pickers. The contract between Diligent and the collector states that the collector should not buy from children but in practice this is difficult to verify (van Eijck 2009). As picking seeds is seasonal work, there would be no reason not to attend school due to seed picking. And according to the ILO definitions it is only considered child labour when the children cannot attend school due to their work. Furthermore the money earned by selling seeds is often used for school fees.

Employees
Companies have to comply with national laws and they mostly forbid child labour. In Mozambique labourers had to identify themselves before they could start working on the plantations, this helps to prevent child labour (Schut et al. 2010b).

5.3.4 *Safety*

In a report by ProForest Ltd. it is mentioned that Jatropha production could potentially have implications for health and safety but the statement is not elaborated (ProForestLtd. 2008).

Smallholders

No studies were found on safety aspects.

Employees

In Tanzania some biofuel companies were analysed in a study commissioned by WWF. It was found that some of the workers working in a factory or on a farm were given safety gear like helmets, uniforms and so on (Gordon-Maclean et al. 2008). Schut et al. observed a difference between casual labourers and permanent staff. The latter was offered clothing, boots and protection where necessary while the casual labourers did not receive this (Schut et al. 2010b).
The report by IFAD/FAO mentions a potential threat: "The labourers face the possibility of poor employment conditions and unsafe working practices for which government and pro-poor civil society institutions will need to establish checks" (IFAD/FAO 2010).

5.3.5 *Health*

Janssen et al (2009) found in literature that except for NOx emission, other emissions for biofuels are lower compared to fossil fuels. If diesel engines are adapted properly, the use of SVOs decreases the emission of mutagenic compounds compared to fossil fuel. Most of the tests however are executed with rapeseed oil or other types of oil, not with Jatropha oil specifically. He found no evidence that the use of Jatropha oil will result in the emission of specific toxic compounds in health-affecting quantities.
Modification of engines is required to reduce emissions from SVO. The amount of compounds emitted depends on the type of engine, the configuration, the load condition and the use of a catalyser.

Jatropha has toxic substances and is therefore not suitable for consumption. Li et al. (Li et al. 2010) have executed experiments with purified phorbol esters (the toxic substance of Jatropha oil and seeds) on mice. It was concluded that the consumption of Jatropha c. in any form is indeed toxic. This is the reason that it is in use as a fence.
See the section on agronomy for more on the toxicity of seedcake.

Tips to improve working and labour conditions:
- Become familiar with cultural differences in work ethics
- Provide training and education
- Use proper equipment, safety gear etc.
- Do not make a distinction between permanent staff and casual labourers.
- Avoid direct contact with Jatropha oil until research has excluded harmful skin impacts
- Monitor management plans, incl recordkeeping of accidents, supply of sufficient amount of safety gear etc.

5.3.6 *Conclusions and recommendations*

Conclusions:
- Labour/working conditions can be analysed by looking at various aspects: legal issues; wages and other benefits; child labour; discrimination; slavery (forced and compulsory labour); disciplinary practices; safety & health; freedom of trade union organisation; education; and rights of indigenous people.

- Many aspects of labour/working conditions have not been researched so far: discrimination, slavery (forced and compulsory labour), disciplinary practices, freedom of trade union organisation, education and rights of indigenous people.
- Legal issues are specific to the country in which the project is implemented
- There is no evidencefrom the studies about below-minimum wages being paid, and most companies provided additional benefits besides wages.
- Child labour does not seem to be a major issue. We found no evidence of children in employment, in child labour or in hazardous work. Only cultural practices of assisting adults with family farm work are in most cases sustained for smallholders.
- In terms of safety, one study observed a difference between permanent workers and casual workers. Information on health issues is lacking.

Recommendations:

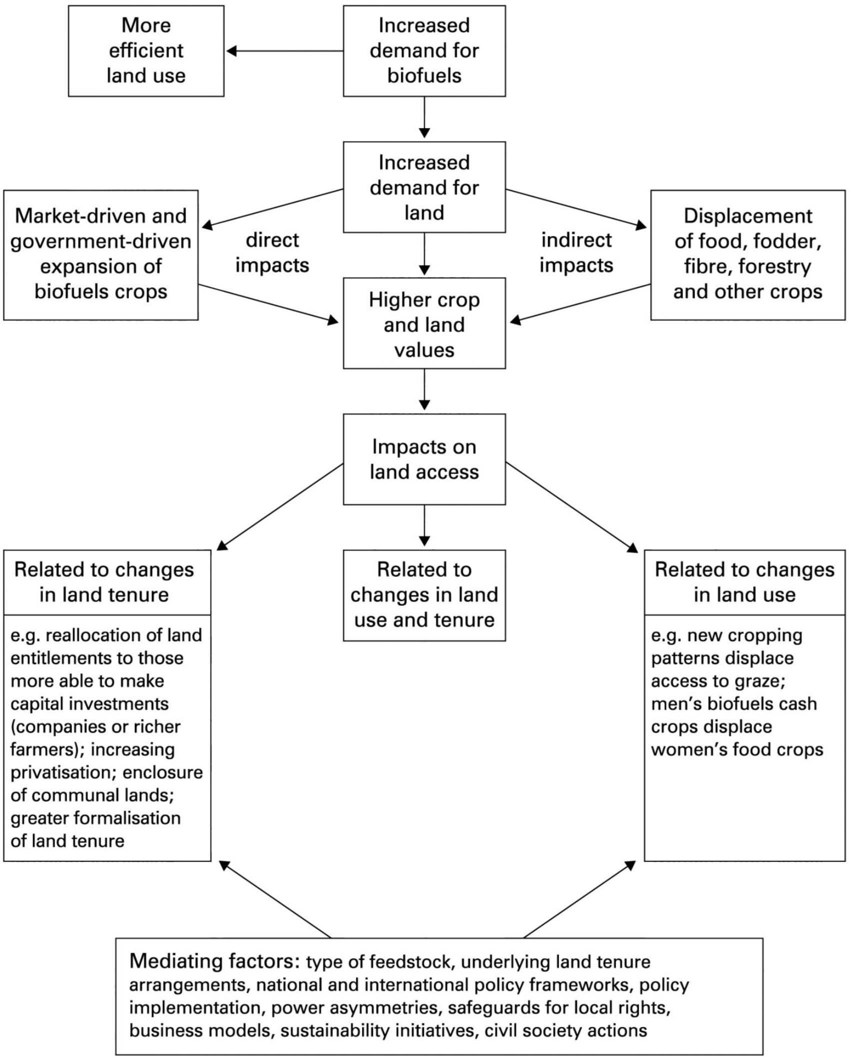
- More research is required to be able to study the impact on working and labour conditions.
- None of the plantation projects have increased their employment up to the planned maximum; this is only expected to occur when harvesting begins in a few years' time. It is recommended to undertake studies that will monitor the impact on labour conditions as employment is being scaled up.

5.4 Land ownership and land rights

There is a lot of literature about land ownership and land rights, as this is a very important and often political issue in developing economies. Land conflicts are common phenomena in Africa because boundaries of many properties are not clearly demarcated and land ownership is generally not documented (ProForestLtd. 2008). Also in China rural land management is highly complex due to the diversity of (informal) land arrangements and rules (Weyerhaeuser et al. 2007). Often lands that are perceived to be 'idle', 'underutilised,' 'marginal' or 'abandoned' actually provide various products and sources of income for the rural poor, for example food, fuel, fodder, drought period sustenance, and offseason activities. (Altenburg et al. 2009; Estrin 2009).

To cultivate land, land both has to be physically available and farmers or companies have to be able to access the land. So, land availability and land access are both required. Land access can be defined as the ability of a household to convert (general) land to their own land use, so to claim a plot for current or future use (Brück and Schindler 2009). Cotula et al. have identified several factors that can influence land access, see figure 5.2 below. From the many factors that they have listed e.g. changes in land tenure and changes in land use, it is clear that land access has many linkages to the spread of biofuels.

Figure 5.2: Linkages between the spread of biofuels and land access (Cotula et al. 2008)



There are also other businessmodels possible whereby the community keeps the land or title deed. For example Self-Help-Groups in India (described by (Wani et al. 2006) or the National Rural Employment Guarantee Scheme described by (GRAIN 2008) see Section **9.2** for more information.

The impacts on smallholders and plantations are analysed separately in Section 5.4.1 and 5.4.2, respectively. Furthermore, we included two case studies, on Tanzania and Mozambique, in respectively Section 5.4.2.1 and 5.4.2.2.

5.4.1 Land availability and access, smallholders

<u>Land availability</u>

Out of 74 jatropha growers in Tanzania interviewed by Mitchell, 93.2% responded that it is difficult to extend their land under cultivation (Mitchell 2008). This is due to customary control and general reluctance to sell land as well as a shortage of suitable land. Another reason mentioned by the interviewed farmers is the increased population. Also Wahl et al.'s (2009) Tanzania study observed that 76%

to 86% of the households use all their available land for agricultural production. Only 23% (Arusha region) to 41% (Manyara region) of the households consider having sufficient land. Unfortunately it is unclear where these percentages came from though most of the report is based on NBS 2005 statistics (National Bureau of Statistics). At the same time, out of 117 farmers In North East Tanzania that did not grow Jatropha, only 1.7 % said this was due to not having sufficient land. The main reason they gave was capital constraints (45%), followed by seeing Jatropha as too risky (26%), and not having enough time which wasreported by 12% (Loos 2008).

Land access

There is a difference between different Jatropha business models on impacts on land access. Sulle and Nelson analysed biofuel projects in Tanzania and concluded that biofuel companies that use a model with contract farming have little direct negative impacts on land access (Sulle and Nelson 2009a). Brittaine and Lutaladio (IFAD/FAO 2010) mention the threat for the people living in rural areas where land tenure systems for sustaining their access to land are weak. This is due to the economies of scale that drive large scale acquisition of land. Their recommendation is to improve land administration systems that harmonize formal and customary land tenure. The prevalence of customary law (>70%) is also mentioned by (Wahl et al. 2009). They further explain that only a rather small percentage of smallholder farmers hold a land ownership title in Tanzania.

One study specifically researched land access by smallholders. In this analysis of Jatropha growers in Mali, the author concluded that small-scale Jatropha production did not change people's access to land (Salfrais 2010). Interviews were conducted in six villages and the main differences in land access between the population where found to be influenced by three factors, indigenousness, gender and seniority. 'Indigenousness' relates to whether a family belonged to the founding families or settled later, the latter having considerable less rights. Also gender played a large role, women have inferior access to land compared to men and have to ask permission before they can start cultivating Jatropha. If men consider they need more land they can take it from e.g. a women's association. This happened in one village where men wanted more land amongst others to cultivate Jatropha as a pilot. Also 'seniority' was an influencing factor; the older a person is, the more rights he receives. This means that unmarried men are only allowed to rent land instead of receiving land in ownership, and unmarried women are not allowed to access any land at all. In other words, the most vulnerable groups (non-founding families, women and younger members of the community) lack access to land and are therefore less able to cultivate Jatropha. However these structures were already in place before the cultivation of Jatropha. But as more problems were observed in villages with higher land pressure, land pressure is an important determining factor. As the expansion of Jatropha cultivation could lead to increased land pressure, the underlying (sometimes informal structures) will have more serious effects and the weaker groups could lose their land (Salfrais 2010). The recommendation therefore is to take land pressure into consideration before Jatropha is promoted in a certain village. When land pressure is high, promotion of Jatropha should be done with great care or minimised. It should also be emphasized during promotion activities that it is important to include women's associations in societies where these play an important role (as in Mali). In Mali, this helped to increase willingness of men's associations to permit women to cultivate their land with Jatropha (Salfrais 2010).

Another problem that is identified by the study is the fact that most people consider planting trees (Jatropha) as claiming ownership of the land. Therefore

people who are renting land are sometimes not allowed to cultivate Jatropha, due to fear of the landowners of being unable to reclaim the land once trees have been planted (Salfrais 2010). The same is reported by another study from Mali, where according to customary law land planted with trees definitively belongs to the person or community who planted the trees. Landowners therefore oppose because they fear to loose their landlord status (Spaan et al. 2004; Practical Action Consulting 2009).
Some pastoralist tribes, like the Masaai in Tanzania, are used to growing Jatropha as a hedge. Growing it on a larger scale however is experienced by many Masaai as upsetting their traditional lifestyle (Laltaika 2008).
When Jatropha is used as a fence, it can however have a positive effect. It helps in delineating properties. If the trees are planted when neighbours are present, this can reduce conflicts over land boundaries (Salfrais 2010).

5.4.2 Land availability and access, plantation

Plantations have to acquire land before they can start cultivating Jatropha. The land is also often used as collateral, to acquire a bank loan. Land tenure in Africa is insecure (Sulle and Nelson 2009a). They identify several issues:

- land targeted for biofuel production might be unoccupied, but not unused
- villagers lack understanding of the process
- many promises are made verbally, not in written contracts
- procedures are not always followed, leading to confusion over processes
- land valuation criteria are inadequate
- the level of risk carried by communities is high

Land conflicts are a common phenomenon in Africa, especially when a large parcel of land is being earmarked for large scale commercial projects such as commercial plantations of Jatropha for example. This is because boundaries of many properties are not clearly demarcated and land ownership is generally not titled, instead it exists as common historical knowledge among elders of the community. It is therefore likely that land ownership conflicts is one of the key constraints that large scale commercial plantations may face (ProForestLtd. 2008).

Problems that large investors face while trying to secure large plots of land are amongst others the uncertainties that involve securing title deed in Africa. In Tanzania, the study by Habib-Mintz stated that the rent for the lands is low, but that there is no provision for judicial arbitration, and if contested, the president's rule overrides any other rule of law. This discourages investors from making structural investments. Most villagers perceive their land as a valueless resource, due to the absence of an efficient and transparent information system. Farmers make their decision based on their own perception of tenure, guided by customary law. Since native land cannot be sold, they see a greater benefit in leasing it out than keeping it unused (Habib-Mintz 2010).

Also in India it has been observed that land issues are problematic. In Tamil Nadu, land owners who do not live on their land (absentee land owners) are interested in ways of using their land without much effort. They also want to keep encroachment on the land to a minimum (Altenburg et al. 2009). In Rajasthan 'wastelands' can be leased out to private companies and government enterprises for 20 years but the identification of certain lands as wastelands remains disputed (GRAIN 2008).

We found many reports on the situation in Tanzania and Mozambique, so we present case studies about those two countries.

Company case study: Sun Biofuels in Tanzania

For phase I of the development, covering approximately 8 000 ha, the company selected and acquired land from six villages, namely Chakenge, Mtakayo, Kurui, Mtamba, Kidugalo, Muhaga, and Majumbo. According to TIC, the acquisition of land is done in nine straightforward steps. In reality, Sun Biofuels had to take at least 20 steps before it received the right of occupancy. The interviews conducted for the BEFS study with the villagers on the one hand and Sun Biofuels on the other hand suggest that there have been controversies about land compensation as well as employment. For instance, the villagers stated in the interviews that they had not been compensated while Sun Biofuels claims to have compensated all individuals who were using Village Land that was going to be converted to General Land. Perhaps there was a misunderstanding among the villagers about which land would come into consideration for compensation, or perhaps the compensation took place only after the interviews of the BEFS team with the villagers. In any case, the villagers were not aware of the compensation they could expect. Also in the case of employment the villagers were not aware of the number of possible jobs that would be created by Sun Biofuels. This can be attributed to poor communication between Sun Biofuels, the district government, the village government and the communities. This could be a basis for social unrest and negative sentiment towards the company (FAO 2010).

5.4.2.1 Case study Tanzania

Gordon-Maclean et al. (2008) describes the Tanzanian situation. There are 3 land categories: Village Land (under jurisdiction of the Village Council), General Land (Central Government) and Reserved Land (Conservation Areas). The Land Act provides the legal framework for General and Reserved Land, an investor can acquire right of occupancy or sub-lease under this law. Village land would first have to be converted to General Land before an investor could lease it. The major land issues in Tanzania according to this study are:

- Conflicts of land use in rural areas especially between farmers and livestock keepers and persistent land disputes as a result of rapid expansion of towns encroaching on surrounding farming areas; tenure conflicts between customary and granted land rights.
- Land degradation and destruction of water sources.
- Absence of adequate and coordinated land information.
- Inadequate human, institutional and infrastructural capital.

The compensation paid for the land is one of the major debated issues in Tanzania. Many Tanzanians are concerned about the amount of land leased and the amount of compensation paid by foreign investors, as well as the long lease periods (33, 66 or even 99 years). Land is often leased out for low prices in anticipation of jobs, infrastructure and new markets (Gordon-Maclean et al. 2008). It is a process in which the amount is established between seller and buyer, there is no formal structure or procedure. This results in some members of the community feeling they got a good deal while others feel they lost out. The report gives some examples of land acquisition:

- Bioshape paid approx. US$ 327,000 in compensation to 4 villages (though it is unclear whether this is the total amount or only part of it). This is around US$ 29 per hectare. Part of this (60%) had to be paid to the District Government, while the remaining 40% was destined for the Village Council. However, in October 2008 the entire amount was still sitting with the District, nothing had been received by the Village Council).

- SunBiofuels confirmed paying US$ 220,000 to be shared between 152 people who had trees on their land, and a further US$ 10 per hectare. In the study the company stated that they will be paying US$ 800,000 to the Ministry of Lands. They have acquired around 8,000 ha. The lead time for the acquisition of village land is very long. In the case of Sun Biofuels in Tanzania, it took over three years (FAO 2010) (see text box).

Company case study: Sun Biofuels in Tanzania

For phase I of the development, covering approximately 8 000 ha, the company selected and acquired land from six villages, namely Chakenge, Mtakayo, Kurui, Mtamba, Kidugalo, Muhaga, and Majumbo. According to TIC, the acquisition of land is done in nine straightforward steps. In reality, Sun Biofuels had to take at least 20 steps before it received the right of occupancy. The interviews conducted for the BEFS study with the villagers on the one hand and Sun Biofuels on the other hand suggest that there have been controversies about land compensation as well as employment. For instance, the villagers stated in the interviews that they had not been compensated while Sun Biofuels claims to have compensated all individuals who were using Village Land that was going to be converted to General Land. Perhaps there was a misunderstanding among the villagers about which land would come into consideration for compensation, or perhaps the compensation took place only after the interviews of the BEFS team with the villagers. In any case, the villagers were not aware of the compensation they could expect. Also in the case of employment the villagers were not aware of the number of possible jobs that would be created by Sun Biofuels. This can be attributed to poor communication between Sun Biofuels, the district government, the village government and the communities. This could be a basis for social unrest and negative sentiment towards the company (FAO 2010).

There are also companies that do not follow the conventional process and deal directly with villagers, bypassing TIC and the Ministry of Land. This has happened in Tanzania in Bahia district where the company East Africa BioDiesel (EABD) was able to acquire 6000 ha of land (Habib-Mintz 2010). This procedure took one year and the company was able to follow this route through their detailed local knowledge and local network (Habib-Mintz 2010). However in August 2008 the Regional Commissioner publicly acclaimed the activities illegal, this caused skepticism and social unrest among farmers. The company threatened to leave the area. Also areas were allocated to the firm which belonged to for example neighboring villages, which is not legally possible.

5.4.2.2 Case study Mozambique

In Mozambique the land is owned by the State, only the Right to Use and Develop the Land (DUAT) is awarded to indivials or legal entities. A DUAT is valid for 50 years (Ribeiro and Matavel 2009). Land requests under 1000 ha are evaluated at provincial level, while larger areas are evaluated at national level with authorization of the Minster of Agriculture. Requests for areas over 10,000 ha are handled by the Council of Ministers. After a certain time frame (2 years for foreigners and 5 years for nationals) the definitive land lease is allocated if production plans have been fulfilled (Ribeiro and Matavel 2009; Schut et al. 2010b). In principle one's community's land ends where that of the adjoining community starts, customary rights are recognized in Mozambique but the community boundaries have been questioned. Therefore 'land grabbing' (as Ribeiro and Matavel claim, often by government officials) has been quite easy. High levels of corruption are a principal problem (Ribeiro and Matavel 2009). It has also created a sense of insecurity of ownership among the rural poor; they feel their land can be taken from them at any time.

Up to December 2008 the government of Mozambique had officially received 12 biodiesel related investment proposals, almost all related to Jatropha; in total

179,404 ha of land had been requested. Some of the projects are shelved, some have received their title deed, one withdrew and some are still in progress to acquire the title deed (Schut et al. 2010b). One company also started operating on the basis of land-rights transferred by another company; however authorization from the government is still required.

Most investors try to avoid resettlement processes due to high costs and time requirements. It was observed in Mozambique that some households themselves took the initiative to resettle near to new roads or the plantation in order to benefit from the infrastructure or be closer to the workplace (Schut et al. 2010b).

Companies often make promises to develop the area, however in one case (Energem) there was allegedly still no activity after two years (Ribeiro and Matavel 2009). Whether this is true or not could not be verified but in any case some local people had had higher expectations, as one person from the local community made a statement that hospitals and schools were supposed to be built. Only waterholes were apparently constructed. Some conflicts also arose about land used by the company, related to the Regulo (community leader) who might have put pressure on the population to sell their land. And the involvement of the same Regulo is questioned as well (Ribeiro and Matavel 2009). This indicates the complexity of land issues. Another company (ESV) involved the communities more than Energem did (and the role of the Regulo was apparenty satisfactory), and these communities were content. Some companies (Sun Biofuels and MocamGalp) acquired old infrastructures from other companies (Ribeiro and Matavel 2009). And in India sometimes old tea estates are converted into Jatropha plantations (D1 oils) (GRAIN 2008).

Tips to minimize impacts related to land availability and land access:
- Check the land pressure before starting to promote Jatropha in a village
- Avoid regions with high land pressure
- Be aware of customary land laws and informal processes
- Land may be unoccupied, but not unused
- Make promises tangible in written letters, with signatures of leaders and other witnesses, this helps to reduce miscommunications
- Be very transparent in land acquisition processes, use an external mediator to guide the process
- Avoid resettlement of local population
- Involve communities in the decision making process
- Look into alternative business models in which the community is a business partner and land rights do not have to be transferred.

5.4.3 Conclusions and recommendations

Conclusion:
- Planting Jatropha is sometimes seen as claiming ownership leading to conflicts with land owners in Africa.
- Identification of suitable land is problematic.
- Land access is influenced by changes in land tenure and land use.
- Planting Jatropha as a fence can reduce land boundary conflicts
- The different procedures for foreign companies to obtain a land lease are not transparent, not uniformal, and often create a lot of social unrest
- One study indicates that land pressure can decrease land access for vulnerable groups.
- Land pressure is an important determining factor for land access

- Communication between communities and the investors are very important.
- Local communities often feel they do not understand the process, meetings and contracts in their local language can help.
- The conventional process is bypassed in at least one case
- Promises on land development are not always kept
- After bankruptcy it is unclear what will happen with the land
- Other business models, besides outgrower and plantation, are suitable to increase participation of local communities.

Recommendation:
- A mediator should be involved with land acquisition processes, this person should serve as a liaison between the government, villagers and the company.
- Take land pressure into consideration before activities in a certain village start
- Improve land administration systems that harmonize formal and customary land tenure.
- Assessment of impacts for other businessmodels, where the community is a business partner, is necessary.

5.5 Gender

The term ‘gender’ refers to the socially constructed roles of women and men. Men and women not only use energy services differently, the impact of energy systems differs as well (Clancy et al. 2004). We did not find a framework that provided a clear base for a gender analysis of Jatropha, but by analysing the studies we found three aspects that are relevant for gender issues and that we have used in our analysis:
- Employment
- Access to energy
- Land availability

Only two studies include a detailed analysis of certain gender related aspects, namely Mota (Mota 2009) and Peters (Peters 2009). Other studies have observed gender differences but have done so as part of a broader analysis framework comprising multiple aspect. . In total 13 studies cover gender related aspects.

Figure 5.3: Women dehulling Jatropha seeds (pic. J. v. Eijck)

5.5.1 *Gender and Employment*

Smallholders

The smallholder respondents interviewed by Mitchell (2008) in Tanzania, indicated that male and female workers both have tasks on the farm and older children generally help after school. In Zimbabwe women were involved in value addition through soap and candle making, this generated more household income than only selling seeds (Tigere et al. 2006). In Cambodia especially women and children are the ones picking seeds (ENERGIA 2009). Henning indicated that in Mali men initially allowed women to harvest seeds for soap making, but when the women turned this into a cash-generating activity the men wanted a share of the profits. This led to some loss of interest in the project since the project goal was to promote women's participation (Henning 2004 cited in (Brittaine and Lutaladio 2010a).

Plantation

The effects of gender aspects on large scale Jatropha cultivation are largely unknown. Potentially there might be a significant gender issue since large scale Jatropha cultivation requires (until mechanised harvesting machines are fully developed, tested and working adequately) a large labour force of mostly women. This is because women are the ones picking and opening the fruits, while male tasks are often centred on and around biofuel processing facilities, management and agronomy extension services. When large scale operations require migrant workers from outside the region, the impacts are unknown. Women tend to take their family along even when work is seasonal, while men are more flexible to move around independently to take seasonal labour. Jobs for women on plantations are often low skilled jobs, while women could also receive training to become for example tractor drivers (Clancy et al. 2004). If plantation owners payon a piece rate basis, this can discriminate against women if the job requires physical strength. Plantation owners sometimes tend to prefer women workers because they feel they can pay them less (FAO 2008a). Picking Jatropha however does not require heavy physical strength so this does not have to lead to discrimination. Wageningen University has studied the effect of female wage labourers on a Jatropha plantation in Mozambique, on the time spent on cultivating food crops. The conclusion of this study (Mota 2009) was that when females are employed, they still have to cultivate the family farm food crops besides their wage job. This causes a reduction in the available time for food crop cultivation. Companies can overcome this partly by creating suitable working hours, e.g. until 16:00, which leaves time for cultivating family land. The effects on leisure time have also been studied by Wageningen University (Peters 2009). She indicated a reduction in leisure time for both male and female workers, where male workers went from not working to working, whereas female workers were working in addition to their own housework and farm work.

5.5.2 *Gender and Energy Services*

In many developing countries the current lack of modern energy services has a disproportionate impact on women, since they are the ones responsible for managing the traditional biomass resources and also often for food production (ENERGIA 2009). In Africa, fuelwood collection is a labour intensive and arduous process. Women usually gather firewood on foot, often walking long distances with an average load of 20 kg (IEA, 2006). Not all Jatropha projects increase access to modern energy services, as many large scale plantations are aimed at exporting Jatropha oil (or even the seeds). But if, for example, Jatropha oil is used locally for cooking purposes or to fuel milling machines, both mostly female tasks, the amount of time required for gathering fuelwood and milling is reduced which is a relief for women (Brittaine and Lutaladio 2010a). The same study also states that smoke emissions could be reduced when Jatropha oil is used as cooking fuel instead of more traditional sources, however they do not refer to any scientific proof of this claim, furthermore the financial feasibility will in the end determine whether females will cook on Jatropha oil or not.

Examples from Multi Functional Platforms (MFP) (see Section 5.2), an arrangement delivering energy services in rural areas (running on diesel, not necessarily Jatropha), show that the time women in Mali spend on grinding is significantly reduced. It also reduced poverty in the areas in specific contextual circumstances, like no pre-existing grinding possibilities, etc. (Brew-Hammond and Crole-Rees 2004). A later report about MFPs by (Nygaard 2010) indicates that though the first results looked promising, actual results on the ground were minimal. This is due to a range of issues, mostly socio-organisational problems (60%) but also technical problems (26%) and economic problems (14%). It was also found that ownership by women's associations, an important target, proved difficult. Customers for a MFP are mainly women since the services are related to household tasks such as grinding. In most of the 515 MFPs men are present in the women's groups (e.g. as operator or 'trusted person') and in some cases operation had been taken over by men (Nygaard 2010). A study done by the University of Copenhagen (MSc. report by L. Vang in 2009, in Danish) at the project site of FACT in Mozambique found no gender bias or cultural obstacle to the adoption of the Jatropha system. This project used a smallholder system where Jatropha oil is used in local diesel engines. However this finding is based on only a few interviews and more extensive research is required according to (Nielsen and de Jongh 2009).

5.5.3 Gender and Land availability

(See also section 5.4 on land rights)
Women are the ones collecting firewood and other products from communal lands. They could lose access to these traditional resources (land, fuelwood, fodder, medicinal plants and so on) if such lands are converted to large scale biofuel production. Marginal lands are particularly important to women and if they would have to travel longer distances because their access is reduced, it affects their time available for participating in income generating activities, study etc. (FAO 2008a).
In Mali large differences between men and women concerning land access was observed (Salfrais 2010). Women have to ask permission to men and are not able to inherit land. When women get married they move to the village of their husband, therefore unmarried women are not given any land either in ownership or on a rental basis. The interviews conducted by Salfrais revealed no worsening in the situation of land access for women after Jatropha cultivation started. However, since increased land pressure increases the risk that the more vulnerable groups (non-founding families, women and younger members of the community) lose their land access rights, this might become an issue in the future. In one case a men's association pressed the women's association to discontinue cultivating one hectare of Jatropha, this shows that men have control over land access. The vulnerable groups should be pre-consulted to determine their access to land before Jatropha cultivation is introduced into an area. Furthermore explaining to stakeholders the importance of the participation of women's associations in Jatropha cultivation is important. In Mali, this helped the women to keep the land they were cultivating (Salfrais 2010).

This analysis shows that in some reports the gender aspect has received attention, but more in the form of random or casual observations than as part of a research design in which the gender aspect was purposively included from the beginning. The case studies by ENERGIA (2009), which do include a proper gender-based analysis, show that it is wise to give special attention to women to ensure that they are not marginalized or excluded from training programmes, extension services and so on. Brittaine and Lutaladio (2010a) recommend that policies should be in place to promote gender equality and women empowerment.

Tips to address gender related issues:
- Create middle and high skilled jobs for women (not only low skilled ones)
- Create suitable working hours (e.g. until 15:00) so women can tend their plots after working hours
- Provide Jatropha oil for local energy services (cooking, lighting, milling etc.) to reduce the burden of women's household tasks (also see Section 5.2)
- Consult vulnerable groups to determine their access to land.
- Involve women's associations in Jatropha cultivation

5.5.4 *Conclusions and recommendations*

Conclusions:
- The effects of large scale Jatropha cultivation on gender are largely unknown.
- The allocation of land for Jatropha production could potentially have serious negative consequences for women (and their households as a whole), if no specific attention is paid to their access to land, water, fuelwood and other products furnished by common property lands.
- The large scale production of Jatropha could also generate employment for women. However, in reality especially in Sub-Saharan Africa, women also need to keep taking care of the householdbesides collecting Jjatropha seeds, which could further increase the pressure them.
- Increased local availability of energy can have several important advantages for women, such as reducing their burden related to traditional tasks such as collecting firewood and cooking, as well as reducing exposure to indoor air pollution.
- Suitable work hours help to maintain household food production.
- With respect to land availability, no worsening of the situation was observed in Mali after the introduction of Jatropha cultivation. However, only one study has researched this so far.

Recommendations:
- Include specific aspects in the project that relate to the participation of women, in smallholder outgrowers schemes as well as in plantation employment.
- Create suitable work hours so (female) workers can tend their plots after work.
- Pay attention to: fair pay, the inclusion of gender in project design and early involvement of women in the project.
- More detailed research is required, because impacts on the longer term gender impacts are still lacking.

6 Ecological aspects

6.1 GHG balance, LCA

By dr. ir. Annelies Balkema (TU/e)

6.1.1 Methodology

The life cycle assessment (LCA) is an international standardised method to quantify the environmental pressure of products and services taking into account the full life cycle (see ISO/TR 14048 (2002), ISO/TS 14047 (2003), ISO/TR 14040 (2006), ISO14044 (2006) and the related new ISO norm on carbon footprint ISO 14067 (2010?)). However, conducting an LCA does require expert knowledge of the system in setting system boundaries, defining the functional unit and allocating or substituting impacts of co-products. A guideline for conducting an LCA on biofuels is provided by the Global Bioenergy Partnership (GBEP 2009). Since the scientific discussion on the critical aspects in the life cycle of biofuels is still ongoing and data on performance and environmental impacts are still rather scarce, conducting an LCA on biofuels is not yet standard procedure.

This section gives a critical refection on published Life Cycle Assessments (LCA) for different Jatropha biofuel production systems. Giving an overview of the results of the LCA's reviewed, however keep in mind that the outcomes of individual studies are not comparable due the large variety of systems, the wide range of different assumptions, the differences in local conditions as well as different methodologies applied (system boundaries, functional units, allocation and substitution, different impact categories etc.). Therefore, the focus of this paragraph is on comparing the underlying data such as land use changes, seeds yields, fertiliser use and transport km overseas. This is done to identify the critical factors in the Jatropha production and usage chain, and gain insight into possible trade-off and directions for improvement.

Table 6.1: Comparison of Jatropha biofuel LCAs and energy analysis

BIODIESEL PRODUCTION:	**description:**	**Functional unit:**
Dehue and Hettinga 2008	Production Jatropha in India for energy use in UK	1 ton biodiesel produced
Lam MK et al (2009)	Palm Oil and Jatropha for biodiesel production Malaysia	1 ton biodiesel produce
Ndong R. et al. (2009)	Jatropha LCA West Africa a field study	1 MJ of JME
Ou X et al (2009)	Comparison 6 biofuels on LCA in China	1 MJ energy produced
Prueksakorn K et al (2010)	Jatropha plantation in Thailand, 2 cases perennial and yearly	1 ha of Jatropha plantation
Reinhardt et al (2007)	Indian Jatropha for biodiesel	1 ha of Jatropha
Struijs 2008	Jatropha in Tanzania for energy production in the Netherlands	1 kWh of energy produced
Veen et al. 2009	Palm Oil and Jatropha for biodiesel in Peru	1 l biodiesel, use: 1 km
Whitaker 2010	Jatropha biodiesel blended with fossil diesel in India	1000 km by train and car
VEGETABLE OIL PRODUCTION:	**description:**	**Functional unit:**
Arvidsson et al 2010	Comparing vegetable oil from rape, oil palm and Jatropha	1 kWh by heavy duty truck
RURAL ELECTRIFICATION:	**description:**	**Functional unit:**
Gmünder et al 2010	Electrification Indian village Jatropha oil in generator	1 kWh electricity generated

As shown in Table 6.1, the scope and goal of different LCAs on Jatropha biodiesel can differ widely. Most studies compare Jatropha biofuels with fossil fuel, other include a comparision on different biofuels as well, or even other energy sources for electrification. Different processes and/or co-products of Jatropha biofuel production may be considered. In this paragraph the conclusions from these different assessments are listed.

Assessments looking at **Jatropha biofuels compared to fossil fuel**[2] conclude that Jatropha biodiesel is favourable over fossil diesel based on green house gas emissions (GHG), although this conclusion is sometimes derived under dangerous assumptions. These assumptions are discussed in the next paragraph. First let us look at some conclusions reported:

- Output-to-input energy ratio of raw plant oil is 6 times higher than fossil diesel (Hossain A.K. and Davies P.A., 2010).
- Overall production and combustion of 1 MJ Jatropha biodiesel emits 23.5 g CO_2 eq in comparison with 83,8 for conventional diesel. Thus a 72% GHG emission reduction is achieved through production of Jatropha biodiesel under these conditions. In different scenarios with energy yield ranging from 3.7 to 26.4, the reduction in GHG compared with fossil diesel ranged from 67% to 84% (Ndong et al., 2009, p205).
- In an LCA comparing Jatropha biodiesel with fossil diesel in India, Jatropha diesel is blended with diesel for road and rail transport and the assessment considers GHG emissions, net energy values (NEV), and petroleum consumption. Land use change is not taken into account. LCA for base case conditions (B20 is 20% Jatropha oil blended with fossil diesel) gives a net reduction of 14% GHG emissions, a 17% decrease in petroleum use, and a NEV of 58% compared with 100% petroleum diesel use. The greatest absolute benefits can be achieved in the road sector, but it is expected that less infrastructural problems will occur when introducing Jatropha biodiesel to the rail sector (Whitaker, M. and G. Heath, 2010).
- GHG emissions from Jatropha Biodiesel are lower than those from fossil diesel, however Jatropha Biodiesel performs worse on acidification, eutrophication and nitrous oxide (Reinhardt et al. 2007).
- Major impacts, i.e. acute water eco-toxicity, chronic water eco-toxicity, and acidification are higher for Jatropha Biodiesel than fossil diesel (Figure). While ozone depletion, human toxicity and global warming effects are more favourable for Jatropha biodiesel (Sampattagul S. et al., 2007).
- Jatropha performs better in terms of global warming potential but in other environmental impact categories it performs worse than fossil fuels, namely eutrophication (emissions of phosphate, phosphorous and nitrate to soil and groundwater – even though fertiliser use was limited, highest impact on summer smog (photochemical oxidants) (Gmünder et al, 2010). Note that Struijs (2008) indicates that soils in Northern Tanzania are depleted, in this area eutrophication will not be high the environmental problems priority list.

An assessment comparing centralised versus decentralised processing concludes:

- Regarding saving of GHG emissions and fossil resources, centralised Jatropha processing facilities deliver better results than decentralised ones, the longer transport distance is compensated by higher oil extraction and lower energy consumption in processing in centralised facilities (Reinhardt et al. 2007, India).

2 Note that both Krikinen et al (2009) and Ou et al (2009) also include a comparison with fossil fuels but since these studies also do a comparison with other biofuels these are categorised in the next section.

An assessment comparing decentralised out-grower business models and centralised large plantation models concludes:

- The % GHG reduction achieved is 60-61%, almost the same for both models (whether expressed per unit of kWh or per hectare per year), assuming there is no GHG effect from prior land use change. The big question is whether this assumption is credible for plantations, since land preparation often appears to entail clearing of existing vegetation and ploughing. In the case of smallholdings, Jatropha hedge plantings may be assumed to involve minimal prior biomass removal and soil disturbance. Heavy machinery is not used (Struijs, 2008).

Assessments making **comparisons of different biofuels** have sometimes conflicting conclusions, perhaps due to local circumstances, different processes or may be due to different assumptions? This question will be answered later, let us have a look at different conclusions first:

- Arvidsson et al (2010) conclude on the basis of their comparison of rape, oil palm and Jatropha for hydrotreated vegetable oil production, that the oil palm with co-production of biogas is the option with lowest environmental impacts.
- Based on data from D1Oils in India, Dehue and Hettinga (2008) concluded the opposite, namely that Jatropha is the best first generation biofuels crop (p32). The GHG performance of Jatropha biodiesel (29 kg CO2 e/GJ, a 66 to 68% reduction compared with fossil diesel) is better than for biodiesel produced from palm oil (45 kg CO2 e/GJ, a 48 to 53% reduction compared with fossil diesel) (Dehue and Hettinga 2008, India).
- Lam et al (2009) also compare oil palm and Jatropha, for biodiesel production in Malaysia. They conclude that 1 tonne of biodiesel requires 118% more land area when using Jatropha compared to oil palm. The energy output-to-input ratio is slightly higher for oil palm, namely 2.27 compared to 1.92 for Jatropha. Furthermore, CO2 sequestration is 20 times higher for oil palm (Lam et al 2009. Exact data used for land use change are not reported. It seems that the Jatropha case is based literature while for Oil Palm local data is available, if so it would be interesting to do an LCA on implemented Jatropha plantation in this region.
- Also in the comparative palm versus Jatropha analysis by Veen and Carillio (eds 2009) in Peru, oil palm is the favourable source for biodiesel production over Jatropha.
- A comparative impact study about Jatropha biodiesel (India) from forest residues (Finland) with fossil diesel, on Global Warming Potential (GWP) and Radiative Forcing (RF), shows that Jatropha biodiesel has the lowest global warming impact during the 100 year time horizon, the impact is about 30% lower than fossil diesel, the forest residues have an impact of about 20% lower than fossil fuels (Kirkinen et al., 2009, p200).
- Ndong at al (2009) in their study of Jatropha in West Africa conclude that regardless of the technical variant Jatropha biodiesel presents higher fossil fuel savings and GHG emission reduction than most current biofuels.
- Ou et al (2009) compare 6 biofuels pathways with conventional petroleum-based gasoline and diesel pathways in China. They concluded that Jatropha biofuel (JB) scores best on GHG and energy reduction (Ou et al, 2009), together with cassava-derived ethanol (KE) and biodiesel from used cooking oil (UB). These three biofuels have lower energy requirements and GHG emissions compared to conventional diesel, as energy inputs are 0,5 (JB) to 0,9 (UB) times the energy contained in the fuel produced. Corn-derived ethanol (CE) and soybean-derived biodiesel (SB) reduced fossil fuel consumption but increased GHG emissions, while sweet sorghum-derived ethanol (SE) increases both!

One assessment comparing different energy sources for rural electrification concludes:

- The PV system for rural electrification in India outperforms Jatropha biofuel, the grid connection and diesel powered generator. On basis of an LCA on cultivation of Jatropha and the use of the oil in a diesel genset for electricity production it is concluded that GHG emissions over full life cycle are reduced by a factor 7 compared to grid or diesel generator. Optimising Jatropha processing (no boiler and better engine performance) would bring Jatropha close to the score of the PV system (Gmünder et al, 2010).

One assessment on biogas production from Jatropha concludes:

- The comparison of energy flows for the two options investigated: (1) using Jatropha seeds for biodiesel production and de-oiled cake for CH4 production and (2) using the Jatropha seeds for CH4 production entirely, shows that energy yield are 72 GJ/ha/yr and 79 GJ/ha/yr respectively (Gunaseelan 2009, Fig. 6, p595).

One assessment of a perennial Jatropha plantation and the annual harvesting of Jatropha plants on an annual plantation concludes:

- Besides the production of Jatropha biodiesel, wood can be harvested for power production, this can double the energy output. Two systems look at (1) a perennial plantation over 20 years and (2) annual harvesting. For both systems net energy ratios as high as 6 to 7 are achieved (Prueksakorn K. et al (2010, p1). On the annual plantation the crop density is as high as 10,000 trees per hectare in the first year and halved in the second year. Trees are cut every year and trees and fruits are then harvested. Around 9 tonnes of wood is harvested during the first year, 4 tonnes in the 20th year. For the annual plantation a average yield of 7 tonnes fruit and 24,5 tonnes wood is assumed every year (Prueksakorn K. et al (2010) on p3). Net energy balance of perennial plantation is 4720 GJ and for the annual plantation 9860 GJ (more than double!), the net energy ratio (output / input energy) is 6 for the perennial plantation and 7,5 for the annual plantation. Note that this research is on energy solely, impacts of emissions due to land use changes are not taken into account.

6.1.2 Explaining the differences

Obviously conclusions are different due to differences in process choices and differences in local circumstances such as climate and soil (which affects yields).

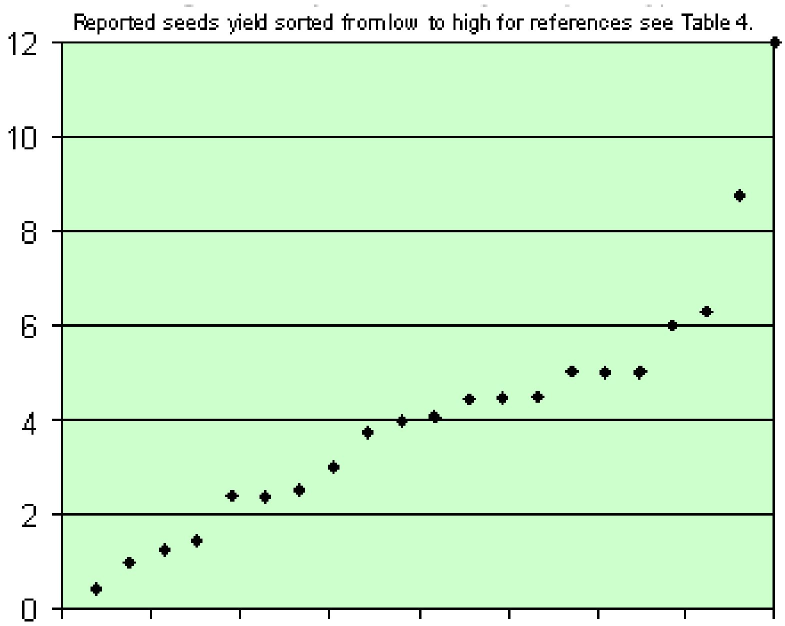


Figure 6.1: Seed yields used in the studies (t ha-1 y-1)

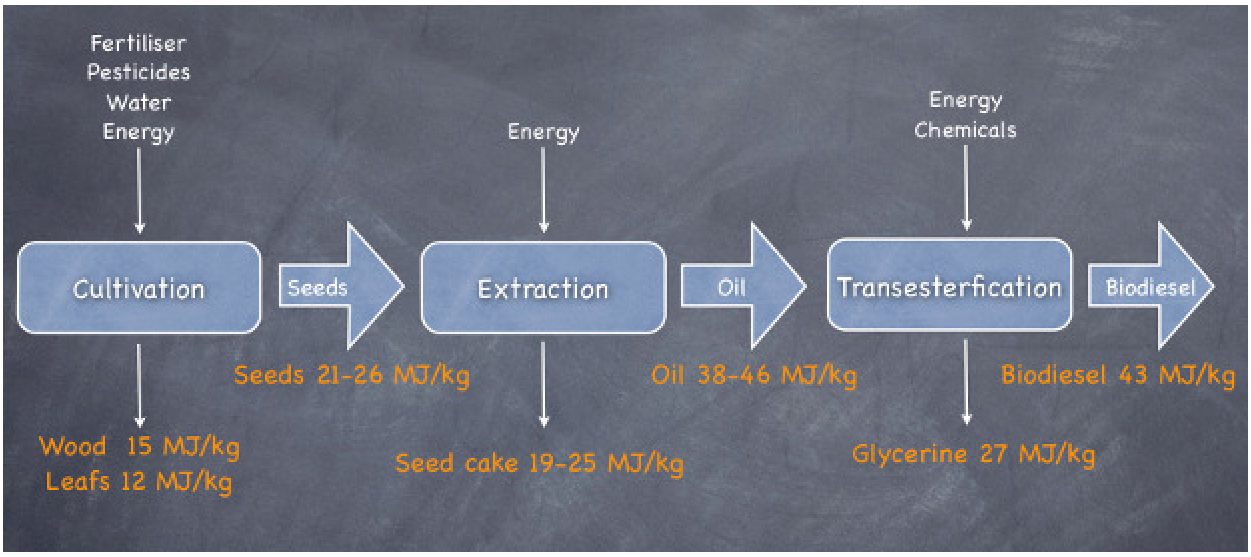


Figure 6.2: Energy content of different products in the Jatropha biofuel chain (Sources: Gunaseelan 2009 Table 4 and 8 and 9, different authors in Prueksakom et al. 2010 Table 1; Struijs 2008 p 52; Veen et al. 2009 p 40)

Important differences also derive from differences in assumptions but this will be looked at in the next paragraph. Furthermore, minor differences are due to methodological choices in different models in for instance allocation[3]. Let us look at the different process steps and differences in data that may explain the different conclusions.

If looking at the cultivation stage of Jatropha it is striking that differences in assumed seed yield, one of the most decisive variables, are very high (see Figure 6.1), ranging from a low of 1 t/ha/y for smallholders in semi arid Tanzania, to 2.5

3 Dehue and Hettinga conclude that RTFO has to change its co-product methodology allocation by energy content to be consistent with the EC proposal (Dehue and Hettinga 2008, pp 32+33, table 6).

t/ha/y for an average Indian village by Gmunder et al (2010, p350), to an average of 6 t/ha/y in Peru reported by Veen et al (2009, p38). Adequate seed yield seems to be very important for realising GHG reduction. Arvidsson et al. (2010, p8), concluded that a drop in seed yield from 5 tonnes/ha to 0.5 tonnes/ha would increase GWP by 770% and an increase of seed yield from 5 to 12 tonnes/ha would decrease GWP by 43%. Whitaker observes that a minimum seed yield of 1.25 t/ha/y is critical for GHG reduction (2010, p xi).

The energy contained in the different by-products is high (see Figure 6.2) and therefore the use of by-products has a large impact on the energy and GHG balances.

Looking at energy use and GHG emissions of the different process steps, it becomes clear that transesterification and fertiliser application are the main contributors. Gunaseelan 2009 table 8 + 9, p S203 report that 67% of the energy required is used in transesterfication and 18% is used for fertilisers, for GHG emissions this is 52% and 35% respectively. Please be aware that emissions due to land use change have not been taken into account.

6.1.3 Sensitivity analysis

Some authors include a sensitivity analysis to find out how sensitive their results are to changes in inputs, from these sensitivity analyses the following conclusions are drawn:

- GHG performance is sensitive to oil and seed yield, but not as high as expected, oil shipping distance is decisive (Dehue and Hettinga 2008, p28 and 29).
- Arvidsson et al.(2010) do find that variations in crop yield and in nitrous oxide emissions from microbial activities in soil can cause significant changes to the results.
- The LCA is sensitive to seed yields (increase of 1 tonne / ha results in 10% reduction of GHG). And transport by truck instead of freight train has an impact similar to yield. Energy consumption of labour force is included. Most important effect on GHG has local use of Jatropha biofuel, energy yield rises from 4,7 to 26,4 and GHG saving increase from 72% to 85%! (Ndong et al. 2009).
- Environmental impacts of individual plantations is site specific and depends on seed yield (Whitaker, M. and G. Heath, 2010).

Critical factors influencing LCA results on Jatropha biofuel production in the LCAs reported are:

- **Land use change**: This survey confirms the patterns signalled in an earlier Jatropha review by Achten et al (2008), i.e.: cultivation on degraded soils and waste lands gives the highest GHG emission reduction. Conversely, the GHG balance can turn unfavourable when cultivation leads to reduction of the carbon stock by removing existing vegetation, as would be case when forest and woodland areas are used (Dehue and Hettinga 2008, Reinhardt et al. 2007; Romijn, 2010; Veen and Carrilio eds. 2009). Also, Arvidsson et al. 2010 conclude that significant contribution of GWP originates from soil during cultivation.

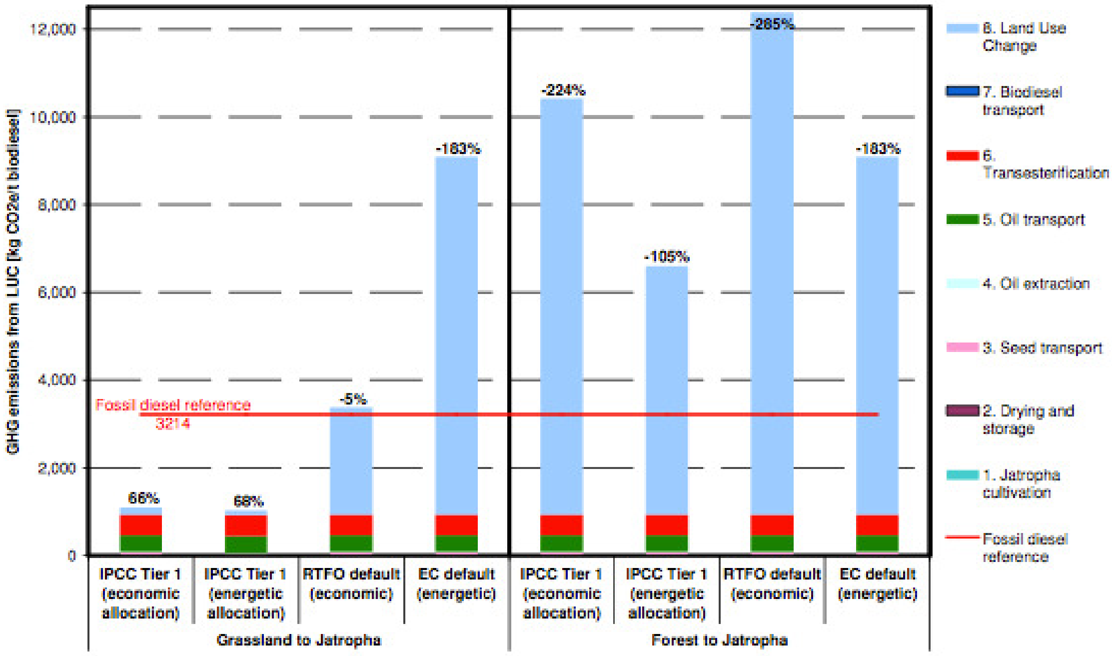


Figure 6.3: Impact of land use change (Source: Dehue and Hettinga 2008, Figure 8).

- **Fertiliser usage**: Applying N-fertiliser results in direct emissions and indirect soil emissions and leads to significant worsening of GHG performance (Struijs, 2008). P-fertiliser and lime addition have limited effect on GHG performance (Dehue and Hettinga (2008) on p23 and in Figure 6.3). Also Ndong et al. (2009) conclude that there is a need to optimise with respect to limiting fertiliser use to reduce energy use and GHG emissions. Ou et al. (2009) conclude that fertiliser input is a major GHG factor. Nitrogen emissions have also negative results in other environmental impact categories such as eutrophication. Of course there is a trade-off in applying less N-fertiliser on degraded soils (where Jatropha is supposed to be planted in any case) and the seed yield. Fertilisation is thus generally necessary to maintain long-term seed yields, since the harvesting of the seeds leads to regular nutrient removal and the plant is not a nitrogen-fixing species (Achten et al., 2007). According to Struijs (2008), nutrients are the limiting factor in degraded soils in Northern Tanzania where the Jatropha is cultivated, in this case eutrophication may be welcome? And as Basili M. and Fontini F. (2009? p9) mention, considering that fertilisation is responsible for 30% of the GHG emissions, the GHG balance can be improved by using natural fertiliser like seed cake or organic manure, instead of mineral fertiliser. Although, Reinhardt et al. (2007) concludes that the energetic value of seed cake is more valuable, Basili and Fontini do have a point with recommending organic manure as well.

- **Energy use in the transesterfication phase**: Considering that transesterfication is responsible for 23% GHG emissions, the GHG balance can be improved by using virgin oil (Basili M. and Fontini F., 2009?, p9). Ndong et al (2009) suggest that there is a need to optimise with respect to reducing energy and chemicals use in the transesterfication process (p203) to reduce both energy requirements and GHG emissions. Or as alternative, selling pure plant oil would reduce GHG emissions by 45% and energy use by 82% (Ndong et al., 2009, p205).

- **Usage and allocation of by-products**: When producing biodiesel out of Jatropha, by-products (seed cake, biogas, glycerin) do contain a lot of energy as well, together slightly more than half of energy contained in biodiesel (Lam et al 2009). Therefore, use of by-products is crucial for the outcome of the LCA. Use for energy production allows significant higher GHG reduction than use for fodder or fertiliser (Reinhardt et al. 2007). If none of the by-products is used for energy, the energy balance is slightly positive, 0.886 MJ energy input per MJ JME output, on the other hand if all by-products are used efficiently this can be raised to 0.16 MJ energy input per MJ JME output (Achten et al 2008, p1077). Prueksakorn K. et al (2010) report that for the perennial Jatropha plantation case, seed cake is the main product, as energy content in seed cake produced is almost double the energy contained in the produces biodiesel (p4 Figure 4). In the annual Jatropha plantation, the second case in that study, Jatropha wood is also harvested on an annual basis for energy production (Prueksakorn K. et al, 2010).

- **Transport**: The impact of long distance intercontinental transport of seeds or oil has a major impact on the LCA. Ndong et al. 2009, report that transport of oil from Ivory Coast to France claims 75% of the energy use of transport (around 12% of total energy use in the Jatropha diesel production life cycle). Local production of biodiesel would reduce energy use by 10% and reduce GHG emissions with 2% (Ndong et al 2009 on p204). Furthermore, due to bad infrastructure and inefficient combustion in heavy duty trucks in some countries, rail transport can be favourable for inland transport. Transport by train (0.19MJ/t*km) instead of truck (1.94MJ/t*km) in India would improve GHG performance overall by 3% pt (111 to 118 kg CO_2 eq/t biodiesel, in the study of Dehue and Hettinga (2008, figure 13 on pp 24-25). Furthermore, a mobile expeller, if not changing oil yield and energy use, lowers the GHG intensity by 75% for the extraction phase by reducing transport needs (Dehue and Hettinga (2008) on p26).

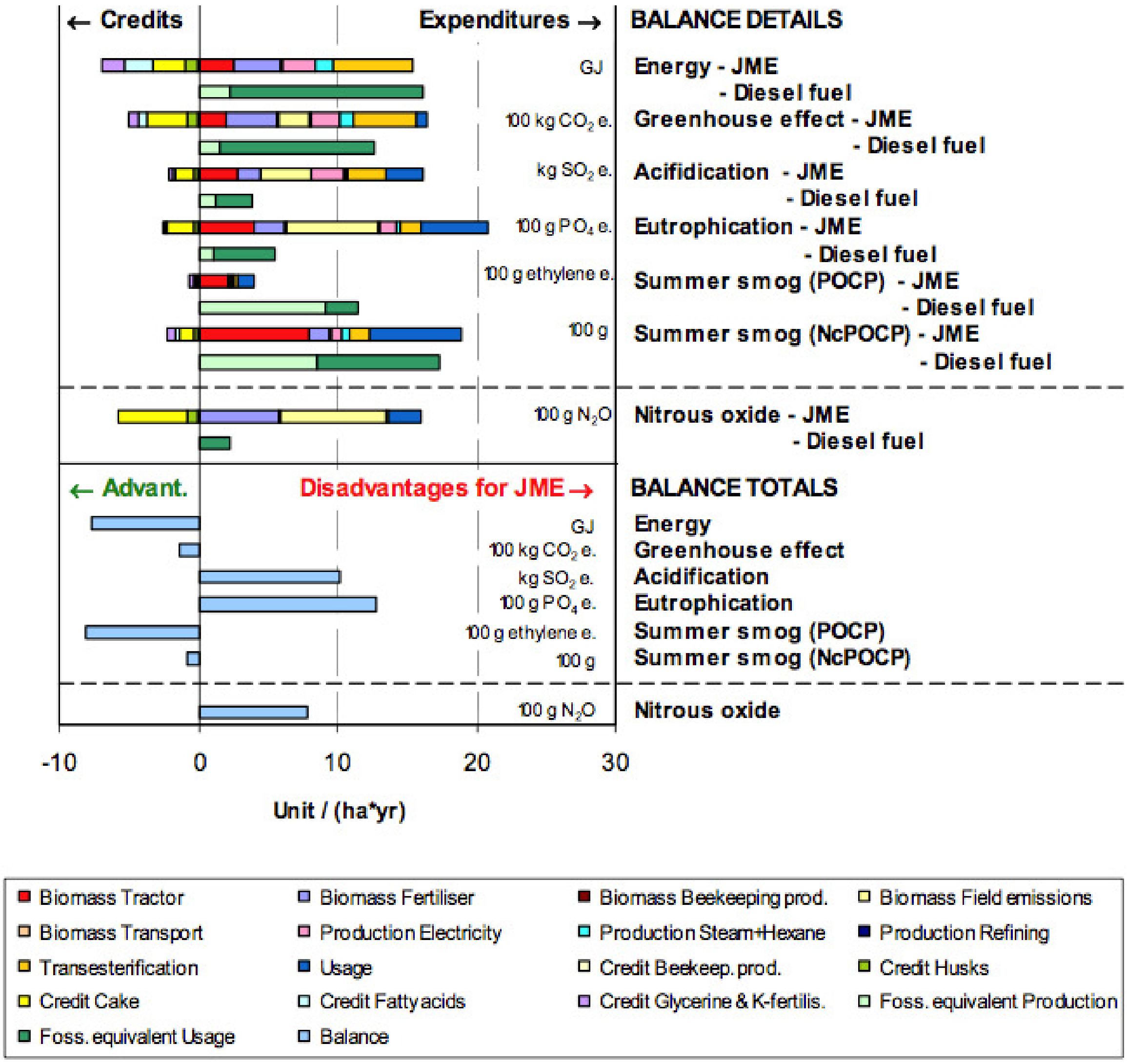
Figure 6.4: Environmental impacts for Jatropha biodiesel (JME)

Upper part: detailed environmental impacts for JME produced in a pilot plant and conventional fossil diesel (Diesel fuel)

Lower part: summary of advantages and disadvantages for JME

Note: Carbon stock changes are assumed to be unchanged, assuming that the initial "scarce vegetation" and the Jatropha plantation both have a carbon stock of 5 tonnes C/ha (see Reinhardt et al. 2007 page 13 Table 3.4).

Source: Reinhardt et al. (2007), Figure 4.1.



Sub conclusion:
Although, LCA does offer a structured method in analysing the environmental impact of Jatropha biofuel production, the assessment is complex and data and time consuming. Therefore a limited number of Jatropha biofuel LCA's is available. This is the reason why also systematic energy and GHG emission analysis are included in this review. These studies differ in location, methods of cultivation and processing, and therefore the data is often not interchangeable. In the 13 studies summarised in the seed yield Table more than 6 different locations are reported on. Furthermore, in executing these LCA's choices have been made to set system boundaries, choose functional units and use allocation methods. For instance, for the 9 studies reported in the comparison, see Table 3, there are 4 different functional units. In addition, lack of transparency of publications on assumptions made, probably due to complexity, makes it even more difficult to compare the LCA's. Similar conclusions are drawn by Gnansounou E. et al. (2009) in reviewing 11 biofuel LCA's finding 5 different functional units, only 4 included land use changes and 5 different allocation methods where used, transparency was also noted as a problem. Therefore, it must be concluded that it hard to draw quantified scientific proven conclusions based the LCA's.

Still, critical variables in Jatropha biofuels LCA can be identified, these are:
- Inclusion of **land use changes and the initial carbon debts** created are crucial for the GHG balance. However in the literature available for this research, only Arvidsson et al. 2010, Dehue and Hettinga 2008, Reinhardt et al (2007), Struijs (2008 - soil based carbon not taken into account) and Veen and Carrillo eds. (2009) do report in detail on emissions due to land use change. Some other studies do mention that land use change in important but assume it not relevant for their case either based on marginal land use or making a comparison between two crops and assume similar land use change. The assumptions may be correct, however since, data and calculation methods are often not specified this is hard to verify.
- The **energy balance reveals the use of by products is crucial**, but trade-off between different applications are hard to reveal. For instance seed cake can be used as fertiliser or energy source but both applications have cons and pro's.
- Based on energy use in different process steps one can conclude that the **most energy is used in transesterification**, furthermore fertiliser use and transport over long distances or with inefficient trucks contributes significantly to energy use and therefore also to the GHG emissions.
- Nitrogen contributions to GHG is often only partly incorporated, while Arvidsson et al. (2010, p5 and Figure 3) conclude that more than half of GWP is caused by nitrous oxide emissions from soil. These emissions originate from both fertiliser and microbiological activity in the soil.
- There are indications that the estimation method for IPCC, that is widely used, might underestimate nitrous oxide emissions by a factor 3 or more (Arvidsson et al. 2010 p.7).

Tips for practitioners:
- Be aware of land use changes and the initial carbon debt created, this can be serious threat to the CO2 balance of your project!
- Be aware of the trade-off for fertiliser use (improved yield but also increase in environmental impacts),
- Be aware of the energy content of the by-products and the large energy use in transesterfication, consider local use of by products and the use pure plant oil instead of biodiesel use overseas.
- Please note that none of the data referred to in this section have been UNFCCC approved.

6.1.4 *Conclusions and recommendations*

Conclusions:
- Based on the literature reviewed in this paragraph the conclusion is that Jatropha Biofuels can contribute to GHG reduction when cultivated and processed in a sustainable way.
- Critical issues are: Land use changes and the initial carbon debt, the use of by products, energy use in transesterfication, fertiliser use and transportation, and effect of nitrogen emissions on the Global Warming Potential.
- Based on the available data, the most promising options seems to be Jatropha cultivated on marginal land with limited inputs of artificial fertilisers and pesticides at a small scale for local use of pure plant oil for rural electrification.

Recommendations for further research:
- Additional research is required to fill in the knowledge gaps by studying land use change as well as the initial carbon debt, including above ground, below ground biomass and soil bound carbon and nitrogen. Followed by defining clear methodological guidelines how to include direct and indirect land use changes and nitrogen in LCA's on biofuels.
- Furthermore, additional research is needed to provide more reliable data to gain better insight into trade-offs and related impacts, for instance marginal land with increased fertiliser use versus more fertile land, long transport distances versus centralised production and local use, by-product for fertilisation versus energy use, etc.
- Due to limited ecological data available Jatropha projects can still be categorised as experiments rather than main stream. Furthermore impacts differ per location, especially with respect to land use changes. Therefore, in decision making processes a participatory LCA including all stakeholders will be best way to assure transparency on assumptions made and prioritising trade-offs according to the interest of all involved actors, reaching consensus on the outcome and decisions to be made.

6.2 Biodiversity

The impact on biodiversity varies with the specific location of the Jatropha trees. There are two determining factors according to Prueksakorn and Gheewala (2008):
- Previous land use
- Intensity of production

Not many reports have analysed the impact on biodiversity. Most studies that do mention biodiversity have analysed previous land use and not the intensity of production. Smallholders typically do not have a high intensity of production, they often do not use pesticides or herbicides and often don't plant in a monoculture way but as fences or intercrop. The impact from smallholders on biodiversity is therefore considered minimal. However, it is only possible to determine the impact when a base line study has been carried out. In some countries an Environmental Impact Assessment (EIA) has to be carried out before the company can receive a license to operate. The impact on biodiversity is often part of this EIA, the potential impact is described.

6.2.1 *Previous land use*

In Mozambique projects that were visited by Schut et al. (2010b) cleared the natural vegetation, some left indigenous trees. This is also observed in Tanzania

(Hooijkaas 2010). Some reports mention the location of the project, as expansion might potentially have a negative influence on biodiversity. In Mozambique the ADPP/FACT project, located in Bilibiza is located in a National Park, (Schut et al. 2010b) citing FACT foundation manual 2009. And two other projects were located close to high-biodiversity areas. However as long as the high-biodiversity area is not converted to Jatropha, the impacts are likely minimal. WWF have made a report (Gordon-Maclean et al. 2008) on the situation in Tanzania.

6.2.2 Intensity of production

There is no record of known impact on biodiversity of indigenous floral species where Jatropha oil is produced (ProForestLtd. 2008) (citing de Padua et al 1999).

Pesticides are normally applied using sprayers (backpack sprayers), in one case it was applied from the air (Schut et al. 2010b).

Tips to minimize impacts on biodiversity:
- Perform a baseline study and/or EIA (Energy Impact Analysis)
- Do not convert high biodiversity areas to Jatropha

6.2.3 Conclusions and recommendations

Conclusions:
- The impact on Biodiversity depends on the specific local circumstances
- Not many studies have analysed impacts on biodiversity
- Base line studies are lacking

Recommendation:
Make sure base line studies are made so that it is possible to determine the impact in a later stage. Also long term impact studies have to be carried out.

7 Economic feasibility of Jatropha activities

By Dr. Henny Romijn (TU/e)

This section comes in five parts. After some introductory remarks (7.1), there is a brief methodological section which introduces the technique of cost-benefit analysis (7.2**Fout! Verwijzingsbron niet gevonden.**). Then follows a review of existing Jatropha feasibility studies, first in an African setting (7.3) and then in India (7.4). In view of the finding that the existing literature does not yet provide good comparative feasibility estimates for different business models, we also worked out our own best estimates for a large plantation model and a decentralized outgrower model, assuming East African conditions. These estimates are presented and compared with the findings from the literature review in 7.5.

7.1 Introduction

Assessment of the economics of Jatropha activities is complex because the Jatropha value chain comprises several different activities that can be undertaken by a range of different actors. In a non-integrated Jatropha energy value chain, one would have separate nurseries, independent seed collectors who gather from hedge-Jatropha on public and community lands, Jatropha seed cultivators operating in a variety of different business models and sizes – hedge, intercropped with food crops, or monocropped –, oil pressing operations, and facilities that convert the SVO into biodiesel. Additionally one has to consider complementary economic activities focusing on the utilisation of by-products, especially seed cake. Economic feasibility assessments of Jatropha activities may thus differ considerably in their coverage and focus.

In addition, comparability among studies is complicated by the fact that researchers have adopted a range of methodological approaches to assess financial attractiveness; a particularly important distinction is between studies that have used:

- cash flow accounting with discounting ('Cost-Benefit Analysis', or CBA),
- less rigorous estimations of annual average costs and benefits.

The latter not only neglect time preference of money but also do not give adequate insights into the typical time-pattern of expenditures and revenues. This is obviously important in the case of Jatropha because it is a perennial whose major share of expenditures preceed the bulk of the revenues in time. Crops with such cash flow patterns generally present problems for farmers, especially when the crop's commercial cultivation is a new phenomenon with many risks, as is the case here.

A further problem encountered by this review concerns data reliability. Reliable information about realized yields, prices and costs is still hard to come by. Most of the studies in this review still mainly rely on estimates made in scientific literature based on assumed relationships between inputs and yields, on results obtained on experimental research stations which may not be representative of real "field" conditions, or on anecdotal accounts of yields of old wild standalone trees. By and large the most detailed and accurate studies have been performed since 2008. Problematic data issues will be flagged in the course of the discussion in view of their importance for the interpretation of results. In the case of the seed yields, we compare the studies against the range of values which were considered to be more or less realistic in Chapter 4.

Remarkably, the bulk of the materials pertain to Eastern Africa and India. There is a dearth of feasibility studies for other parts of the world. By far the largest number focus on feasibility of Jatropha seeds cultivation for smallholders as hedges, intercropped with food crops, or monocropped. We could not find a single detailed feasibility of a truly large estate plantation model defined as a scheme spanning thousands of ha. E.g., in the Indian context a "large" farmer maybe someone with 50 or 100 ha; this could be considered from our perspective as small/medium scale production and is quite compatible with a contract farming model. A few studies calculated costs and benefits per ha without specifying any business model at all.

7.1.1 Conclusions

Conclusions:

- Just 8 studies use (aspects of) CBA methodology, 6 of these were published - since 2008. The best-quality CBA research has been done in Kenya and Tanzania.
- There are many more feasibility studies relying on annual cost/benefit estimations, qualitative assessments, etc.
- There are 9 studies that are partly or wholly based on self-collected primary data; of which 5 also applied a formal CBA methodology.
- Eastern and Southern Africa (i.e., Tanzania, Kenya and Mozambique) are heavily represented, and this makes it possible to paint a reasonable comprehensive picture of the viability issues in that area. There are also some good studies about India. The rest of the world's Jatropha regions are hardly represented, and the one or two lone studies covering them also do not add much additional insight compared to the African and Indian cases. We therefore decided to leave these out and concentrate on building a good review for the African and Indian situations. We believe that the issues emerging from these two important Jatropha regions are also broadly representative for other regions.
- There has been a heavy emphasis on the assessment of the viability of the seed cultivation stage. Sometimes, but not always, this includes a comparative viability assessment of competing crops. A handful of studies have also included the oil and biodiesel processing stages and the market situation with respect to Jatropha by-products, and have tried to assess their competitive situation versus competing products.

7.2 Methodological note on Cost Benefit Analysis

Cost Benefit Analysis (CBA) is a technique that has been designed to help people and organisations select those projects that will contribute most to their objectives, bearing in mind the limitations on their investible resources. When policy makers and managers in organisations are contemplating to undertake a project, they can use CBA as a tool to assess in advance the financial impact effects that a project is likely to give rise to. In other words, CBA helps people to get insight into the likely economic feasibility of projects and to take go/no-go decisions about planned projects. It is also useful to assess the likely longer term performance of projects that have already been started. CBA was originally developed by the World Bank in Washington D.C. and the United Nations Industrial Development Organisation (UNIDO) in Vienna and is now a widely used technique in international development and public policy.

The simplest form of CBA is an assessment of financial feasibility from the investor's point of view; this is basically the type of CBA that we are concerned

with in this report. There are several more complex forms of CBA that assess projects from a broader societal perspective, sometimes also including distributional consequences across population sections and environmental impacts. These will not be considered here, as they have not been undertaken for Jatropha activities to date.
Central to the CBA technique is the concept of cash flow. A cash flow occurs whenever a project makes a payment (cash outflow) or receives an income (cash inflow). Ultimately, the financial feasibility of a project depends on the total cash outflows and cash inflows that it gives rise to, over the entire life-time of the project. CBA takes the estimated total life-time of the project as its time-horizon. All project expenditures are recorded when money ('cash') flows out, i.e. at the time when payments are made. Likewise, all incomes are recorded at the time when money flows in. This is called the 'cash flow accounting' principle. In general, a project is considered to be an attractive investment opportunity for an investor if the estimated net cash flows arising from investment are higher than the costs of financing the project.

There are four common yard sticks that relate the estimated net project cash flows to the cost of financing:
- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Benefit / Cost Ratio (BCR)
- Pay Back Period (PBP).

The first three measures rely on so-called discounting of the cash flows with the cost of financing (i.e., the prevailing rate of interest on project loans) to take due account of time preference of money. Discounting is the converse of calculating interest. Just like $100 worth today will be worth $ 103 next year when put into the bank at 3% interest, so too is the current value of $103 which is to be obtained next year equal to 103/1.03 = $100 today.

NPV: The sum of the discounted annual net cash inflows (= all cash inflows minus all outflows) during the lifetime of the project. If the NPV < 0, the expected net cash inflows over the total project lifetime are lower than the cost of financing the project, so the project should not be undertaken. When the NPV is close to zero, there is an expected break-even scenario. A positive NPV indicates that a project is likely to be profitable; it indicates the total amount of surplus that the project is expected to generate over its lifetime. The second yardstick, the IRR, will then tell us about the *rate* of profitability that this amount represents.

IRR: The rate of discount in the NPV formula which results when the NPV is set to zero while the discount rate is instead taken as the variable to be determined. The IRR thus yields a rate of interest, which can be directly compared to the prevailing cost of capital. If the IRR is lower or equal to the cost of capital, the project should not be undertaken. An IRR higher than the cost of capital indicates potential profitability and is the exact equivalent to an NPV > 0. However there should also be a good margin between the IRR and the cost of capital, to allow for unexpected project risks. A project whose baseline IRR estimate is just a few percentage points above the cost of capital is still not a good investment opportunity. What is considered to be an acceptable margin between the cost of capital and the IRR is also situation dependent and investor dependent. In projects with a new crop like Jatropha, high margins are required in principle, especially for smallholders who cannot take substantial risks.

BCR: The ratio of the sum of all discounted cash inflows and the sum of all discounted cash outflows. A BCR lower than 1 implies an expected loss; a BCR close to, or equal to 1 is equivalent to an NPV equal to zero, and to an IRR equal to the prevailing cost of capital/discount rate.

PBP: The number of years needed to recover the initial project investment. The best way to calculate the PBP is to use discounted cash flows, but this is not always done. Even the undiscounted PBP gives a reasonable approximation of project risk. PBPs longer than 2-3 years are to be considered highly problematic for smallholder farmers with limited resources.

CBAs are usually conducted by estimating all entities in so-called constant prices, i.e. estimated inflation effects are removed from all future cash flows as well as from the discount rate. This ex-inflation discount rate is commonly called the 'real' discount rate to distinguish it from the inflation-inclusive market discount rate. Similarly, the ex-inflation IRR which is estimated on the basis of project cash flows in constant prices is called the 'real' IRR. A real IRR which is higher (lower) than the real discount rate signifies exactly the same result as a 'nominal' (inflation-inclusive) IRR which is higher (lower) than the inflation-inclusive market discount rate/cost of capital. There is no effect from the inflation removal procedure on the NPV. This is because the NPV is defined in terms of year-0 prices.

The reliability of the CBA technique stands and falls with accurate estimations of the expected cash flows, implying that we can never just look at the results of the yardsticks and draw conclusions about the financial viability of projects from those indicators. We first have to assess the validity of all major assumptions underlying the cash flow estimations In this particular assessment, two types of problems are highly prevalent that were found to have major effects on the estimated results:

- seed yield estimates
- the proper valuation of resources, especially land and labour, according to their opportunity costs, i.e. their productive value in a scenario in the absence of the project. These opportunity costs constitute lost values to the investor when the project does get implemented, and should thus be adequately taken into account as project costs.

7.3 Feasibility of Jatropha in Eastern and Southeastern Africa

The financial feasibility estimates for this region have yielded quite unfavourable results, irrespective of precise methodology and scope.

7.3.1 Kenya

The worst estimations come from Kenya, most likely because a large part of that country has dryer and more infertile conditions than the other countries covered here. The most substantial and best-quality Kenyan study is based on a large field survey among 289 predominanty smallholder farmers across 6 provinces (GTZ 2009a). Actual yield patterns from 3-year plants were extrapolated until maturity reached in year 8, based on scientific literature, mainly from India. This is generally not a good procedure, as there is absolutely no evidence that these projected increases will be realized. To give credit to the study, "high" and "low" yield scenarios were worked out in order to take account of uncertainties. It also distinguished between monoculture, intercropping and fence plantings. The overall average dry seed yield across all scenarios is 0.421 kg/yr per mature tree. The authors note that this is far below yields reported elsewhere. However, it has been noted in Chapter 4 that the information conveyed by yield per tree is limited without complementary information about tree density and acreage.

The study concludes that a Jatropha fence model with *zero labour and land opportunity costs* can be somewhat profitable. I.e., Jatropha is unable to compete with other common staple crops, and the study recommends that its cultivation should only be undertaken when otherwise unoccupied family labour and reasonably fertile but unused land is available to manage it. The undiscounted pay back period for this model is 5 to 7 years, depending on yield assumptions. The internal rate of return (IRR) ranges between 14% (low yield scenario) to 24% (high yield scenario), which cannot be considered good for a new crop with unknown risks. The authors say that for Jatropha to be competitive with food crops, a yield 10 times higher than the high-yield scenario in their study would be required.

The study also analyses an intercrop model. Although the fence model has a lower yield/tree than the intercrop model, this is compensated by the greater nr of trees/acre. The seed yield per ha is therefore about the same, while the fence model has lower input costs. The study further concludes that simultaneous reclamation of barren lands and growing a commercial oil crop will inevitably imply use of fertilizer and irrigation, which will lead to cost increases and reduce the energy and GHG efficiency of the crop.

Moraa et al (2009) conducted a smallholder survey in Shimba Hills District (Southeastern Kenya). She reports an average dry yield of a mere 100 kg/acre (about 250 kg per ha/yr), but since the Jatropha planting started only in 2006, these are not yields from mature plants. One can also not predict how high productivity could become in subsequent years. *If* the given figures could be taken as representative, one could conclude that Jatropha is far less profitable than oranges and maize, the dominant local crops.

In a somewhat earlier Kenyan study without any specific regional focus, Tomamatsu and Swallow (2007) attempt to assess Jatropha viability prospectively, based on yield estimates from other parts of the world, mainly India. They take 1500 kg dry seeds per *acre* for rainfed conditions and 3200 for irrigated lands, which they consider the most optimistic scenarios. These figures are indeed very high when compared to the yield estimates given in Chapter 4: on that basis, a dry seed yield range of between 1000-2000 kg/ha/y would seem realistic for East African conditions. The seed sales price which they assume for Kenya (US$ 0.10-0.12 per kg) compares with real conditions prevailing in Tanzania and seems reasonable. Even with those optimistic yields, the authors calculate that Jatropha will have significantly lower gross profit margins (from the 8th year onwards, when the trees are considered to be mature) than common crop alternatives, and they conclude that it is currently (2006/7) unattractive as a smallholder crop and should not be promoted except as a hedge model. Raising seed sales prices is not considered to be a feasible option either, since this would drive up the cost of biodiesel too much for it to be able to compete with fossil diesel.

One important assumption made in all three Kenyan studies is that the seed cake has no value. Thus, the feasible seed sales price depends entirely on the value of the oil that can be extracted from it. This assumption is questioned by Flemming Nielsen (personal communication at FACT, 2010), who claims that Jatropha seed cake should be treated as a valuable fertiliser. There is supporting evidence for this statement from Dr Flemming's own FACT project in Mozambique as well as from Indian projects cited in section 5.4. However, in most cases it has been found infeasible to undertake oil extraction – except for very minor quantities – close to farmers' homesteads because of oil quality considerations. After centralised pressing, it is simply too costly and unwieldy to return the bulky and heavy cake to the farmers. A proposed solution is to use the centrally collected cake as input in a biogas plant and use the (much less bulky) slurry as fertilliser instead, but there is no evidence yet that this works well in practice.

In Tanzania, Diligent Tanzania Ltd has been experimenting with the biogas model, but it reports that the mimimal quantities of resulting slurry output do not justify returning it to their outgrower farmers. Another possible use of the press cake is to press them into fuel briquettes. This can work for large boilers and ovens, but briquettes that can do the job in domestic cookstoves are still under development; major unsolved problems include extensive fumes and their possible toxicity (see also section 8.1).4

Tomamatsu and Swallow state that the cake of various indigenous oil tree species such as canola can be used as animal fodder, which has a much higher market value than fertiliser. The cake of the Jatropha variety commonly grown in Africa cannot be used as fodder unless it is first detoxified, which is expensive and energy intensive. Recently, new patents from Hohenheim University and D1 Oils have been approved which seem to alleviate these negative side-effects. Also, Jatropha with non-detectable phorbol ester content has been identified in Central America (Guatemala and Mexico), which has been taken up in breeding programmes (EU FP7 JATROPT www.jatropt.eu).

Still, widespread accesss to these emerging solutions on the ground will still be some way off, especially the uptake of non-toxic varieties whose full value could only be realized a number of years after planting them. Thus, for the time being difficulties in productively using Jatropha press cake (and other byproducts) from current plants remain major barriers to establishing economic feasibility of the Jatropha value chain as a whole.

One of the Kenyan studies, GTZ (2009), has provided insights into the costs of different activities in the SVO/biodiesel value chain. If we assume that the costs of the first 3 years of a Jatropha project constitute the costs of plantation set up, these costs amount to Ksh 26372/acre or Ksh 65930/ha, or US$ 824/ha (nov. 2010 exchange rate) for a mono plantation scenario. Out of this, 30% are labour costs (excluding opportunity costs of unpaid family labour) and 70% physical inputs. By far the most expensive inputs are pest/disease control costs (42% of total costs) and manure (14% of total costs) (calculated from GTZ, 2009, Table 14). It is interesting to compare this cost breakdown with the estimates given for India in the next section. While the total set up costs do not seem to differ dramatically between the two countries (US$ 726-740 per ha in the case of India), there is a remarkable difference in the division of these costs. The highest cost items in India are plant acquisition and labour, with costs of inputs being minority items. In contrast, in Kenya, key physical inputs are obviously very expensive in comparison to labour and plant acquisition costs.

The annual running costs of a fully set up mature plantation in Kenya is estimated at Ksh 9217 per acre (Ksh 23043/ha), or US$ 288 per ha. This is substantially higher than the estimates for India given by Altenburg et al (2009) in the next section. It appears that the difference is largely due to continued need for expensive inputs like manure and pesticides in the Kenyan case. It thus appears that, on the whole, the cost of cultivation of Jatropha is lower in India.

4 Souce: J. van Eijck, General Manager, Diligent Tanzania Ltd, personal communication, 2008.

GTZ (2009) also gives data for a Jatropha fence model: set up costs of Ksh 3288 costs per acre (Ksh 8220 per ha), or US$ 103 per ha (calculated from Table 16). This amount solely consists of physical inputs. The labour cost component is assumed to be zero in this case, since this model would only require family labour which is assumed to remain unpaid. The running costs of a mature hedge are given as Ksh 190 per 1-acre hedge (Ksh 475 per 1-ha hedge), or a mere US$ 6 per 1-ha hedge. These only consist of pruning/weeding equipment and harvesting equipment. Opportunity costs of unpaid labour are again assumed to be zero. Unfortunately we have not found any comparable data for an Indian hedge set up.

There is but little information about costs in the processing stage of the value chain. Based on a recommended producer price of Ksh 7-9 (US$ 0.10-0.12) per kg dry seed, Tomamatsu and Swallow (2007) estimate that the seed cost per litre of SVO would come to Ksh 25-31 or US$ 0.35-0.42, but unfortunately they do not provide estimates of the other costs of producing SVO, or biodiesel.

7.3.2 Tanzania

There are several insightful recent studies examining the feasibility of Jatropha cultivation for smallholders in Tanzania under a variety of conditions, based on primary data and some also using a proper CBA methodology. Wahl et al (2009) undertook a detailed examination of Jatropha monocropping and Jatropha intercropping with sunflower on fertile arable land in Northern Tanzania (Moshi, Arusha and Manyara). Yields at maturity were estimated carefully based on a mix of own observations from plants at different growth stages, a literature review, and interviews with local experts. On this basis, an average seed yield of 2000 kg/ha/y was assumed from year 5 onwards, which is at the upper bound of the feasible yield range distilled from the evidence in Chapter 4. However, not a single Jatropha cultivation scenario was found to be profitable with this yield figure, assuming a positive opportunity cost of labour of US$ 1.72/day (which is still well below the official minimum wage of US$3 per day). At an optimistic yield scenario of 3000 kg/ha/y, Jatropha intercropped with sunflower breaks even somewhere in year 5, but this scenario should be considered infeasible. It would require high-yielding varieties with optimised management. In any case, even in this scenario cultivation of sunflower on its own remains far more profitable.

According to the authors, the low (or non) profitability of Jatropha is mainly caused by high labour intensity, especially weeding in the early years, and harvesting in later years. Hence the crop has high opportunity costs of labour. Its opportunity costs of land are also high when the soil is fertile. These high opportunity costs are not balanced by high revenues. Just like Tomamatsu and Swallow, Wahl et al argue that increasing the seed sale prices is unrealistic because this cuts into the competitiveness of Jatropha SVO and biodiesel further down the value chain. Planting Jatropha on marginal & arid lands with lower opportunity costs is also not a good option, because it would give rise to lower yields. Like the Kenyan studies, the authors therefore recommend Jatropha cultivation only in the form of hedge plantings, since these could be created on fertile land and yet do not have substantial opportunity costs. Rural Multi Functional Platforms (MFP) using SVO sourced from local hedges are seen to have potential. However, Nygaard (2010)'s MFP study (see section 5.2) notes that the use of Jatropha SVO for MFP in Africa has been largely abandoned, among other things due to its poor financial viability compared to fossil diesel and organisational and management problems.

One major weakness of Wahl's study is that the cash flow range was limited to just 5 years, which is too short and thus underestimates the profitability of

Jatropha versus annual crops like sunflower. Other recent Tanzanian studies do better here. Wiskerke et al’s (2010) study focused on small monoculture plantations on grazing land and plantations intercropped with foodcrops on arable land. The life span of the estimated cash flows in this study is a more realistic 21 years. However, in this study, too, Jatropha is found to be uneconomical for any type of use when workers are paid minimum wages, i.e. when realistic opportunity costs are taken into account. Only with a dry seed yield of 3.2 kg/shrub (and assuming a shrub density of 1600/ha under monocropping and 1333/ha under intercropping) and a shadow wage cost of US$ 1.35/man-day – less than half of the official minimum wage — would a farmer be able to produce at a cost of 100 Tsh per kg, which is equal to the current seed sales price at the farm gate. However, the assumed high seed yield is definitely out of sinc with the feasible range based on the evidence in Chapter 4.

The authors conclude that only soap production, or SVO as a diesel substitute for an MFP might work (which in their research areas would give rise to a cost of US$0.60/kWh versus US$ 0.79/kWh with fossil diesel), but not when full minimum wage costs are accounted for. Moreover their calculations are based on oil extraction with a cheap ram press, which is truly impractical for an MFP which requires larger quantities. Results with a more expensive and energy-using mechanized oil expeller would have been more unfavourable, most likely this would not lead to a competitive scenario for Jatropha. The authors further conclude that Jatropha oil also cannot economically substitute for fuel wood or charcoal for cooking purposes, even if working cooking devices for oil would exist locally, which is still not the case in Tanzania. The stove made by KAKUTE does not work at all, and trials with the German-designed Protos stove were abandoned because the stove and the oil were too expensive for poor people (there were also initial problems with clogging of pipes but these have since been resolved).

Jatropha cultivation on non-crop land was also not a problem-free option. It was found to interfere with grazing activities; moreover it can be a competing use of labour in view of the labour-intensity of seed & oil production. More information about competing uses of labour is given in section 5.2.

In the particular area where this research was done, labour rather than land is locally the dominant constraint. Depending on local specifics, Jatropha may thus compete with a range of different resource uses, including: alternative productive labour use; grazing land use; cropland use; fodder production and use; and water use (the latter two options mentioned especially in Indian studies reviewed below). This underlines the importance of valuing all required resources at realistic opportunity costs in Jatropha feasibility assessments.

Another survey-based feasibility study in Northern Tanzania was conducted by Messemaker (2008). Unlike the previous two studies which mainly concentrated on smallholders, he analysed all Jatropha value chain activities, including running a nursery, hedge-collecting, seed cultivation, oil production, biodiesel production, and soap production. His "largest" plantations were a farm of 80 acres and one of 20 acres, the others were true smallholders. This study, too, was focused on cultivation in arable land conditions. His estimations – which, however, are not based on a formal CBA but on average annual costs and revenues - reveal that it is impossible for all value chain activities to be profitable at the same time – there is an incompatibility between profitability for seed growers and oil processors. The seed growers require a minimum seed sales price of around 300 Tsh/kg (US$ 0.24), but this is infeasible for the downstream operations because they can only operate profitably at a farm-gate seed buying price of no more than Tsh 100/kg (US$ 0.08) (e.g., as practiced by Diligent Tanzania Ltd).

Seed yields in this study were based on actually observed values but the number of observations is limited due to insufficient numbers of mature plantings. Messemaker gives an estimate of around 1700 kg dry seed/ha/y for 3 year old plants in a fertile area using occasional flood irrigation and virtually no fertiliser inputs, which seems realistic in the light of the figures given in Chapter 4. The yield is still likely to increase due to maturation, but there is no expectation expressed in the study that biodiesel could be produced competitively any time soon.

Messemaker's study is interesting because it shows that the Jatropha chain as a whole is unprofitable, even with rather good yields obtained on fertile land, showing that progress is needed especially to improve oil processing efficiency and by-product utilization. The study also brings out – confirming the other studies reviewed so far – that producing SVO could be financially more attractive than making biodiesel.

Yet another detailed Tanzanian study (Loos 2008) was undertaken in Mpanda among a large number of smallholder farmers who are outgrowers for a central oil processor. Loos could only find plants of up to 3 years old, hence some yield extrapolation was required to take account of maturation. On the basis of a "moderate" yield estimate of 2000 kg/ha/y, the benefit/cost ratio is a mere 1.06 (1.00 would mean no-profit, no-loss) and the IRR is 16% compared with a 12% discount rate, taking a 10 year horizon; this is a bit short, but it still gives a reasonable indication that Jatropha could be at best modestly profitable over a longer life span of, say, 20 years. In an African context, investors tend to require IRRs of around 40%, especially in new sectors with many unknown risks. Results are different in a "high" yield scenario of 5200 kg/ha/y (but this is way above the realistic range of 1000-2000 kg/ha/y based on the evidence presented in Chapter 4). In that case the IRR becomes 65% and the benefit/cost ratio assumes a value of 2.75. The author himself seems to be well aware of the lack of realism of these estimates. He cautions that the average actual experienced yield in the 3rd year is just 358.6 kg/ha/y, and he expects that even his assumed "moderate" 2000 kg/ha/y at maturity may not be feasible. At a "low" yield of 1500 kg/ha/y, the benefit/cost ratio is just 0.81. We have to conclude that profitability is marginal under these conditions.

In the interviews conducted by Loos, the outgrowers indicated that the yields are not rising as fast as they had expected. He concludes that only under good management, ie, continuous weeding, pruning and, if possible, fertilisation and integrated pest management, the Jatropha plants grow nicely and may develop fruits. But this, of course, implies substantial work and costs for farmers. With low seed yields, growing food crops is likely to be much more profitable for them. A comparison is made with paddy, sunflower, groundnuts and tobacco, which are the dominant crops in the area. Their average annual net income is (much) higher than that of Jatropha over a 10 year period. Loos points to dangers of adopting Jatropha monocropping in view of these results.

A somewhat earlier study with a more limited fieldwork scope was Struijs (2008). His main aim was to assess the GHG balance of Jatropha cultivation in a smallholder hedge setup (equivalent to 0.4 ha) and in a small 1 ha Jatropha monocrop plantation set up on savannah bushland near Makanya. As part of this work he also estimated the profitability of both, based on average costs and revenues per year. He worked out a low-fertilizer and medium-fertilizer scenario, both for rainfed conditions. Makanya is not the most expensive place for obtaining inputs like fertilizer, even so the costs of fertilizer are shown to be considerable. In the smallholder hedge model, the estimated net revenue for the low-input & low-yield scenario (1000 kg/ha/y) is a mere US$ 11/ha/y. To put this in perspective: this is just 0.5% of the annual minimum wage in Tanzania. In the high-input & high-yield scenario (3000 kg/ha/y), the annual net revenue would reach US$33, or 1.6% of the annual minimum wage, but this may not be feasible in the light of the yield evidence quoted in Chapter 4. The 1 ha plantation would net US$ 101- 604 ha/y; assuming that the seedcake is used locally as fertiliser, which lowers the costs of this input in his model. However, we have already discussed the limited realism of this assumption earlier on. Struijs also worked out more favourable scenarios with carbon credits, but their price (US$ 20 per tonne) should now be considered to be unrealistically high, and he did not account for any costs to acquire these. Moreover, his carbon sequestration assumptions should be considered unreliable due to lack of good data about biomass growth of Jatropha.

Interestingly, Struijs observes that although 7% of cultivation area is lost when Jatropha is planted as a border, there is still a win-win situation with food production because the crops are better protected against animals and erosion. Food production may even increase. Further discussion of food & fuel links is contained in section 5.1 on food security.

One of the earliest feasibility studies in Tanzania is Kempf (2007). In the absence of data about real cultivation conditions for small and large farms, he set out to estimate the cost per litre of SVO and biodiesel irrespective of cultivation plot size, although he took an interest in intercrop & hedge models, which suggests a smallholder focus. His yield estimates of 3200 to 4800 kg seeds/ha/y in semi-arid conditions (Dodoma, Singida) now seem much too high in view of the accumulating evidence presented in Chapter 4. At the (then) extraction rate of 5-6 kg seeds for 1 l oil (at Diligent Tanzania Ltd), and a farm gate price of 100 Tsh (US$ 0.08 per kg seed), the SVO could be sold at around $ 0.77-1.15 with a modest profit for the processor. It would also give a reasonable return per ha for the farmer, but this conclusion hinges on the realisation of the high yield/ha, which is not realistic at all. The profit for the processor is possible thanks to the fact that no taxes are levied on SVO. However, processing SVO into biodiesel was found to be unprofitable, largely due to VAT and fossil fuel taxes of $ 0.31 per litre. The raw material costs and the taxes together already amounted to $0.77, compared with a fossil biodiesel price in Tanzania of $0.84-0.92 (at that time). Selling biodiesel on the EU market is also not straightforward, despite various subsidies and tax exemptions for biodiesel. There, African biodiesel has to compete with heavily subsidized US biofuels like rapeseed, with a cost of crude rape oil of just $ 0.55/l to EU bio-oilrefineries in 2006. Kempf notes that more advanced expelling technology should help improve the competitiveness of Jatropha PPO and biodiesel. However, and quite remarkably given the high yield assumptions, even at an improved efficiency of, say, 4 kg of seeds per litre SVO, the annual *gross* revenues for a small farmer will not be able to exceed US$ 200 per ha/y (in a 750 m hedge set up). This is comparable to the estimates given by Struijs, above.

A second assessment of the economic viability of Jatropha biodiesel production was undertaken by Muguletta (Mulugetta 2009). His study is entirely based on secondary sources, and its average Jatropha seed yield estimate of 7000 kg/ha/y now has to be considered unrealistically high; in addition the study assumes a very high seed sales price of US$ 0.18-0.40 per kg; under this combination of assumptions, the crop would certainly be profitable for growers. It is estimated that a net profit of between US$ 0.06 and US$ 0.10 per litre biodiesel should be feasible when fossil diesel costs around US$ 0.70 per litre. Partly, however, this profit comes from crude glycerin sales at US$ 200/t – another unrealistically high price (US$ 100/t would be closer to the mark in recent years[5]). Given its unrealistic yield and price assumptions, the findings of this study cannot be taken seriously.

Useful anthropological insights into the impact of Jatropha on village life and income security are given in a study by Mitchell (2008) who undertook a household survey in three villages in Arusha and Manyara in Northern Tanzania (see also section 5.1, food security). Jatropha had been planted here in hedges as well as in small intercropping arrangements with maize. She tried to establish the details of the competing resource-uses of the crops, and their comparative profitability.

Intercropping was found to be feasible only during the first two years. This practice does give farmers a temporary income from the land until the Jatropha crop matures, but it may compromise food production in the longer term, particularly since respondents did not plant Jatropha on their worst land; the crop was treated essentially the same as any other crop. Furthermore, the smallest and poorest farmers neglected Jatropha more than richer ones, who could afford to look after it because of more resources. In the longer term this would mean that the poorest farmers would be likely to get lower yields. Adequate weeding of Jatropha was particularly problematic for poor farmers because of competition with weeding requirements of staple food crops like maize and beans during the rainy season. The author concludes that the extent to which smallholders are able to invest labour and capital in pruning, appropriate spacing, fertilising, weeding and harvesting may determine to what extent they will benefit in the future. It was also clear that the management requirements of Jatropha had been underestimated by the smallholders. Pests and lack of crop management may compromise viability. A comparison of gross revenue per acre per annum between Jatropha and maize (with Jatropha yields based on the average of the range of 0.4–12t/ha/y reported in Achten et al's (2008) survey, and a farm gate sales price of Tsh 100,-) showed maize to be 5-6 times more profitable, except in the one village with marginal land and inadequate rainfall and low maize yields. Moreover, the author notes that the Jatropha yield figure that she used is likely to be an overestimate for these poor conditions. We can only agree with that observation, given the figures reported in Chapter 4. Not surprisingly, villagers expressed a desire for a Jatropha minimum price about 4 times higher than what companies were willing to pay. Under the (then) current conditions, the gross income from Jatropha worked out at around Tzs 80,000 per acre per year (around US$ 200 ha/y), which is again compatible with the estimates given by Struijs and Kempf.

Some Tanzanian studies have provided good data about costs of production at different stages of the jatropha value chain. Kempf (2007) quotes a figure of 460 euro set-up costs per ha, and Tsh 607030, or US$ 486, according to Loos (2009, calculated from Table 14). The direct running costs of a plantation producing 2000 kg seed per year – without overhead for the plantation itself and with a low seed picking rate of 4 kg/h – come to Tsh 200.000 (US$ 160) according to Kempf (2007). Loos (2009) estimates the running costs for a mature plantation as Tsh 208.000 per year, or US$ 166. This is much lower than the Kenyan estimate of US$ 288, and more comparable with the Indian estimates in the next section.

5 See: J. Taylor et al. (2010) 'No clear outlook for glycerin', *ICIS Chemical Business,* Oct 4-10, 278 (11): 32.

Interestingly, Kempf concludes that because of the high harvesting costs associated with running a plantation, a plantation operation is not cheaper than buying from independent outgrowers at Ksh 100/kg seed. Wiskerke et al (2010) observe that harvesting costs make up as much as 81% of total production costs. The conclusion that plantation-based cultivation is not necessarily more profitable than an outgrower model is supported by our own comparative analysis in section 7.5.

The one processor of SVO in Tanzania (Diligent) could make some profit by selling its oil at Tsh 1000-1500 (US$ 0.77-1.15), but its margin was reportedly not handsome. It initially needed 5-6 kg seeds to produce one litre of SVO (Kempf, 2007), but efficiency has since improved with better equipment. Note that the SVO sales prices realised by Diligent was substantially higher than the US$ 0.41 which Francis et al (2005) felt was the minimum SVO price required for oil processors to break even in India. This suggests that costs of SVO production are higher in Tanzania than in India, even though at US$ 0.08/kg the farmgate seed cost price in Tanzania is actually lower than in India (US$ 0.11-0.14). It is likely, however, that seed transport costs in Africa are much higher. Extension activities for outgrowers in Tanzania are also reported to be very expensive and difficult, due to the remote and scattered location of the farmers (source: personal communication by Diligent).

Due to the high SVO costs, production of biodiesel for the local market – which will most likely be taxed by US $ 0.31 per litre, unlike SVO – is currently unattractive in Tanzania. It cannot compete with fossil diesel. The fossil diesel price would have to rise above the current SVO sales price, far enough so that one could also make good on the tax levy before it would make sense for an oil processor to incur the costs of SVO transesterification. This is an unlikely scenario in the foreseeable future. At the time of Kempf's research, the diesel price was around US$ 0.84-0.92.

7.3.3 Mozambique

Two studies about Mozambique complete the African part of this assessment. One is a recent national biofuels assessment (Econergy International Corporation 2008), based on a mix of secondary data and interviews with industry stakeholders. Its focus is on the national level, and its main aim is to assess the national viability of biodiesel production from different crops. As in the studies by Muguletta and Kempf, there is no discussion at all about how the organization of the value chain in different business models (large estate plantations or decentralized outgrower systems) could affect viability. One merely tries to work out an average national cost per litre of biodiesel, which is inevitably somewhat crude. Even so, the results point in the same direction as those achieved for Kenya and Tanzania. At current prices, Jatropha biodiesel would not be competitive with fossil diesel, even when assuming unrealistically high seed yields of 3000-4000kg /ha/y. The authors of the report caution that in order to secure commercially viable volumes and yields of oil, large plantation owners will want to use good land for Jatropha cultivation. Cultivation of Jatropha on marginal land with correspondingly low yields and volumes is likely to occur only in the family sector (p. 170).

IRRs were calculated for biodiesel processing facilities of different sizes. A small scale facility can achieve an estimated IRR of 20%, but, oddly,this is without any tax costs, without any profit for farming and oil extraction, without any capital expenditure in farming, and without any positive opportunity costs of land. This is of course highly unrealistic. A large scale biodiesel facility would be able to produce at an IRR of 71%, but given that the assumptions are the same as for the small scale facility it is quite unclear whether this estimate actually signals profitability. In any case, it is worth mentioning that biodiesel production from sunflower, African palm and coconut yields higher IRRs than Jatropha biodiesel production. The study concludes that the two 'unusual' crops (i.e. Jatropha and Castor) have a higher cost due to the absence of high value co-products. As their co-products are non edible, these oilseeds only produce low value by-products such as fertiliser (p. 339), whereas some other crops such as palm and coconut have the advantage that heat can be produced from their biomass wastes; this is an important factor in Mozambique.

The other study focusing on Mozambique covers the other extreme of the macro-micro perspective: it is focused on a project in a remote rural area focused entirely on enhancing self-sufficiency and local development through small scale (hedge) production as well as full local use of the Jatropha products (Nielsen and de Jongh 2009). The authors analyse their own project, hence their information is based on first hand observations. They analyse SVO costs versus local fossil diesel prices (although these are not perfect substitutes); Jatropha cultivation and harvesting cost versus current Jatropha seed market prices; and the viability of using labour for Jatropha cultivation versus using labour for cultivation of alternative crops. Like other studies reviewed above, they report that Jatropha survives on exhausted soils but yields almost no seeds there. An important principle in the project is therefore that the seed cake should be returned to the farmers as fertilizer. Also, as in several of the Tanzanian studies, the dominant constraint is labour, not land. This meant that the introduction of Jatropha did not lead to land clearing in their project. However, the authors caution that such effects could happen in other land/labour scenarios. At the current seed price of MZN 2.5 and an extraction rate of 4.5 kg seed per litre of SVO, they find that Jatropha biodiesel can compete with a fossil diesel price of MZN 22-40 (assuming no taxes are levied on SVO) if the local transport costs of moving seeds and seedcake can be kept reasonably low, and assuming that local machinery can run on SVO instead of fossil diesel on a long term basis. Moreover, with a harvesting rate of 1-3 kg decorticated seeds per hour per person, the value of an 8-hour working day in Jatropha cultivation is comparable to alternative local income options.

This is the only project in the entire African part of the review that reports possible financial viability for Jatropha. Undoubtedly this is due to:

- the fact that only hedge plantings are undertaken with marginal opportunity costs of resources;
- the rural location of the project and the locally high cost of fossil diesel;
- the fact that the small-scale set up allows the seedcake to be utilised productively as fertilizer; and
- the use of SVO rather than more expensive biodiesel in the oil press.

Some of the studies reviewed above have provided details of costs of cultivation and biodiesel production, which can give us additional insights into the profitability situation in the Jatropha value chain.

Tips for practitioners:

- For the time being, Jatropha cultivation is best undertaken as a hedge crop in reasonably fertile conditions, where it will not compete substantially with alternative uses of required resources.
- Currently, Jatropha should only be promoted as a supplementary income opportunity, not as an alternative for extant cash crops.

- Investors in large monoplantations and intercropping schemes should be aware of high failure risks on account of low profitability. Preferably, for the time being these business models should be developed only on a limited experimental basis.
- It makes sense from a financial point of view to promote projects where the cultivation of hedge Jatropha is closely tied to the local use of its oil and by-products.
- From the profitability point of view, projects should emphasize SVO applications rather than the production of biodiesel through transesterification (which tallies with the findings about energy-efficiency and greenhouse gas emissions in section 6.1).
- Projects should attempt to enhance profitability of the Jatropha supply chain by emphasizing experiments to develop productive uses for Jatropha by-products, and also conduct experiments with alternative local oil seed crops that yield non-toxic seed cake.

7.3.4 Conclusions and recommendations

Conclusions:

- There are large methodological and quality differences between the studies reviewed in this part, and many have used unrealistically high seed yield assumptions.
- Even so, with one notable exception of a study about a local self-sufficiency-oriented project in Mozambique, all point to the lack of long term viability of Jatropha cultivation under current conditions and with the current state of knowledge and experience.
- On fertile lands and using irrigation and fertiliser, yields can be reasonable or even good, but under these conditions the same resources can produce far more profitable crops.
- On true wastelands with zero opportunity costs, yields would be far too low to be of economic interest.
- On in-between scenarios with marginal lands and grazing lands, opportunity costs of key resources cannot be assumed to be zero while yields will be modest, and these options are therefore also likely to be unviable.
- The Jatropha value chain as a whole needs to become more profitable, especially through finding higher-value uses for by-products, further increasing oil processing efficiency, developing seed varieties with higher and more reliable seed yields under semi-arid conditions, and optimizing cultivation practices. These challenges are, however, unlikely to be resolved within a few years.
- Currently, the only possibly feasible scenario for Jatropha cultivation that emerges from the studies is resource-extensive Jatropha hedge cultivation. This is so because it has very low opportunity costs and can yet be undertaken on fertile lands with good water access. The studies seem to agree that Jatropha cultivation in any scenario other than hedge plantings should not be recommended for the time being.
- Local projects that link seed production closely to local processing and oil use – like the FACT project in Mozambique – appear to have better potential for achieving financial viability than larger, non-local ones. The reasons are: the ability to return the seedcake to farmers, thereby aiding higher long term yields; low transport costs; and the use of SVO rather than more expensive biodiesel produced through transesterification. Moreover, currently biodiesel has a tax disadvantage compared to (as yet) untaxed SVO in African countries.
- Seed or oil production for export to the EU is unlikely to be profitable due to stiff competition from highly subsidized US bio-oils, except in some niche markets

with high sustainability requirements, such as supply of biokerosene feedstock for airlines. The situation might of course change once import sustainability criteria will be introduced.

Recommendations for research:
- Feasibility studies should be undertaken which compare production of SVO and biodiesel in large plantation scenarios with decentralized small independent 'outgrower' farmers grouped around a central processor. Economic viability information about large scale plantations in particular is currently non-existent in the public domain. This is worrying, given the large numbers of big Jatropha plantation investors currently operating and starting up in African countries, and their possibly invasive effects on ecosystems and local communities. In section 7.1.5 we present some initial comparative estimates of our own.
- Possibly adverse distributional effects on farmers of Jatropha cultivation should be probed (see also section 5.2 about local prosperity).
- Research should focus on improving profitability by finding higher-value uses for by-products, further increasing oil processing efficiency, developing seed varieties with higher and more reliable seed yields under semi-arid conditions, and optimizing cultivation practices.
- The energy-crop potential of alternative, indigenous trees and shrubs should also be explored, especially those whose seedcake is non toxic, which allows its productive utilization as animal feed. This could make these alternatives financially more viable than Jatropha.

7.4 Feasibility of Jatropha in India

The Indian CBA study that is among the most widely cited in the Jatropha literature is Francis et al (2005). The study was produced when the Jatropha hype just got underway, and this is reflected in its claims that the crop could be used for simultaneous wasteland reclamation, oil production and income generation. It assesses the financial viability of a large central plantation combined with a small scale biodiesel plant producing 2000 tonnes oil/y, using secondary data for costs and yields. Its yield assumption of 1800 kg/ha/y at maturity (from the 5th year onwards) appears reasonable at first, but one has to take note of the fact that these yields are expected to be obtained in a wasteland scenario without opportunity costs and with minimal inputs from year 5 onwards, this may not be possible (see Chapter 4). The real (ex-inflation) IRR of approx 22% seems high, but due to the lack of detailed information provided about costs it remains hard to detect why. There may be some underestimation of labour costs, since harvesting Jatropha is labour intensive. In any case, the reported realisation of an extra intercropping income of $109/ha per annum throughout the 30 year lifetime of the project is unrealistic. We now know that, when Jatropha matures, its crown becomes too wide for other crops to be able to flourish between its rows unless perhaps a very wide spacing is used and pruning is undertaken regularly, but that would cut into the obtainable yield per ha. If this intercropping income – US$ 2833 over 27 yrs – is deducted from the total income of the project, the plantation would in fact yield an IRR substantially lower than the cost of capital, and a highly negative NPV.

More recent studies have since brought more realistic insights into the Indian Jatropha scene. One of these is Altenburg et al. (2009) which tries to assess the competitiveness of Jatropha biodiesel based on annual costs and revenues taken from secondary data and information about yields from 3 year old plants. On the basis of estimations of net agricultural revenue per ha (without specific assumptions about business models, however) it is concluded that Jatropha biodiesel is currently unprofitable, with the exception of a few small niche markets. Oil companies have to buy biodiesel from producers at Rs 26.5 (approx US$ 0.58) per litre according to government directions, but according to the biodiesel producers, biodiesel production becomes viable for them only if they can fetch Rs 45-50 (US$ 0.98-1.09) per litre.

A recent article in an Indian newspaper sheds more light on the competitiveness problems of Jatropha biodiesel under current conditions.[6] It reports that collective biodiesel producers recently requested the Indian government to raise the official purchase price of Rs 26.5 to Rs 36, which they say is needed to ensure sustainable growth of their sector. So, although the flagging of the earlier Rs 45-50 estimate was probably part of a strategic bargaining strategy on the part of the biodiesel plants, this move does show that the biodiesel sector is not in good financial health. Allowing the price to rise to Rs 36 would, however, cost the government an estimated annual Rs 6 million in price support to the sector, at the current blending rate of 2%.

One cannot conclude from this, however, that Jatropha would be unable to compete without subsidies in a market environment, because the retail price of regular diesel (Rs 37.99-39.88 per litre) is heavily stabilised and subsidised in order to protect the consumer from the spikes and large fluctations of the international oil market. The country’s energy regime is so distorted by all kinds of policies and regulations that it is hard to work out what the real competitive situation of Jatropha biodiesel would be in their absence. All we can conclude at this time that the playing field between fossil and biodiesel is currently skewed against biodiesel.

Altenburg et al conclude that the reason why large plantations are taking off in many parts of India in spite of these competitiveness issues in the value chain can be solely ascribed to heavy government subsidies for investment in Jatropha cultivation. One other major factor that necessitates these subsidies has turned out to be the lower-than-expected seed yields. Initial research and experimental stations predicted yields of over 3500 kg/ha/y for mature plantations, but we now know that this could possibly only be obtained in the future with improved varieties combined with fertile soil, irrigation or high rainfall, and fertiliser and pesticides inputs (see Chapter 4 for more details). Food crops can also be grown under these ideal conditions and are then often much more profitable. On wastelands, Jatropha survives but does not yield much. Moreover, many so-called ‘wastelands’ do have positive opportunity costs; they are especially valuable as common lands for the poor with limited land resources.

Due to mandatory blending targets in the EU and the US, exports could become lucrative for India in due course (see section 5.6 for more details about international market prospects). Indian biodiesel is around US$ 200/t cheaper to produce than EU/US biodiesel, and has a better carbon balance. However, the Indian government may not permit exports, given its drive to achieve ambitious biodiesel targets in the country itself. Raising profitability of the Jatropha chain is therefore a must, but will require considerable time: it requires the development of higher and more reliably-yielding seed varieties for harsh conditions; it will also take time and political effort to cut the domestic fossil fuel subsidies; further experimentation with efficient ways of organising the production of biodiesel (i.e. finding efficient business models) is also required in order to cut costs. These findings and conclusions are very similar to the ones reached in the African part of

6 ‘Industry moots Rs 36/litre for jatropha biodiesel’, *Businessline,*Chennai, April 21, 2010.

the review, with the exception of the heavy fossil fuel subsidies and strong government support for Jatropha investors to offset the effects of these.

A more substantial quantitative CBA assessment of Jatropha cultivation and biodiesel production than the studies discussed above was undertaken by Estrin (2009), but again this study is also still based on a literature review and interviews with experts rather than new primary data from the field. Different agricultural models were elaborated, all of which show negative NPVs in spite of assumed high seed yields per ha, ranging from 5200 kg/ha/y for mature irrigated conditions to 3450 kg/ha/y for mature rainfed conditions.

Estrin claims that the main cause of the lack of cultivation profitability is the fact that the current SVO market prices are much too low; according to him they would need to be about 100% higher in order for Jatropha cultivation and processing to be profitable for farmers and oil processors (and perhaps much higher still with more realistic yield estimates!); but then the SVO and the biodiesel made from it cannot compete at all with India’s cheap subsidised fossil diesel. Estrin says that biodiesel plants of different sizes can be run profitably at the current low SVO prices, which contradicts the studies discussed above. He also says that the SVO price is indeed the only factor that affects profitability of biodiesel production significantly. Raising the SVO price to the benefit of growers and SVO producers would cut significantly into the profitability of biodiesel production. Therefore Estrin’s overall conclusion *does* concur with the studies discussed earlier, in that the profitability of the Jatropha chain *as a whole* is insufficient in India, just like in African countries. An additional noteworthy conclusion from this study is that small-scale rainfed cultivation scenarios produce much better energy and GHG emission performance than large irrigated ones, yet the small-scale scenarios are quite unprofitable. Their superior environmental performances are not translated in terms of material rewards.

What the studies discussed so far lack in micro-level socio-economic insights is provided by a piece of detailed field research among farmers of different landholding sizes ranging from very small to large, who had been growing Jatropha for some time in Tamil Nadu state (Ariza-Montobbio and Lele 2010a). It focuses on economic viability, livelihood trade-offs, and latent and emerging conflicts. Annual gross and net returns are estimated based on data about 3rd year harvests. Average yields were found to be three times higher on irrigated plots than on rainfed ones. The highest rainfed yield was 450 kg/ha, versus 750 kg/ha on irrigated land. The percentage of non-yielding plots after 3 years was much higher for rainfed lands (82%) than for irrigated ones (44%). They note that these performances are much lower than estimations of Indian agronomists who have consistently estimated 7500 kg/ha for irrigated lands and 2500 kg/ha for rainfed land for 3-5 year old plants.

Based on the best obtained yields in year 3, the net returns are still quite negative, even at zero opportunity costs of land but with costs of labour factored in as wages of hired labour. The researchers estimated that a tenfold increase in irrigated yields would be required in order to make a profit (assuming a good seed sales price of Rs 10 per kg, which is well above the Rs 6.5 average [US$ 0.14] which is being reported in India). Even though the yields are still likely to increase after year 3, realising a tenfold increase is quite unlikely unless one would add more inputs. But this would imply a cost increase, and also reduce the energy returns of the crop. The researchers also found that 30% of original plantations had already been removed while 50% were kept without maintenance due to the disappointing results so far. Negative consequences for food security signalled by this study are discussed in section 5.1.

The authors conclude that promoting Jatropha under the current circumstances could have many negative public welfare effects. A recent IFAD study confirms the writers' disappointing yield statistics for marginal conditions, citing various Indian studies reporting yields of 1000-1250 kg/ha/y for mature plantations (IFAD/FAO 2010). This is also broadly in accordance with the yield findings reported in Chapter 4. The authors also caution that unequal benefits from Jatropha could become a problem in the future when profitability improves, due to unequal access to required investment resources by different social strata.

We end this section about India with some remarks about costs. Although, as we have seen, several Jatropha feasibility studies have been undertaken for Indian conditions, not all of them also provide itemised cost breakdowns for the different activities in the Jatropha value chain.

Punia (2007) and Altenburg et al both provide estimates of the costs of bringing 1 ha land into cultivation. Punia's average estimate amounts to Rs 29992 (US$ 740) spread over two years, but there will be variations according to location, geography, availability of inputs, etc. Based on the information provided, one can work out that a full 40% of the total consists of the acquisition costs of plants; approximately 33% consists of labour and equipment costs; roughly 17% is for costs of irrigation, fertiliser, insecticides, and manure; and 10% is for contingencies (2007: 16).

Altenburg et al's estimate is Rs 29405 (US$ 726) which is very similar to Punia's. They spread the establishment costs over 3 years. In their case, however, labour is the largest cost item (47%). This is largely due to the fact that they have included pruning activities, as well as initial harvest activities in the 3rd year, which Punia does not have. Plant acquisition accounts for 24%; fertiliser, manure, pesticides, etc, take 18% (very similar to Punia); and contingencies 10% (2009: 38).

Altenburg et al. also report details of estimated annual plantation running costs per ha, after establishment has been completed (see tabulated data). These costs vary with seed yield per ha, since harvesting is a highly labour-intensive activity (2009: 40).

Seed yield/ha (kg)	**Running costs, Rs**	**Approx costs in US$**
750	2490	61
1500	3390	84
2250	4290	106
3300	5550	137
3750	6390	157
Assumption: US$ 1= Rs 40.50		

Francis et al (2005) give estimates of costs of producing biodiesel in a small-scale biodiesel facility producing 2000 tons of SVO per year. They assumed a (now somewhat low) seed price of US$ 0.11/kg, and a 3.57 kg seed requirement per litre of SVO (i.e. a seed cost of US$ 0.39 per litre of SVO). If the facility sells the raw SVO, the authors figure that it should be able to recover all its costs at a sales price of US$ 0.41., or approximately Rs 17 per litre. If it also processes the SVO into biodiesel through transesterification, the minimum viable sales price would need to rise to US$ 0.53 or approx Rs 21, which is below the current official biodiesel purchase price of Rs 26.5, but as we have noted, the average market costs of seeds has risen by (at least) US$ 0.03 since that study was carried out. The estimates by Francis thus confirm the picture that emerged earlier in this section, that the long term viability of biodiesel production in India is currently not assured.

Tips for practitioners:
- These are similar to those listed in section 7.3.

7.4.1 *Conclusions and recommendations*

Conclusions:
- The problems with Jatropha in India are very similar to the problems reported for Eastern and Southern Africa discussed in the previous sub-section. Mainly, the profitability of the whole Jatropha chain is insufficient; it is impossible for cultivators, SVO and biodiesel producers, and biodiesel sellers at the pump to make a profit simultaneously.
- Similar reasons for these problems also emerged: at the cultivation stage, we see disappointing yields and high opportunity costs for cultivators.
- At the biodiesel stage, the competitiveness problems in India appear to be worse in India than in Africa, because of the low official maximum biodiesel sales price which squeezes producer margins. Raising the price would need to entail a government subsidy on biodiesel, otherwise it would become too expensive in relation to India's subsidised fossil diesel.
- The perverse public subsidy regime impacts negatively on the competitiveness of biofuel versus fossil diesel. At the same time, subsidies for the cultivation of Jatropha have raised the attractiveness of plantation investments. The long-term implications from the highly distorted incentive structure are likely to be adverse, as it is encouraging a lot of structurally unprofitable Jatropha investment schemes (unless the structural subsidies on fossil fuels would be abolished, but this is likely to be politically unviable in the forseeable future).
- The issue of non-effective utilization of by-products curiously does not appear in the Indian review.
- There can be disturbing implications for social equity from the introduction of the crop, which confirm Mitchell's conjectures about how the crop could affect different rural households in Tanzania. When the crop's performance is disappointing the poorest suffer most, because they give up resources that are very essential to their livelihoods without receiving an adequate alternative income in return. Conversely, the poor also can be expected to benefit less from the crop as and when it would indeed become successful, due to the lack of essential complementary resources that are needed to make Jatropha cultivation a viable undertaking.

Recommendations for research (in addition to those listed in section 7.3):
- As in the case of Africa, more information should be collected on the relative profitability of different cultivation and processing models which could guide investors and government policy makers.
- It is important to keep reviewing the reliability of Jatropha CBA assessments in the light of more reliable observed yields in different conditions, which are now becoming available as Jatropha plantings begin to mature in different regions.
- Undertaking more research on distributional aspects of the financial impacts of Jatropha cultivation is highly important in the coming years, when Jatropha plantings mature and the full impacts from the crop's cultivation begin to materialize.

7.5 Preliminary feasibility estimates for two contrasting business models

Modelled on inside information about the business plans and practices of two Jatropha investors in Tanzania, we present here our own best estimates for the expected financial profitability of one large centralized plantation setup and one decentralized outgrower model with one (or a few) central oil processor(s). The data and information obtained from the two companies were somewhat adapted according to the latest insights, and in order to make the two cases as comparable as possible. In particular, the two companies are both expected to upscale in the course of 20 years to a total cultivation size of 80,000 ha. A full list of assumptions underlying the results is given in the appendix to this section.

For the outgrower model, two different input scenarios were estimated: "low input", meaning no fertilizers and no irrigation, and "intermediate input", which assumes some weeding, fertilizer and pesticide application and pruning. The assumed yields between the two scenarios differ by about one tonne dry seeds per ha per year. The assumed yields of respectively 1002 and 1981 kg/ha/y are in line with findings for not so fertile East African conditions reported by the most recent studies in section 7.1.3, which are in turn compatible with the realistic yield range reported in Chapter 4.

Table 7. below displays the results of the outgrower scenarios. The main observation is that the estimated profitability of the activities is bad, especially for the seed growers. For these smallholder farmers (who receive a relatively 'good' market price of US$ 0,14/kg seed), pay back periods of 16 to over 20 years, and real IRRs of 5.3% to 8.9% (compared with a real discount rate of 6.5%) essentially imply zero profitability over a 20 year period. The intermediate input scenario performs even worse than the low input scenario because the extra costs of fertilizers are not made good by sufficient extra revenues from higher yields.

The results for the processing company (in this case producing and selling SVO rather than biodiesel, in view of the latter's lower profitability) are only marginally better than for the smallholders. Payback periods of 12-13 years are long. The best IRR for the processor is 17.2% obtained in the intermediate scenario, but in that scenario the supplier farmers are expected to make a loss, so this scenario is infeasible. In the low input system, expected returns for the smallholders are marginal, and with an IRR of 13.4% they are also very modest for the processing company. The NPV for the processor looks big in absolute terms, but is poor when seen in relation to the amount of required investment.

Table 7.1: Estimated profitability and pay back periods for the decentralised outgrower model. Source: own estimates. For assumptions see Appendix III.

Low input system		
Smallholders (Outgrowers)		
NPV	**PBP**	**IRR**
$102	**16**	**8.9%**
Processing company		
NPV	**PBP**	**IRR**
$9,963,355	**13**	**13.4%**
Intermediate input system		
Smallholders (Outgrowers)		
NPV	**PBP**	**IRR**
-$86	**>20**	**5.3%**
Processing company		
NPV	**PBP**	**IRR**

$23,826,872	**12**	**17.2%**

Interestingly, the base case profitability estimations for the central plantation model shown in Table 7. below are quite comparable to the outgrower model, even though the land, capital and labour configurations are quite different in the two models. A Pay Back Period of 13 years and a real IRR of 16% has to be considered a marginally profitable undertaking for an investment which requires a huge up-front capital outlay, and which is risky given the lack of commercial experience with Jatropha as an energy crop. The bad results for both business models are all the more remarkable since the base case estimations include a substantial annual income from carbon credits; they would be even worse without these revenues.

Table 7.2: Estimated profitability and pay back periods for the centralised plantation model. Source: own estimates. For assumptions see Appendix III.

Central Plantation Model		
Plantation		
NPV	**PBP**	**IRR**
$19,518,551	**13**	**16.0%**

7.5.1 Conclusions

Conclusions

- Our financial feasibility estimates of a decentralized outgrower business model and a central plantation business model in an Eastern African setting give rise to concern about the long-term financial sustainability of current Jatropha investments. Both models are expected to have very poor long-term viability prospects with the current state of technologies and markets. These results lend further support to the poor financial viability findings reported for Jatropha value chains by the studies reviewed in sections 7.3 and 7.4 .
- There is no significant difference in expected viability between an outgrower model and a centralised plantation model of equal production size, while the outgrower model scores better on environmental and social impacts than plantations (see Chapters 5 and 6). These non-economic issues should therefore weigh heavily in strategic decision making about how to organise the Jatropha supply chain.

8 Some technical aspects

By J. van Eijck (UU)

This section includes only a small portion of the technical articles and reports that have been published. We have identified only those topics that are directly relevant to the use of seedcake as fertilizer vs fuel. We have only looked at published reports that mention practical problems or solutions. See ANNEX IV for a table rating 16 studies. More technical studies can be found on: https://jatropha.uni-hohenheim.de/64545.html.

We discuss seedcake and processing.

8.1 Seedcake

Jatropha seedcake is the residue left after oil has been pressed out of Jatropha seeds. On average ⅔ of the seed weight remains as seedcake, and the other ⅓ is oil. The seedcake still contains some oil, the amount being dependent on the efficiency of the extraction process; the review by Achten et al. mentions a 9-12% oil content by weight on average (Achten et al. 2008). There are different options for the use of seedcake. The most suitable use is determined by specific local factors such as the distance to places where it can be used, market conditions, and economic feasibility. In Tanzania for example seedcake is made into briquettes, charcoal and biogas (van Eijck 2009).

8.1.1 Fertilizer

There is some discussion about whether it is better for the GHG balance to use the seedcake as fertiliser (thereby closing the nutrient cycle and reducing the need for artificial fertiliser which has high GHG emissions) or to use the seedcake as fuel (thereby making optimum use of the energy content of 18.2 MJ/kg).

Many studies describe the potential value of Jatropha seedcake as fertilizer. The exact composition of the seedcake varies per batch but Achten et al. have found a range of 3.8 - 6.4% by wt of nitrogen, : 0.9 - 2.8% by wt of phosphorus, and 0.9 - 1.8% by wt of potassium in the literature. Studies like Tigere et al. (2006) and Wani et al (2006) mention specific contents that fall within these ranges for seedcake from Zimbabwe and India, and also (Reinhardt et al. 2008) in their Basic Data on Jatropha have values in line with this. The Jatropha handbook by the FACT Foundation reports that the seedcake also contains trace amounts of calcium, magnesium, sulphur, zinc, iron, copper, manganese and sodium. According to the handbook, one ton of seedcake is equivalent to 153 kg of NPK industrial fertilizer (15:15:15), on the basis of the nitrogen content (FACT Foundation 2009). Furthermore, Achten et al. found the average crude protein content of the seed cake to be 58.1% by weight (Achten et al. 2008).

This means that, as mentioned by many studies, in theory Jatropha seedcake has good fertiliser properties . However, very few studies describe the effectiveness of Jatropha seedcake as fertiliser in practice. Only three studies in our review mention some practical experience; Wani et al (2006), Tigere et al. (2006) and Achten et al. (2008). However, of the four case studies in Achten et al., one is similar to Wani et al.. The results of the Achten et al. case studies are summarised in Table 8.

Table 8.1: Results Jatropha seedcake application as fertiliser, table from Achten et al., 2008

Country	**Crop**	**Dosage** (t per ha)	**Remarks**
Mali1	Pearl millet	5	46% yield increase in comparison to zero-input
Zimbabwe2	Cabbage	2.5-10	• 40–113% yield increase in comparison to zero-input• Free from pest and disease, while cutworm infestation occurred with cow manure application
Nepal3	Rice	10	11% yield increase in comparison to zero-input
India4	Jatropha	0.75-3	13–120% yield increase in comparison to zero-input

1 : R. Henning, F. Samaké and I. Thiéro, La valeur fertilisante du tourteau du pourghère, Projet Pourghère DNHE-GTZ, Bamako, Mali (1995).
2: (Ngoma 1999)
3: Heller J. Physic nut. PhD dissertation, Institute of Plant Genetic and Crop Plant Research, Gatersleben, Germany, and International Plant Genetic Resource Institute, Rome, Italy, 1996 http://www.ipgri.cgiar.org/Publications/pdf/161.pdf
4: A. Ghosh, J.S. Patolia, D.R. Chaudhary, J. Chikara, S.N. Rao and D. Kumar *et al.*, Response of *Jatropha* curcas under different spacing to *Jatropha* de-oiled cake, *FACT seminar on Jatropha curcas L. agronomy and genetics, Wageningen, The Netherlands, March 26–28*, FACT Foundation, Wageningen (2007) Article no. 8.

The results of these case studies indicate a high potential for using Jatropha seedcake as fertiliser. However the studies are outdated and no more recent studies were found. Only (FACT Foundation 2009) mentions that the seedcake should be composted before application, but there are no studies done to verify this. The economic value of the cake, its acceptability to local people as fertiliser as well as their willingness to pay for it are also unclear.

8.1.2 *Fuel*

Figure 8.1: Jatropha seedcake briquettes to be used as fuel (pic J. van Eijck)

No reports have been found that describe problems with using seedcake as fuel. Technical data are available on the energy content (Kerkhof 2007) and (Achten et al. 2008). Achten et al. found an average gross energy content of 18.2 MJ kg^{-1}. This is in line with (Kerkhof 2007).

8.1.3 *Conclusions and recommendations*

Conclusions:
- Jatropha seedcake has good fertilizer value (no reports were found that claim the opposite). It contains 4-6 % nitrogen, 1-3% phosphorous and 1-2% potassium.
- The energy content of the seedcake is around 18 MJ/kg
- Hardly any data are available about impacts and practical applications
- The market, economic feasibility and possible adoption by local population are unclear.
- There is unresolved discussion about whether it is preferable to use seedcake as fertilizer or as fuel.
- Hardly any data are available on the use of processes such as pyrolisis and charring.
- Only technical feasibility of detoxification to make seedcake suitable for animal feed has been researched.

Recommendations:
- More experiments are needed with the application of seedcake as fertilizer, taking possible issues with adoption by the local population into account.
- Market analysis and economic feasibility need to be undertaken.

8.2 Processing

Several studies mention that there are different possibilities for extracting Jatropha oil from the seeds. An overview is given by (Achten et al. 2008) while more technical details are discussed by (Beerens 2007). The different aspects are combined in the Jatropha handbook of the FACT Foundation (2009). The options are manual pressing, mechanical pressing and chemical extraction. Reports on practical issues related to chemical extraction are missing. This might partly be due to the fact that many Jatropha projects have started fairly recently and the seed volumes are still too limited to start chemical processing yet.

8.2.1 *Hand pressing*

Two reports describe problems experienced with manual presses. In Mozambique the use of a hand press was problematic due to clogging and slow production (less than one litre per hour) (Nielsen and de Jongh 2009). These authors also stated that quality control of the oil is only feasible with a centralised oil production facility. In Zimbabwe, where hand operated ram presses are also used, 90 kg of seeds were found to yield 15-18 litres of oil (5-6 kg per litre) which is a rather low productivity (Tigere et al. 2006).

8.2.2 *Mechanical pressing*

Three reports describe projects that were involved in processing by means of mechanical extraction; in Tanzania (van Eijck 2009, and some economic data by (Messemaker 2008), in Mozambique (Nielsen and de Jongh 2009) and in Honduras (Moers 2010).

The optimum equipment for processing depends on the expected volumes , and the required quality. For these reasons, Diligent in Tanzania tested different types of equipment. However, it is also important that the workers who have to operate the machines have certain skills; with the required skill level varying with the type of equipment (van Eijck 2009). In Honduras it was learnt that existing processing technologies could be adapted for Jatropha. This means that equipment could be repaired (and manufactured) locally, in places where the necessary technical

capacity was present, e.g. at a technical school which is often found in a provincial capital city. Theauthor of the Honduran study concludes that this could be a selection criterion for choosing the headquarters of a Jatropha promotion project (Moers 2010). In the case of Diligent, the more advanced presses that were obtained from Europe required spare parts that could not be locally repaired, this can slow down the processing.
Furthermore in Mozambique it was observed that in local communities a press is not always kept in good condition. "Limited availability of Jatropha seeds is preventing optimal use of the press, which is therefore not well maintained and in bad condition" (Schut et al. 2010b) p 81. See also the text box on Multi Functional Platforms in Section 5.2 on local prosperity.

8.2.3 Chemical extraction

Several studies have been published about the technical feasibility of chemical extraction, but all are still laboratory scale tests. Some of them are:

(Lim et al. 2010):	New extraction method with methanol, only 80 minutes required
(Qian et al. 2010):	Two-phase solvent extraction
(Balat and Balat 2010):	Dilution, micro-emulsification, pyrolysis, and transesterification

No reports were found which report data from practical experiments.

8.2.4 Further processing

The processing steps after pressing, such as sedimentation, filtration etc. are described in the FACT handbook, which combines lessons from Honduras and Diligent in Tanzania, and lists various types of equipment for filtration and so on. Jatropha oil contains a high amount of sediment, therefore filters clog up easily and rapidly, especially with oil filters under pressure (FACT Foundation 2009). Prior sedimentation is therefore required. The production of biodiesel (which requires transesterification of the SVO) is described in the handbook as well, but no data have been reported about practical implementation issues. Theoretical studies and those based on with tests on laboratory scale are available. Some of them mention enzymatic transesterification, this has several advantages over alkali catalysis, namely "reducing process operations in biodiesel fuel production and an easy separation of the glycerol byproduct" (Fukuda et al. 2008; Rakshit et al. 2008). But until now the price of the lipase enzyme has been the main obstacle for commercially feasible production. Various other problems can also be expected to occur in the transesterification step, such as, lack of availability of methanol, problems with the quality of the biofuel, insufficient technical skills of operator, and problems with finding a suitable use of byproducts such as glycerine, and so on.

8.2.5 Conclusions and recommendations

Conclusions:
- No practical data are available about chemical extraction.
- Manual presses are considered to be slow and inefficient.
- If local equipment can be adapted for Jatropha seed pressing, equipment can be repaired more easily and faster than imported equipment.
- Technical skills are required by the operators of mechanical presses, technical training capacity is needed. The more advanced the equipment, the more training is required.
- Maintenance of the equipment in rural areas might be problematic.
- The amounts of sediment in the oil are high.

- There are no data on biodiesel production in practice, e.g. about the use of glycerine and other byproducts, and about the quality of biodiesel produced.

Recommendations:
- More research on various aspects is required, both in lab setting and in pilot or experimental set ups.

9 Other relevant aspects

By J. van Eijck (UU)

9.1 Market prospects

International markets and domestic markets for Jatropha products have been identified in the literature.

9.1.1 International markets

The EU and US create a large demand for biofuel. The European Union has opened a large market for biofuels through its biofuels directive (2003/30/EC) that came into force in May 2003. It states that countries in the EU must take measures to ensure that 5.75% of all fossil transport fuels will be replaced by biofuels by 2010 (Wikipedia). This target might still be slightly reduced, however, as the EU is currently rethinking the goals, not wanting to stimulate unsustainable biofuel production.
In the USA, the Energy Policy Act, signed by the president in 2007, sets a target of almost 29 billion litres of renewable fuel (5% of gasoline consumption) and a call for 5 times as much in 2017 (Jank et al. 2007).

9.1.2 Domestic or local markets

Potentially the domestic market for Jatropha biofuels could be as large as the fossil fuel market. However, domestic markets are restricted by the absence of a legal framework. As Schut et al. indicate, most (large scale) projects produce for external, international markets because a domestic or regional market is absent (Schut et al. 2010b). Projects that are specifically set up for local energy supply however can create local demand. For example the ADPP/FACT project in Mozambique established local production of Jatropha seeds and processing capacity, as well as a local market for the oil (Schut et al. 2010b). There is also a local market for other products from Jatropha. In Mozambique Bos et al. (2010) analysed the Nhambita community, they see an opportunity for the use of Jatropha soap, SVO use in oil lamps and business generators, and use of residues as fertilizer (Bos et al. 2010). The size of this potential market is analysed as well. Average household consumption is 250 ml of fuel per week (petroleum lamps), for the community consisting of 68 households this would mean 816 l per year (roughly 4,400 kg Jatropha seeds) if 80% has a lamp (Bos et al. 2010). The surveyed households use an average of 2 bars of soap per month; this would also mean 816 l jatropha oil per year. A generator (for an NGO's electricity needs) would consume 10,000 litres per year, a generator for a carpentry workshop 1,250 l, and a maize mill 500 l per year (Bos et al. 2010). This means that if Jatropha oil could be used as an alternative energy source for lamps and generators (which would require some organisational and technical issues to be overcome), the total market demand by a small community would be around 14,000 l per year. This relates to 28-56 ha when we calculate with 4 kg seeds l^{-1} and 1-2 ton seed ha^{-1} (similar to the data used in Section 7).

Another study undertaken in Kenya analysed the market for Jatropha oil as a kerosene replacement. The survey among 2,300 households in rural and urban areas revealed that 82% used kerosene for lighting in lanterns, and 88% used kerosene for domestic cooking. Average annual kerosene consumption is 90 litres in urban and 51 liters in rural areas. In rural areas kerosene is mainly used for lighting and in urban areas for lighting and cooking. Moreover, as the landed price for kerosene has gone up by a factor of 3.5 during 1996-2005 (compared with a 2.5 rise in the average consumer price) the prospects are good (Tomomatsu and Swallow 2007). However, there are still some technical problems when Jatropha SVO is used in (adapted) equipment that is normally fuelled with kerosene. In his survey in Tanzania, Messemaker did not observe any household that successfully used Jatropha oil for domestic purposes (Messemaker 2008). He did find that all women groups in Tanzania had stopped producing soap due to a lack of market at the high price that was being charged for the soap (Messemaker 2008).

9.1.3 *Sustainability criteria*

There are numerous certification schemes being developed; see for example (ProForestLtd. 2008) in which potential risks and impacts based on the UK Renewable Transport Fuel Obligation (RTFO) are analysed, and (Froger et al. 2010) who analysed 44 sustainability standards in a study commissioned by NL Agency. Their conclusion was that the RSB (Roundtable on Sustainable Biofuels) principles are the best for assessing Jatropha plantations. They also created a framework to assess sustainability.

Tips to address market prospects:
- Take sustainability criteria into account
- Target the marketing of Jatropha oil on areas where people are already incurring high costs for lighting and cooking with fossil kerosene (people may not be interested when Jatropha is supposed to replace 'free' firewood)

9.1.4 *Conclusions and recommendations*

Conclusions:
- There is a large international market due to biofuel directives.
- When there is no (clear prospect for a) domestic market, projects will target the international market.
- However, there is potentially a large market for local use of Jatropha products.
- Technical issues, lack of continuous supply of affordable Jatropha products, and the lack of domestic markets have hindered the local use of Jatropha products so far.

Recommendations:
- Biofuel policies are needed to open domestic markets in Jatropha-producing countries (e.g. with blending policies).
- More research is required about adapting equipment to Jatropha oil in rural areas.

9.2 Organisation (business models, production structure)

First we discuss the different models that are possible, second we discuss the impacts of the models.

9.2.1 *Different models*

For investors, there are different ways to structure the Jatropha supply chain. A plantation can be set up, smallholder farmers incorporated, and a mixture of central production and contract farming is possible as well. Jatropha has some specific characteristics which makes investment slightly risky. This is described by Bijman et al. who analysed contractual arrangements for Jatropha smallholders in Mozambique, but the factors apply for plantations as well. Bijman et al. (2009) state that there are high transaction costs between farmers and Jatropha processors, which also have the effect of increasing risks. These high costs & risks are due to the long time lag between planting and harvesting, the lack of knowledge about and experience with the crop, and the lack of access to inputs and supporting services. Processors also risk abuse of inputs (if provided) and sideselling of the crop. Finally, formal contractual arrangements may be hard to maintain due to weak property rights enforcement (Bijman et al. 2009). Vermeulen and Cotula have listed possible business models for projects that want to include smallholders. See Figure 9.1 below.

	Farming →	Milling →	Refining →	Distribution →	End uses
Business arrangements to include small-scale owners and enterprises	Outgrower schemes Purchase agreements Land leases Share-cropping Management contracts Joint ventures (e.g. community land inputs = shares in the business)	Cooperative mills Share ownership Small-scale facilities aimed at local end-uses Supply contracts with larger refineries and distributors	Limited options given high capital costs of biorefineries	Intermediary traders Transport contractors Utilising existing distribution systems (e.g. networks of rural retail outlets aimed at farmers)	Sliding-scale energy pricing for different categories of consumers Subsidised multi-function platforms Subsidised improved appliances Use of unrefined oil rather than refined biodiesel
Options for government policy support	Support to positive models through regulation, information, model contracts and brokerage Underwriting community business involvement	Active promotion of small-scale milling operations, e.g. via supply of prototypes Business support to shared equity models	Employment laws Holding developers accountable to job projections in approved investment contracts	Local content requirements	Support to off-grid energy schemes Subsidies as above
	Subsidised finance and insurance schemes Cost incentives (e.g. tax breaks, reduced fees) Local supply quotas and local content requirements Active support: information, guidance, research				

Figure 9.1: Smallholder-inclusive business models at different stages of the biofuels value chain (Vermeulen and Cotula 2010)

Bijman et al. make a distinction between different models that can be used for Jatropha contract farmers: a *centralized model* (in which a processor sources from a large number of (small) farmers), a *nucleus estate model* (in which a processor sources from farmers and its own production facilities) and a *multipartite model* (which is a joint venture between the state, a private company and farmers). The problem with the first model is that the processor cannot provide technical know-how based on own experience; the second model is slightly better, but the multi-partite model is preferred. The processor has contracts with farmers for the seed delivery while the state agency provides technical support and inputs. In this way the state agency takes care of some of the risks such as access to inputs, etc., while the farmers have a guaranteed market (Bijman et al. 2009).

In India a model has been set up whereby people’s livelihoods are improved by using Self-Help-Groups (SHGs) on common lands like degraded forests, community owned lands, and low quality lands (railway setbacks, canal embankments, etc). Groups who manage the plantations receive guaranteed 'harvest-rights' to, while the land rights or title deeds are not transferred (Wani et al. 2006). However no assessment of impacts is available. Contract farming, also known as 'buy-back agreements' or 'outgrower models', are also found in India, for example in the case of D1 oils in Tamil Nadu (Altenburg et al. 2009). These arrangements are similar to models used in Tanzania (Loos 2008; van Eijck 2009).

In Honduras a new model has been developed. Jatropha farmers have a 49% stake in a company (BYSA) that has been established to produce and distribute biofuels (with Jatropha as main feedstock). The remaining 51% is held by an NGO that will withdraw its shares when the company will have become economically viable (Puente-Rodríguez 2009; Moers 2010).

Farmer clubs have been set up by two projects in India and Mozambique (Altenburg et al. 2009; Nielsen and de Jongh 2009). These clubs consist of a number of members (10-40). Formation of these clubs facilitates access of the members to credit schemes. Another model involving partnership between the state, private companies and the *panchayat* (village committee, in India) is called Rural Business Hubs (RBH). They are established to connect rural producers and rural markets to national and international markets with the help of business. This concept is being tested in three states in India, for example by D1 oils in Haryana[7] (GRAIN 2008). Also in Andra Pradesh, under the Rural Employment Guarantee Scheme (NREG), public-private partnerships have been established to explore the possibilities of biofuel feedstock production[8]. The NREG guarantees rural people 100 days wageemployment per household per year[9]. However, social movements have been complaining about government support for the corporate sector and feel that the NREG should not be used to promote the 'corporatisation' of land (GRAIN 2008). Lessons from other crops might be useful in this respect.

(Altenburg et al. 2009) distinguish three organizational models, based on a study of 13 cases. The *government centered* model is characterized by cultivation on communal and government land. The *farmer-centered* model is characterized by cultivation on private land, and the *corporate centered* model by large scale cultivation.

9.2.2 Impacts of the models

Arndt et al. (2009) compared an outgrower-based arrangement to a plantation system, and concluded that an outgrower (smallholder) model is more pro-poor. This is due to differences in labour- and capital intensity between the two models. An outgrower arrangement uses more unskilled labour and can result in technology spillovers. This is also concluded by the FAO who found in their model that, although all biofuel production scenarios improve household welfare and local prosperity, small-scale outgrower schemes – especially for Cassava and Jatropha – are most effective at raising poorer households' incomes (FAO 2010).

However, as experiences show, besides having a clear benefit for local people, setting up an outgrower network is also very time consuming. It takes effort to convince outgrowers and requires adequate funding to cover for the long pay back period, while market distortions reduce the reliability of feedstock supply. In Mali, local authorities have prohibited the sale of Jatropha seeds outside their commune in order to ensure enough feedstock for their village hybrid power plant (Practical Action Consulting 2009).

7 http://www.thehindubusinessline.com/bline/2006/12/26/stories/2006122603480100.htm
8 http://www.rd.ap.gov.in/EGS/BIO_Diesel_Memo_23153.htm
9 http://nrega.nic.in/netnrega/home.aspx

Furthermore, distance and accessibility are crucial in an outgrower system; in Tanzania certain regions were found to be easy to source from, because of their proximity to long-distance transport routes along which (empty) trucks pass on their way back to the coast. This made these regions suitable for network development, in contrast to inaccessible regions with bad infrastructure and hence high transport costs (van Eijck 2009). When developing an outgrower system, it is important to work in accordance with the government structure of the country (van Eijck 2009). In Tanzania the set procedure to approach farmers is to first start with regional authorities and then (when approval has been received) the district authorities, followed by the village leaders. Only then the farmer can be approached (van Eijck 2009). Smallholder development requires good extension services, which is expensive. At the same time, a smallholder system carries lower risks related to large scale plantations, such as adverse impacts on biodiversity and ecosystem functions (Achten et al. 2010b).

In Mozambique, a project designed for the energy needs of local people decided to press the seeds at a central location because quality control was only feasible with larger quantities. It made transport expenses higher and seedcake could not be returned to farmers easily (Nielsen and de Jongh 2009). In Tanzania similar factors contributed to the decision by Diligent to set up a central processing unit (van Eijck 2009).

In Kenya, the company Energy Africa Limited organised group leaders (10 for a total of 200 contract farmers) to assist the staff with daily extension services.

Tips:
- Be aware of different business models and their pros & cons, take the local context into account when deciding how to organise the supply chain.

9.2.3 Conclusions and recommendations

Conclusions:
- There are many different business models.
- The most suitable business model is determined by local context-specific circumstances.
- Outgrower models can have benefits for local populations because of their high labour intensity and knowledge spillvers, but they also have downsides, like time-consuming and expensive extension and sourcing and more risk in feedstock supply.
- Large scale plantations can generate local incomes from wage employment, but carry higher risks of causing adverse impacts on ecosystems than smallholder systems.

Recommendations:
- In choosing a particular business model, the local context should be taken into account.
- Flexibility in the implementation of business models can improve sustainability.
- Participation of smallholders in business model development is recommended.

9.3 Policy issues

The study by IFAD/FAO (2010) lists several policy recommendations (P.87):
"At the global level, there is a need for coordination of biofuel development and an international food reserve system to protect the vulnerable poor. To meet pro-poor objectives, international support for research into Jatropha agronomy and genetic improvement is needed. The development of nontoxic varieties should be a priority. CDM methodologies and certification to support sustainable Jatropha production systems need to be accessible by the rural poor."

"Taking advantage of the opportunity Jatropha presents for rural development will require developing countries to address the policy, regulatory and public investment constraints that generally affect their agricultural development. Biofuels need to be integrated within a broader framework of investment in rural infrastructure and human capital."
"Large-scale plantation type schemes should be promoted as part of the pro-poor development strategy to generate employment and incomes, and make biodiesel affordable to the poor. Too much regulation of the biodiesel industry in the early stages could exclude small producers. Small feedstock producers can be assisted by legislation that sets quotas, requiring the large oil processors to source minimum quantities from small farmers. The expectation that Jatropha can substitute significantly for oil imports will remain unrealistic unless there is an improvement in the genetic potential of oil yields and in the production practices that can harness the improved potential. For the present, the main pro-poor potential of Jatropha is within a strategy for the reclamation of degraded farmland along with local processing and utilization of oil in a way that can improve and diversify rural livelihoods, particularly for the disadvantaged rural poor in semi-arid regions. In addition, by providing physical barriers, Jatropha can control grazing and demarcate property boundaries while at the same time improving water retention and soil conditions. These attributes, added to the benefits of using a renewable fuel source, can contribute in an even larger way to protecting the environment."

Some issues that came up in individual countries:

9.3.1 Mozambique

In Mozambique the government is proactive in facilitating biofuel developments. But earlier, between October 2007 and May 2008, it froze large-scale land requests because it was concerned that it lacked control over issuing land for large scale biofuel projects (Schut et al. 2010a). A zoning-exercise followed, and in 2009 the government published a national biofuels policy and strategy (Schut et al. 2010b). Jatropha was chosen as one of the feedstocks for biodiesel production, and it is being promoted by the government; an agro-ecological zoning exercise has to determine where it can be planted. The allocation of land used for basic food crops and establishment of monocultures have to be avoided. The government wants to promote local processing capacity, increase export and at the same time establish a national biofuel market (Schut et al. 2010a; Schut et al. 2010b). The first zoning exercise received quite some criticism, the scale was considered too large and data on soil and rainfall outdated. Currently a second phase is being carried out. In Mozambique the highest concentration of biofuel projects is found in areas with relatively good infrastructure, relatively easy access to goods and services, dense population and good agricultural conditions (around the Maputo and Beira corridor) (Schut et al. 2010b). This does not fit with the objective of the government to target rural areas. Another objective is the development of a national biofuel sector, but so far the companies have been targeting external markets. This does not reduce the energy dependency of

Mozambique. Adequate policies are required to avoid conglomeration of biofuel companies. Currently, 80% of the (proposed) projects will be located in less remote regions (Schut et al. 2010a). As the government of Mozambique wants to target the remote areas and the domestic market, instruments are needed to reverse this trend effectively. as One project in Mozambique has been abandoned by its main investor after which their contract was declared void by the government (United Press International 2009 (Schut et al. 2010b). In Mozambique, the land title deeds (DUATs) are linked to the specific feedstock and production plan. This means DUATs can be transferred, but the government needs to authorize a new use. One company in Mozambique, Procana ltd, already saw their land lease contract being declared void (Schut et al. 2010a). In India, the different state policies are described by (Altenburg et al. 2009). Many Indian states promote Jatropha. In Mozambique a project was launched (funded by the Dutch government) to identify a methodology to assess the sustainability of Jatropha producers (Froger et al. 2010).

9.3.2 India

In 2003 the Government of India launched a National Mission on Biofuels. The aim is to achieve a 20% biodiesel blending target in 2012 (Rajagopal 2008). In India initiatives on land identification have been executed: a 'Wasteland Atlas of India' was produced in 2005 to identify potential areas for Jatropha (see http://tinyurl.com/2crtc5) (GRAIN 2008). But difficulties in identifying 'real' barren land remain; sometimes the lands identified as such function as pasture lands for certain communities, as a lifeline for jobless labourers etc..

9.3.3 Indonesia

(Sheng Goh and Teong Lee 2010) review the biofuel policy in Indonesia, they claim that due to the many uncertainties the biofuel industry is becoming weaker, and demand dropped despite a policy to promote biofuels. Similar trends are noted in neighbouring countries: In Malaysia biofuels are mainly derived from palm oil, but out of 92 biodiesel projects that were approved only 14 functional units have been built, and only 8 were operational in 2008. In Thailand ethanol plants were not running on full capacity (if running at all) despite the promotion of biofuels.

9.3.4 Tanzania

In Tanzania the Petroleum Act was revised (in 2008/2009) to allow blending of biofuels with fossil fuels (Martin et al. 2009). However, Gordon-Maclean et al. (2008) (WWF), have indicated that the development of an integrated national biofuel policy in Tanzania has been problematic. One of the reasons, they argue, is that the National Biofuel Task Force (NBTF) is chronically underfunded and that the Task Force members have lack of time since they have mostly fulltime day jobs. In September 2008 the NBTF did, however, release draft national biofuel guidelines. Gordon-Maclean et al. furthermore list some points of critique, for example about the absence of clear definitions e.g. 'win-win'.

9.3.5 Kenya

In Kenya, the Kenya Biodiesel Association was created in 2008 to promote the production of Jatropha biodiesel; a 3% blending was proposed (Ndong et al. 2009a).

Tips about awareness of policy issues:
- Try to create a link to the government (for which purposes, please specify?)
- Make sure not to bypass a legal authority or institutionalised structures when dealing with the government or local communities

9.3.6 Conclusions and recommendations

Conclusions:
- Biofuels need to be integrated within a broader framework of investment in rural infrastructure and human capital.
- Clear definitions are required when exchanging information and in formulating policies
- So far biofuel companies have targeted external markets which does not reduce the energy dependency of the producer countries

Recommendation:
- At the global level, there is a need for coordination of biofuel development and an international food reserve system to protect the vulnerable poor.

10 Conclusions

To identify knowledge gaps, we have made a score table in which we identified whether or not studies were available on the different aspects. A √-symbol indicates that studies have been found on the relevant aspect.

10.1 Agronomy

Table10.1: Data found on agronomy aspects

Agronomic aspects	Literature	Experimental	Small-scale production	Industrial production
Germination	√	√		
Transplanting	√		√	
Propagation	√	√	√	√
Production Systems				
Monoculture	√	√		√
Intercropping			√	
Hedges			√	
Solitary trees	√		√	
Response to resources				
Radiation				
Temperature				
Water	√	√		
Nutrients	√	√		
Fertilization				
Mineral	√	√		
Organic	√	√		
Irrigation	√	√		
Plant health measures				
Yields	√	√	√	
Pruning				
Hormones / PGR	√	√		

The agronomy aspects of jatropha production are merely reported for juvenile jatropha plants (seedlings and relatively young production systems of less than 3 years old). Reports on germination, transplanting and propagation are quite complete, but mostly refer to (greenhouse) experiments, and to a lesser extend to small-scale and industrial scale field production sites.

The lack of well described methodologies for the response of *Jatropha curcas* to resources such as radiation, temperature, water and nutrients is striking, but understandable, as the majority of jatropha stakeholders are not equipped and not educated to produce scientifically sound reports on *Jatropha curcas* growth and production. As a result, only some experimental fertilization have been presented so far, and recommendations on fertilization and irrigation strategies are still lacking. Pruning methods (timing, frequency and technique) play a very important role in *Jatropha curcas* flowering capacity, but are not well covered in the experimental and the small-scale and industrial production domains.

Productivity reports most probably refer to fresh seed weights on a per tree basis (g $tree^{-1}$), instead of dry seed weights on a per area unit basis (kg ha^{-1}). Productivity reports lack important information on plant spacing (in-row and between-row distance) and other crucial information, such as the sample size (number of measured trees). The of intercropping and hedge row production systems not well represented, as these production systems will become very important in small-scale jatropha production.

In general, the comparison between different *Jatropha curcas* genotypes is not available.

10.2 Social aspects

Table 10.2 shows which aspects are covered by current literature. The empty spots indicate knowledge gaps. For the social aspects these are on food security comprehensive studies that include all four aspects, for local prosperity no information has been found on local employment for smallholders or the impact on the local economy, furthermore development of skills for plantation workers are unclear.

Table10.2: Data found on social aspects

Social aspects	Literature	Smallholder	Plantation
Food security	√		
Food availability	√	√	
Food access	√	√	√
Food stability			
Food utilization			
Local prosperity	√		
Local usage	√		
Local employment/labour requirements			√
Local economy			√
Skills	√	√	
Attitude	√	√	√
Labour working conditions	√	√	√
Wages and other benefits		√	√
Child labour	√		
Discrimination			
Safety	√		
Freedom of trade union org.			
Education			√
Land rights	√		
land availability	√	√	
Land access	√	√	√
Gender	√		
Employment	√	√	√
Access to energy	√	√	
Land availability	√	√	

10.3 Ecological aspects

Although Table 10.3 indicates available literature on many environmental aspects, the quality, consistency and comparability of data are generally weak. Hardly any reliable information is available on carbon sequestration potential of Jatropha biomass, and on the effects of intensification of cultivation on the carbon balance; and only limited good-quality information is available about the impact of direct and indirect land use change on the carbon balance.

Table 10.3: Data found on ecological aspects

Ecological aspects	Literature	Smallholder	Plantation
LCA	√		
Energy content	√		
Land use change impacts	scarce		
Use of by-products (energy b)	√		
Transesterification	√		√
Transport	√		√
Biodiversity	√		
Previous land use	√		√
Intensity of production			

10.4 Economic and technical aspects

There are also still many gaps in the information about economic issues (Table 10.4). CBAs have been undertaken for smallholders (1 ha plantations, and some intercropping set ups and hedge plantings), and a few from a national (macro) perspective, without making any specific reference to business organisation and sizes of production. However, none have been undertaken for large scale plantations. The majority of CBAs rely on unreliable and often unrealistic yield data that do not match with the findings about observed yields in chapter 4 (1000-2000 kg dry seed ha/y for mature plantings). CBAs often take too short a time horizon (10 years or less) to be able to reliably assess long term average Jatropha viability. There is a general dearth of information outside the Eastern/Southern African and Indian context.

Data on financial viability of plantations are almost completely missing, although there are some data about their set up costs and running costs. There are also no studies that systematically compare the financial feasibility of outgrower schemes and centralised plantations of similar production volume, except our own preliminary estimates given in section 7.5. Data about the cost of SVO and biodiesel production in facilities of different scales are scarce, especially in Africa where commercial oil production is only just beginning.

Table 10.4: Data found on economic aspects

Economic aspects	Literature	Smallholder	Plantation
Cost benefit analysis (IRR, NPV)	√	√	
Average annual costs/benefits	√	√	
Set-up costs and running costs	√	√	
Yield	√	√	
Processing costs (SVO, biodiesel)	scarce		

Table 10.5: Data found on technical aspects

Technical aspects	Literature	Smallholder	Plantation
Use of seedcake as fuel or fert.	√		
Market prospects	√		
Organisational issues	√		
Business models	√	√	√
Policy	√		

Overall, we advise NL Agency to monitor carefully the inputs and outputs from all their Jatropha projects, to improve the data and come to a good and reliable data set. A format for such monitoring needs to be developed.

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ANNEX I: Literature used for agronomy	Study	Propagation						Production System						Crop management												Resource use						Plant traits / Performance											
		1 In vitro propagation	2 Seed selection	3 Germination	4 Direct seeding	5 Transplanting	6 Cuttings	7 Mono-culture	8 Intercropping	9 Agroforestry	10 Hedges	11 Single trees	12 Age in years	13 Plant density	14 Contour ridging	15 Pruning	16 Hormonal treatment	17 Weeding	18 Flowering	19 Irrigation	20 Fertilization (mineral)	21 Fertilization (organic)	22 Plant health care	23 Soil improvement	24 Harvest technique	25 Radiation	26 Temperature	27 Water	28 Nutrients	29 Soils	30 Others	31 Biomass productivity	32 Roots	33 Wood production	34 Fruit production	35 Seed production	36 Oil percentage / production	37 Oil quality / composition	38 Press cake quality / quant.	39 Methane production	40 Energy production	41 Toxicity	42 Others
01	(Abdelgadir et al.																√		√																√	√	√	√					
02	(Achten et al.																																										
03	(Ariza-Montobbio																																										
04	(da Schio 2010)		√	√				√	√																	√			√			√											
05	(Herak et al. 2010)																																				√	√	√				
06	(Jing et al. 2010b)																		√																								
07	(Mazumdar et al.	√																																									
08	(Pompelli et al.																									√						√											
09	(Ruíz-Valdiviezo et																					√		√					√														√
10	(Silva et al. 2010)												0.3																														
11	(Spöttle and			√																																							
12	(Yong et al. 2010)					√		√					0.8								√								√														√
13	(Abdelgadir et al.															√	√																										
14	(Abdelgadir et al.																																										
15	(Abou Kheira and			√				√												√								√						√		√							
16	(Gallo et al. 2009)													√				√					√							√						√							
17	(Gerbens-Leenes et																									√		√				√					√						
18	(GTZ 2009b)							√	√		√																									√							
19	(Gunaseelan 2009)																																							√			
20	(Hoekstra et al.																									√		√				√					√		√				
21	(Jamil et al. 2009)																												√		√	√											
22	(Jing et al. 2010a)							√																		√	√	√		√													
23	(Jongschaap et al.							√	√	√			4.0			√										√			√	√													
24	(Jongschaap et al.							√				√	6.0	√						√								√		√						√	√						

25	(King et al. 2009)		√																																							√	
26	(Lam et al. 2009b)																																										
27	(Lapola et al. 2009)																									√	√	√				√				√							
28	(Maes et al. 2009c)																										√	√															
29	(Maes et al. 2009a)																																			√							
30	(Maes et al. 2009b)												<1														√	√				√											
31	(Makkar et al.																																									√	
32	(Nallathambi							√					1.7	√		√											√	√				√		√	√	√	√		√	√			
33	(Ndong et al.					√		√						√		√		√			√	√	√		√		√	√	√			√		√		√	√		√		√		
34	(Nielsen and de			√	√	√	√	√		√																																	
35	(Ou et al. 2009)																																									√	

		Propagation						Production System						Crop management												Resource use						Plant traits / Performance											
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
	Study	In vitro propagation	Seed selection	Germination	Direct seeding	Transplanting	Cuttings	Mono-culture	Intercropping	Agroforestry	Hedges	Single trees	Age in years	Plant density	Contour ridging	Pruning	Hormonal treatment	Weeding	Flowering	Irrigation	Fertilization (mineral)	Fertilization (organic)	Plant health care	Soil improvement	Harvest technique	Radiation	Temperature	Water	Nutrients	Soils	Others	Biomass productivity	Roots	Wood production	Fruit production	Seed production	Oil percentage / production	Oil quality / composition	Press cake quality / quant.	Methane production	Energy production	Toxicity	Others
036	(Pradhan et																																		√								
037	(Pritchard et al.																																			√							
038	(Rajendra et al.																																					√					
039	(Sharma et al.																																				√						
040	(Sharma et al.																					√																	√				
041	(Sirisomboon																										√										√	√					
042	(Sricharoenchai																																							√	√		
043	(Sunil et al.																		√													√		√	√		√						
044	(Torres												0.50																														
045	(Veny et al.																																					√					

046	**(Yadav et al.**												1.00																√		√	√											
047	**(Ye et al. 2009)**	√		√			√	√		√				√					√							√	√	√					√			√						√	
048	**(Abdelgadir et**												0.25				√		√																								
049	**(Annarao et al.**																																					√					
050	**(Azurdia et al.**																																			√	√	√	√				√
051	**(Chaudhary et**							√					4.00																√	√													√
052	**(Chimbari and**																																									√	
053	**(Debnath and**																																										√
054	**(Dehue and**			√		√	√									√						√	√																				
055	**(Deore and**			√				√																	√																		
056	**(Devappa and**																																									√	
057	**(Diao et al.**																																									√	
058	**(Elefan 2008)**			√									0.17								√	√										√											
059	**(Garg et al.**																																										√
060	**(Georges et al.**																																										√
061	**(Jongschaap**							√	√		√																																
062	**(Juwarkar et**												0.50								√	√							√	√													
063	**(Kathiravan et**			√									0.17																														
064	**(Kochhar et al.**						√						1.00																			√	√		√	√							
065	**(Kumar and**																												√									√	√				
066	**(Kumar et al.**												0.50																	√		√											√
067	**(Kumar et al.**												2.00	√					√															√									√
068	**(Kumar et al.**																																									√	
069	**(Lingfeng**																									√																	
070	**(Lu et al. 2008)**																		√																								

		Propagation						Production System						Crop management								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Study	In vitro propagation	Seed selection	Germination	Direct seeding	Transplanting	Cuttings	Mono-culture	Intercropping	Agroforestry	Hedges	Single trees	Age in years	Plant density	Contour ridging	Pruning	Hormonal treatment	Weeding	Flowering	Irrigation	Fertilization (mineral)	Fertilization (organic)
071	(Makkar 2008)																					
072	(Makkar et al.																					
073	(Mao et al. 2008)												0.25									
074	(Ogunwole et al.													√							√	√
075	(Qin 2008)																					
076	(Qin et al. 2008)																					
077	(Rahuman et al.																					
078	(Rakshit et al.																					
079	(Rao et al. 2008)											√	2.83	√					√			
080	(Ruiling 2008)	√																				
081	(Sunil et al. 2008)		√									√										
082	(Thomas et al.																					
083	(van der Linde							√								√					√	√
084	(van Loo et al.																					
085	(Worang et al.																					
086	(Ajose 2007)																					
087	(Basha and																					
088	(Chandel et al.							√														
089	(Chaudharry et al.							√														
090	(Chikara et al.							√														
091	(Daey Ouwens et					√		√														
092	(de Lourdes Silva					√																
093	(Desai et al. 2007)			√								√	0.12									
094	(Ghosh et al.				√			√						√							√	√

		Crop management			Resource use						Plant traits / Performance											
		22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
	Study	Plant health care	Soil improvement	Harvest technique	Radiation	Temperature	Water	Nutrients	Soils	Others	Biomass productivity	Roots	Wood production	Fruit production	Seed production	Oil percentage / production	Oil quality / composition	Press cake quality / quant.	Methane production	Energy production	Toxicity	Others
071	(Makkar 2008)																				√	
072	(Makkar et al.																				√	
073	(Mao et al. 2008)							√														
074	(Ogunwole et al.		√																			
075	(Qin 2008)																				√	
076	(Qin et al. 2008)																				√	
077	(Rahuman et al.																				√	
078	(Rakshit et al.																				√	
079	(Rao et al. 2008)														√	√						
080	(Ruiling 2008)																					
081	(Sunil et al. 2008)															√						
082	(Thomas et al.																				√	
083	(van der Linde	√												√	√	√					√	
084	(van Loo et al.															√	√					
085	(Worang et al.																					√
086	(Ajose 2007)																					√
087	(Basha and																				√	
088	(Chandel et al.																					
089	(Chaudharry et al.																					
090	(Chikara et al.																					
091	(Daey Ouwens et														√							
092	(de Lourdes Silva								√				√									
093	(Desai et al. 2007)		√								√	√	√									√
094	(Ghosh et al.							√							√		√	√				

095	**(Gush and**							√		√	√	√	4.00	√						√								√		√			√			√	√						
096	**(Jongschaap et al.**	√	√	√	√	√	√	√	√	√	√	√		√		√	√		√	√	√	√		√		√	√	√	√	√		√	√		√	√	√	√	√			√	
097	**(Kaushik et al.**		√				√					√				√	√			√	√	√			√				√							√	√		√		√		
098	**(Sharma and**															√			√																								
099	**(Sharma and**																						√																				
100	**(Sharma and**							√																																			
101	**(Sharma and**																																			√							
102	**(Sharma 2007b)**			√																																							
103	**(Soares Severino**																																√										
104	**(Soares Severino**																																√										
105	**(Wan et al. 2007)**																											√															

Sub ANNEX I: Appendix to Figure 4.2 about Jatropha productivity

Age (year)	Country	Lat N-S	Lon E-W	Altitude (m)	Plant density (trees ha-1)	Row (m)	In-row (m)	Seed / Cutting	ETP	Seed oil content (%)	Seed yield (g tree-1)	Seed yield (kg ha-1)	Reference	
2.50	IND	11.13	78.66	150	833.3	4.0	3.0	S	RF		690	575	Ghosh, A., J.S	x
2.50	IND	11.13	78.66	150	833.3	4.0	3.0	S	RF		780	650	Ghosh, A., J.S	x
2.50	IND	11.13	78.66	150	833.3	4.0	3.0	S	RF		1050	875	Ghosh, A., J.S	x
2.50	IND	11.13	78.66	150	833.3	4.0	3.0	S	RF		1310	1092	Ghosh, A., J.S	x
2.50	IND	11.13	78.66	150	833.3	4.0	3.0	S	RF		1520	1267	Ghosh, A., J.S	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S	RF		450	750	Ghosh, A., J.S	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S	RF		520	867	Ghosh, A., J.S	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S	RF		630	1050	Ghosh, A., J.S	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S	RF		750	1250	Ghosh, A., J.S	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S	RF		870	1450	Ghosh, A., J.S	x
2.00	IND	21.67	71.78	682	10000.0	1.0	1.0	S	RF			0	Chaudharry, I	x
2.00	IND	21.67	71.78	682	5000.0	2.0	1.0	S	RF			0	Chaudharry, I	x
2.00	IND	21.67	71.78	682	4444.4	1.5	1.5	S	RF			0	Chaudharry, I	x
2.00	IND	21.67	71.78	682	2500.0	2.0	2.0	S	RF			0	Chaudharry, I	x
2.00	IND	21.67	71.78	682	1666.7	3.0	2.0	S	RF			0	Chaudharry, I	x
1.67	IND	21.67	71.78	409	4444.4	1.5	1.5	S	RF	35.0%	911	4049	Nallathambi G	x
2.75	EGY	30.24	31.35	26	2500.0	2.0	2.0	S	125%	25.0%	46	115	Abou Kheira,	x
2.75	EGY	30.24	31.35	26	2500.0	2.0	2.0	S	100%	29.9%	78	195	Abou Kheira,	x
2.75	EGY	30.24	31.35	26	2500.0	2.0	2.0	S	75%	29.3%	41	103	Abou Kheira,	x
2.75	EGY	30.24	31.35	26	2500.0	2.0	2.0	S	50%	24.5%	35	88	Abou Kheira,	x
1.08	IND	22.31	75.98	217	1000.0	5.0	2.0	S	RF	33.0%	2350	2350	Sharma, N. a	x
1.08	IND	22.31	75.98	217				C	RF	33.0%	2160	0	Sharma, N. a	x
2.00	MLI	10.96	-7.63	349								550	Wijgerse, I., 2	x
3	IND	11.09	76.88	529								1573	Trabucco, A.,	x
2	INDO	-4.70	105.65	8								1000	Trabucco, A.,	x
2.50	ZAM	14.36	28.46	652								5000	Trabucco, A.,	x
3.00	IND	8.27	77.53	314								2000	Trabucco, A.,	x
2.50	IND	11.38	77.43	263								350	Trabucco, A.,	x
2.00	IND	22.40	71.25	177								1270	Daey Ouwens	x
4.00	NIC	12.59	86.71									2500	Foidl et al. (19	x
2.50	IND	6.89	75.82									313	Achten et al. (	x
2.50	IND	17.49	77.94	615								1000	Gexsi (2008)	x
3.00	IND	28.06	76.87	293								208	NOVOD (200	x
3.00	IND	17.22	78.63	521								911	Rao (2006)	x
5.00	IND	10.87	76.62	423								4000	Gunaseelan (	x
4.00	IND	25.50	82.51	86								2000	Achten et al. (	x
5.00	IND	20.02	73.93	563								1200	Wani (2006)	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	33.1%	226	251	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	34.7%	150	167	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.5%	213	237	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	34.5%	188	209	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	31.7%	145	161	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.5%	264	293	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	34.8%	187	207	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	34.4%	207	230	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	31.8%	100	111	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.1%	71	79	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.7%	153	170	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.1%	58	65	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	35.1%	204	226	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	34.2%	137	153	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	34.5%	232	258	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	36.5%	236	263	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	37.1%	123	137	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	36.0%	214	238	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	30.7%	155	172	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.9%	134	149	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	37.0%	42	46	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	35.5%	73	81	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.7%	45	50	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.9%	94	104	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	35.4%	110	123	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF		131	145	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	35.7%	156	173	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	34.3%	221	245	Rao, G.R., G	x
2.83	IND	17.37	78.47	536	1111.1	3.0	3.0	C	RF	32.3%	37	41	Rao, G.R., G	x
2.00	IND				1600.0	2.5	2.5	S	RF		760	1216	GTZ, 2009. J	x
3.00	TZA	37.34	-3.33	1331	1600.0	2.5	2.5	S	RF		358	573	Messemaker,	x
3.00	TZA	36.67	-3.37	0	1666.7	3.0	2.0	S	ETP		405	675	Messemaker,	x
1.00	TZA				1600.0	2.5	2.5				0	0	Loos, T.K., 20	x
1.00	TZA				1600.0	2.5	2.5				8	13	Loos, T.K., 20	x
3.00	TZA				1600.0	2.5	2.5				224	359	Loos, T.K., 20	x
3.00	TZA				1600.0	2.5	2.5				772	1235	Loos, T.K., 20	x
3.00	CHI	25.04	102.72	1800	#DIV/0!			S	RF			773	Yang, C.-y., X	x
1.50	IND	11.13	78.66	150	10000.0	1.0	1.0	S	RF		32	319	Chikara, J., A	x
1.50	IND	11.13	78.66	150	5000.0	2.0	1.0	S	RF		50	248	Chikara, J., A	x
1.50	IND	11.13	78.66	150	4444.4	1.5	1.5	S	RF		52	233	Chikara, J., A	x
1.50	IND	11.13	78.66	150	2500.0	2.0	2.0	S	RF		82	206	Chikara, J., A	x
1.50	IND	11.13	78.66	150	1666.7	3.0	2.0	S	RF		94	157	Chikara, J., A	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3314	7	12	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3284	10	17	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.2854	3	5	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3173	3	5	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3084	7	12	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3143	4	6	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.295	5	9	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3111	4	7	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3139	4	6	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.2984	3	6	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3132	15	26	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3206	3	5	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.349	15	26	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3409	3	5	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3473	8	14	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3434	3	5	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3227	7.18	12	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.263	2.34	4	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3447	2.47	4	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.2673	3.83	6	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3268	6.4	11	Patolia, J.S.,	x
1.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3256	2.91	5	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3314	146.49	244	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3284	223.56	373	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.2854	139.12	232	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3173	116.7	195	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3084	153.1	255	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3143	189.76	316	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.295	91.55	153	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3111	86.87	145	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3139	130.54	218	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.2984	136.15	227	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3132	134.8	225	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3206	130.98	218	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.349	155.37	259	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3409	119.98	200	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3473	100.28	167	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3434	68.92	115	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3227	110.09	183	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.263	76.01	127	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3447	99.8	166	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.2673	85.61	143	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3268	77.81	130	Patolia, J.S.,	x
2.00	IND	11.13	78.66	150	1666.7	3.0	2.0	S		0.3256	89.04	148	Patolia, J.S.,	x

ANNEX II: Literature used for socio economic aspects

Nature of Publication:
- J = Publication in scientific Journal
- M= Thesis Msc.
- P= Thesis PhD
- R= Report from research institute (FAO, EU, ICRAF etc.)
- N= Report from NGO
- D= Report by Industry (consultants)

Ecologic aspects:
1. GHG, LCA,
2. biodiversity

Other aspects:
1. Market Prospects
2. Business models
3. Policy issues

Social aspects:
1. Food security
2. Local prosperity (rural and social development)
3. Labour/working conditions
4. Land ownership, land rights
5. Gender

	Study	Year	Country		Agronomy	Social aspects							Economic				Technical	smallholder	Large scale	Source	Remarks
						1	2	3	4	5	1	2		1	2	3					
1	(IFAD/FAO 2010)	2010		R						√								√		FAO report (review based on input from consultation + R. henning)	Review of literature, experiences in West, east Africa and India
2	(Schut et al. 2010b)	2010	Mozambique	R			√	√	√			√				√				Funded by dutch ministry of	Lessons from Brazil, sustainability criteria

																agriculture, wageningen university	(FSC, globalGAP, fair trade
3	(Bos et al. 2010)	2010	Mozambique	D			√				√			√		Initiated by minitry of energy of Moz., financed by GTZ-Probec	Fieldreport from smallholder project Nhambita
4	(Schut et al. 2010a)	2010	Mozambique	J			√	√				√		√	√	Literature review, analysis of investment data, 10 field visits, 50 interviews	location of biofuel projects in Moz currently near good infrastructure, high labour availability and access to inputs
5	(Habib-Mintz 2010)	2010	Tanzania	J		√		√		√		√			√	Based on fieldwork in Kisarawe and Bahi, Tz	food security in Tz, 2 examples sunbiofuels + EADB land acquiring process, one was illegal
6	(Moers 2010)	2010	Honduras	N			√						√	√		NGO report	Report on one project in Honduras, Gota Verde, running for 3 years, results and lessons learnt
7	(FAO 2010)	2010	Tanzania	R		√										Based on real country data	Bioenergy and Food Security (BEFS) analysis for Tanzania
8	(Behera et al. 2010)	2010	India	J	√											Field trials	Only agronomic issues
9	(Prueksakorn et al. 2010)	2010	Thailand	J					√							Data from research sites in Thailand	Comparison of 20 yrs jatropha plantation for biodiesel with annual jatropha wood harvesting
10	(Arvidsson et al. 2010)	2010	India, Germany	J					√							Based on literature	LCA jatropha seeds from India, processed in Germany
11	(Gmünder et al. 2010)	2010	India	J			√		√							Based on pilot power plant in India	LCA village electrification in India (SVO)
12	(Wiskerke et al. 2010)	2010	Tanzania	J						√						Based on MSc. Thesis	Rotational woodlots, agroforestry and jatropha oil production, only economic information

13	(Sheng Goh and Teong Lee 2010)	2010	South East Asia	J												√				Opinion	Conclusion: research on economics nesscary to avoid white elephant
14	(Achten et al. 2010b)	2010		J										√				√	√	Opnion, only 2 pages	Global hype to local opportunity, recommendation to use smallholders
15	(Ariza-Montobbio and Lele 2010a)	2010	India	J		√	√	√					√							in-depth interviews, 49 plots in coimbatore and Thiruvannamalai, Tamil Nadu, (45 interviews) but only 14 older than 2.5 yrs and only 1 irrigated yielding plot	yields, economics and social aspects; loss of food and fodder and labour migration
16	(Achten et al. 2010a)	2010		J	√															Literature review	Agronomy only, germplasm etc.
17	(Froger et al. 2010)	2010	Mozambique	D												√				Report from consultants, Jatropha alliance	Sustainability methodology based on RSB to assess jatropha producers (and others), pilot to be executed
18	(van Eijck et al. 2010)	2010	EA	J									√							Submitted, based on literature	East Africa, economic analysis for smallholders
19	(Finco and Doppler 2010)	2010	Brazil	J		√						√						√		Survey in Northern Brazil, 6 month study, 27 jatropha producers	Deforestation and food security
20	(Salfrais 2010)	2010	Mali	M					√	√								√		UU thesis Geosciences, field study in Mali, 6 villages, 66 interviews	Land rights did not change but increased land pressure could cause vulnerable groups to loose, inclusion needed
21	(Hooijkaas 2010)	2010	Tanzania	M							√									UU thesis	review of GHG and social aspects Bioshape
22	(Nygaard 2010)	2010	Mali	J			√			√										Based on secondary	Critical analysis of Multi

												sources, internal reviews and literature, and 6 month fieldstudy in 2002/3	Functional Platform
23	(Trabucco et al. 2010a)	2010		J	√							Based on model and measured yields	Global Mapping, yields Jatropha, max 5 ton/ha/yr
24	(Li et al. 2010)	2010		J								Based on experiments with mice	Toxicity issues
25	(Wahl et al. 2009)	2009	Tanzania	R	√	√		√				Working paper ICRAF (literature+field trips)	Kilimanjaro region, calculations on food security, population, land issues
26	(Estrin 2009)	2009	India	P	√		√	√				PhD Imperial college	large thesis on India, agronomy, GHG and economy, no social issues
27	(Mulugetta 2009)	2009		J				√				Journal of Renewable and Sustainable Energy reviews	Theoretical economic analysis for biodiesel in Ghana, Kenya and Tanznaia
28	(Rossi 2009)	2009	Tanzania	P			√					PhD	Soil Carbon in South East Tanzania
29	(FACT Foundation 2009)	2009		N	√					√			
30	(Janssen 2009)	2009		N						√		Literature review	emissions from biodiesel and SVO, not all jatropha
31	(Mujeyi 2009)	2009/7	Zimbabwe	J		√					√	Field interviews in Zimbabwe 2007 (120hh, 43 jat. growers)	Size of land holding, household wealth and price were determining factors
32	(Nielsen and de Jongh 2009)	2009	Mozambique	N	√	√		√		√	√	Based on field data, 3 years old project	Agronomic, social, technical and economic issues from the project with farmer clubs in Mozambique
33	(Ariza-Montobbio 2009)	2009	India	J		√		√				Paper, Field visits,	Loss of food, decrease in

																			46 farmers, 10 plantations	income, but no proof or data
34	(Ribeiro and Matavel 2009)	2009	Mozambique	N				√	√									√	Field visit, 7 plantations, 27 questionnaires and 50 interviews	3/4 good case studies. Rest is quite negative, most problems mentioned are not related to jatropha
35	(Jatropha Alliance 2009)	2009	Mozambique	D	√	√											√		Review by Jatropha Alliance	Critial review of study above
36	(van Eijck 2009)	2009	Tanzania	D			√	√						√			√		Based on experience	mady by consultant (J. van Eijck), lessons on outgrowers system
37	(Practical Action Consulting 2009)	2009	Cambodia, India, Guatemala, Thailand	D		√	√												DFID, FAO sponsored, PISCES, 15 case studies (4 jatropha), 3 continents	Smalll scale bioenergy initiatives, case studies, only briefly described
38	(Arndt et al. 2009)	2009	Mozambique	J			√										√	√	literature, model contains 56 activities+ 3 types of labour, un-, semi-, skilled	Jatropha+sugarcane, using dynamic computable general equilibrium model, positive impact, outgrowers preferable
39	(Bijman et al. 2009)	2009	Mozambique	R										√			√		conference paper	Strengths and weakness of centralized, nucleaus estate and multipartite model
40	(Peters 2009)	2009	Mozambique	M		√	√	√		√								√	Field work in Mozambique, household survey (84) in 3 villages, Bilene Macia district	Plantation lead to increased income, increased expenditures, decreased leisure time and food production
41	(GTZ 2009a)	2009	Kenya	N	√		√	√				√	√			√	√		based on interviews with 289 jatropha farmers, 2009	Commisioned by GTZ; Endelevu energy, World agroforestry centry + Kenya forestry research institute, Jatropha,

																		Castor and Croton
42	(Puente-Rodríguez 2009)	2009	Honduras	J		√	√								√		8 month fieldwork, literature, interviews (60) and observations	Gota Verde project and WUR project compared, lessons by a certain framework, much on genebiologics (D1 vs PRI)
43	(Bindraban et al. 2009)	2009		J						√						√	Opinion article	large scale biofuel production not sustainable, some GHG data compiled
44	(Moraa et al. 2009)	2009	Kenya	R							√				√		Paper, conference proceeding, based on 3 month-fieldwork in 2009, shimba hills jatropha growers	CBA of Kwale district in Kenya (Shimba Hills)
45	(Martin et al. 2009)	2009	Tanzania	J									√				Based on literature review and interviews with key stakeholders, incl 3 week fieldtrip	
46	(Ndong et al. 2009a)	2009	Ivory Coast	J						√			√				Based on field data from a Mali research station, combined with observations of jatropha smallholders in Ivory coast	Overview of current (2008) biofuel developments in Tanzania
47	(Burley and Griffiths 2009)	2009	Swaziland	N								√					Based on anecdotal information and literature	concerns about impact of jatropha and claims that D1 in Swaziland makes
48	(Salé and Dewes 2009)	2009	India	J									√				Based on internet and research reports, 4 projects are analysed	SNM applied on Jatropha projects in India
49	(Mwamila et al. 2009)	2009	Tanzania	R		√		√										Feasibility of large-scale bio-fuel production in Tanzania
50	(ENERGIA 2009)	2009		N					√		√						case studies, Jatropha: Cambodia,	ENERGIA, international network on Gender and

																	Ghana, India, Nepal, Sri Lanka, Uganda, Zimbabwe	Sustainable energy
51	(Altenburg et al. 2009)	2009	India	R						√			√					Biofuel chain in India
52	(Ewing and Msangi 2009)	2009		J		√	√											tradeoffs in welfare and food security
53	(Mota 2009)	2009	Mozambique	M				√									4 month field work, 2 villages adjacent to plantation Energem	characterize and identify changes in smallholder farming systems
54	(van Baren 2009)	2009		M								√			√			Linking smallholders to bioenergy chains, governance structures
55	(Vlimmeren and Roks 2009)	2009	Tanzania	M								√					not MSc. but part of project	Stakeholder analysis
56	(Struijs 2008)	2008	Tanzania	R					√	√					√	√	Field trip and calculations from literature	GHG calculations, some costs as well (fertiliser)
57	(Dehue and Hettinga 2008b)	2008	India	D					√								Ecofys, Based on(and commisioned by) D1 plantations in North East India	Also recommendations to improve the GHG performance
58	(Prueksakorn and Gheewala 2008)	2008	Thailand	J					√								data from 14 research sites and 10 practical sites in Thailand in 2006/7	detailed LCA , no social issues
59	(Whitaker and Heath 2008)	2008	India, Thailand	R					√								National Renewable Energy Laboratory, data from 14 research sites and 10 practical sites in Thailand	detailed LCA calculations, enhancement of prueksakorn, Reinhardt
60	(van Eijck and Romijn 2008)	2008	Tanzania	J										√			Based on MSc., interviews	SNM method, regime influences
61	(Ogunwole et al. 2008b)	2008	India	J	√												Based on field trials on degraded soils in West India	Soil quality improvement by planting jatropha
62	(Econergy International	2008	Mozambique	D						√	√		√	√			Consultancy firm,	Not very specific

	Corporation 2008)														Based on literature sources	information on jatropha, mainly costs and yields. Good transport info for mozambique
63	(GEXI 2008)	2008		D												Global study on jatropha projects
64	(Muok and Källbäck 2008)	2008	Kenya	R					√	√		√				jatropha in kenya, recommendations
65	(Reinhardt et al. 2008)	2008		R									√			basic data
66	(Croezen 2008)	2008	Tanzania	D					√						Made by CE Delft, consultancy	
67	(Achten et al. 2008)	2008		J	√				√				√		Literature review	Agronomy and oil production and use
68	(Daniel 2008)	2008	India	N	√										Paper (unclear if published), based on research and literature + interaction	Claims and Facts, brings hype down, only usefull yield data, no other facts. From electronic source BAIF, development foundation referred to in Ariza-Montobbio 2010
69	(GRAIN 2008)	2008	India	N				√			√	√			Published in Quarterly Magazine of NGO	Referred to in Ariza-Montobbio
70	(Gordon-Maclean et al. 2008)	2008	Tanzania	N		√		√				√			WWF 2008/2009, 1.5 months study, interviews with key stakeholders from all levels, case studies on companies	all active biofuel companies in Tanzania compared, large part on biodiversity Bioshape, EIA
71	(ProForestLtd. 2008)	2008	all	N	√		√	√						√	Based on literature review and questionnaire survey of experts	risks+ potential impacts, good list according to RTFO
72	(Rajagopal 2008)	2008	India	J			√					√			Based on literature (FAO and others)	Comparison of jatropha with other short-duration crops, recom. sweet sorghum

73	(Amigun et al. 2008)	2008	all	J						√				Data from various technical sources	Cost of biodiesel production in Africa, based on EU costs
74	(Laltaika 2008)	2008	Tanzania	R			√	√						Conference paper	Jatropha in Masaai land, cultural aspects, only opinion
75	(Loos 2008)	2008	Tanzania	M	√		√	√		√			√	Household surveys (248)with Jatropha farmers from Prokon in Tanzania	Socio-economic impact of jatropha smallholder
76	(Mitchell 2008)	2008	Tanzania	M		√	√	√						Msc, fieldwork in Tanzania	food security and socio-economic development, Diligent farmers
77	(Messemaker 2008)	2008	Tanzania	M						√				Msc, fieldwork in Tanzania, UU report	
78	(Mndeme 2008)	2008	Tanzania	M										fieldwork in Same district	
79	(Kerkhof 2008)	2008		M								√			
80	(Wijgerse 2008)	2008	Mali	M			√								
81	(Achten et al. 2007)	2007		J					√					Literature	Very general data, outdated
82	(Tomomatsu and Swallow 2007)	2007	Kenya	R						√	√			Working paper ICRAF (MSc student+coordinator)	Based on fieldtrips, interviews. Good economic analysis, no field data for social issues
83	(Reinhardt et al. 2007)	2007	India	R					√					Ifeu database, field and laboratory measurements, interviews	GHG calculations, different chains
84	(Weyerhaeuser et al. 2007)	2007	China	R				√						Paper World Agroforestry Center, literature	South West China, challenges, potential issues and some data on China
85	(Peters and Thielmann 2007)	2007		R						√				Based on data from Tanzania and India	costs of biofuel taxation for developing countries
86	(Kempf 2007)	2007	Tanzania	N							√				

87	(de Jager 2007)	2007		P		√									
88	(Wijgerse 2007)	2007	Tanzania	M		√								not MSc. but part of project	
89	(UN 2007)	2007		R										UN	Small scale production in SSA
90	(Tigere et al. 2006)	2006	Zimbabwe	J	√	√							√	Field interviews in Zimbabwe (60 jatropha growers), same region as Mujeyi	Farming practises, weeding 50%, hand hoes, content of seedcake
91	(Vanparys 2006)	2006	Tanzania	M				√						MSc., quality unknown	Soil Carbon in South East Tanzania
92	(Wani et al. 2006)	2006	India	J	√	√						√		review journal article	some lessons on agronomy and example of carbon credits for women group, unclear impact analysis
93	(Asselbergs et al. 2006)	2006	Cambodia	R										Universiteit van Amsterdam	
94	(Benge 2006)	2006		N		√						√		Literature	USAID senior officer, nice overview, no new facts. Comments from the field by email
95	(Francis et al. 2005)	2005	India	J					√	√				Based on literature	Overview of expenses and potential, no facts or new figures
96	(Spaan et al. 2004)	2004	Burkina Faso, Mali	J	√		√							based on literature, jatropha in Mali (fences)	Contour vegetation, labour days for jatropha and other crops
97	(Brew-Hammond and Crole-Rees 2004)	2004	Mali	R		√					√		√	UNDP	Review of MFP
98	(Wiesenhütter 2003)	2003	Cape Verde	N					√	√				GTZ	
99	(Openshaw 2000)	2000		J					√						One of the first reviews of Jatropha

	Not specifically for Jatropha:			
100	(Cotula et al. 2009)	2009	SSA	
101	(Sulle and Nelson 2009a)	2009	SSA	Tanzania
102	(Sulle and Nelson 2009b)	2009	SSA	Tanzania
103	(Tittonell et al. 2010)	2010	SSA	
104	(Nhantumbo and Salomão 2010)	2010	SSA	Mozambique
105	(Cotula and Vermeulen 2009)	2009	SSA	
106	(Vermeulen and Cotula 2010)	2010		
107	(FAO 2008a) (Rossi and Lambrou)	2008	all	
	only technical			
108	(Vyas and Singh 2007)	2007		
109	(Manurung et al. 2009)	2009		
110	(Makkar et al. 2008a)	2008		
111	(Martínez-Herrera et al. 2006)	2006		
112	(Lestari et al. 2010)	2010		
113	(Beerens 2007)	2007		
	only GHG / LCA			
114	(Basili and Fontini 2009)	2009		
115	(Caniëls and Romijn 2009)	2009		
116	(Global Bioenergy Partnership GBEP 2009)	2009		
117	(Gnansounou et al. 2009)	2009		
118	(Nallathambi Gunaseelan 2009)	2009		
119	(Hossain and Davies 2010)	2010		
120	(Kirkinen 2010)	2010		
121	(Ou et al. 2009)	2009	A	China
122	(Sampattagul et al. 2007)	2007	A	Thailand
123	(Veen and Carrilo 2009)	2009	LA	Peru
124	(Romijn 2010)	2010	SSA	Tanzania
125	(Kirkinen et al. 2009)	2009		
126	(Almeida 2009)	2009		
127	(Lam et al. 2009a)	2009	A	Malaysia

ANNEX III: Appendix to sub-section 7.5

List of assumptions underlying the profitability estimations.

General assumptions

The horizon of the CBA is 20 years

The plants are mature from year 5 and will then produce on average a constant amount of seeds

The exchange rate: 1 Euro = 1,3206 Dollar (On 5 August 2010)

Tax of 45,2% is paid when profits are made

After 20 years 80.000 ha is in use

Ratio Jatropha oil and press cake: 3,8 ton Jatropha seeds = 1,0 ton Jatropha oil + 2,8 ton press cake

There are revenues from carbon credits

The discount factor (real interest rate) is 6,5%

Smallholders (Outgrowers) assumptions

The low input system includes only weeding (no fertilization, no pesticides, no pruning, no irrigation)

The intermediate input system includes weeding, fertilization, pesticides and pruning (no irrigation)

Labour costs are $2 per day

Yields using the low input system will be 1102 kg / ha / year when the plants are mature (from year 5)

Yields using the intermediate input system will be 1981 kg / ha / year when the plants are mature (from year 5)

Weeding is only needed up to year 3

The farmer pays the bags of $0,45 per bag for the packaging of the Jatropha

A person can harvest on average 40 kg per day

The sales price of the seeds for the farmers is $0,14 per kg

When the plants are mature, less pesticides are needed (in intermediate input system)

When the plants are mature, pruning is only needed once per 5 years

Post Harvesting Activities (PHA) labour costs are 10% of the labour costs of harvesting

When only family labour is used, labour costs can be set to zero

Outgrower Model assumptions

Promotion expenses decrease over time, because land extension decreases too

Collection costs are $59,43 per ton seeds

Processing costs are $36,98 per ton seeds

SVO storage and transport costs are $3,68 per ton seeds

General costs increase with 1% per year

Working capital increases will decrease over time and will be zero after eight years

All seeds which are collected from the farmers can be processed (no capacity restrictions)

The selling price of press cake is $66,03 per ton

New Jatropha plants are planted up to year 18

Plantation Model assumptions

One field officer per 500 ha is needed to establish new plantations

One field officer per 800 ha is needed to monitor/support existing plantations, not yet productive

One field officer per 1000 ha is needed to monitor/support existing plantations, productive

Payments to loan guarantee fund are made

Labour costs for harvesting Jatropha are $0,09 per kg (included all relevant costs)

Storage/collection materials (reusable waterproof big bags) are $6,60 per ton seeds

Truck capacity for seeds transport is 7 ton seeds per truck on average

Average driving time per truckload (incl. return) is 6 hours (e.g. 40 km dirt roads; 80 km tarmac - vice versa)

There are 120 collection days per year, in which the harvested seeds are collected from the field

The seed transport capacity per truck per year is 1680 ton

The transport costs per truck (fuel, maintenance, insurance) is $13,21 per hour

The collection staff per truck includes 2 staff members, plus one coordinator per 10 teams

The average costs per truck collection team are $990,45 per month, including bonuses, expenses and overhead

The extraction costs are $33,02 per ton seeds (electricity, maintenance and insurance)

The briquetting costs are $33,02 per ton press cake (electricity, maintenance and insurance)

General costs increase over time

Working capital increases will decrease over time and will be zero after nine years

The costs of transesterification are $0,28 per litre

The diesel selling price is set to $1,75 per liter

The selling price of press cake is assumed to be $66,03 per ton

The SVO/diesel rate can be randomly changed

New Jatropha plants are planted up to year 11

A low input system is assumed (1102 kg / ha / year when the plants are mature)

ANNEX IV: Literature used for technical aspects

		Production / Usage								byproducts							Remarks
No											Seed cake						
		Unprocessed seed/oil	Pre oil extraction equipment	Chemical extraction	Mechanical extraction	Processing Byproducts	Usage of oil	Usage of by products	Engine performance	Seed husks	Fertiliser	Charcoal	Biogas	Briquettes	Animal feed/toxicity	Other	
1	(Vyas and Singh 2007)									√							Jatropha seed husk can be used as feedstock for open core gasifier Seed husk -> gas
2	(Manurung et al. 2009)									√							Seed husk -> pyrolysis oil Oil yield: 50 wt%, char+gasses
3	(Sricharoenchaikul and Atong 2009)															√	Seedcake to oil, pyrolysis
4	(Makkar et al. 2008a)														√		Still some toxic elements
5	(Martínez-Herrera et al. 2006)														√		4 provenances, different treatments, reduction of: Trypsin inhibitors, Phytate levels, saponin contents, lectin activity and phorbol esters
6	(Lestari et al. 2010)															√	Extract highest rate of protein for potential non-food applications

7	(Narayana Reddy and Ramesh 2006)							√									Performance in compression ignition engine
8	(Pradhan et al. 2010)		√														Manual decorticator
9	(Oliver-Bever 1982)	√															Purgative action of the oil, reduces prothrombin time and coagulation time. Seed as insecticide. Fruits + seeds contraceptive. Action against lymphocytic leukemia,
10	(Lim et al. 2010)			√													New form with methanol, only 80 min time required
11	(Kratzeisen and Müller 2010)						√										Prediction model for deposits from Jatropha oil in cooking stove
12	(Qian et al. 2010)			√													Two phase solvent extraction
13	(FACT Foundation 2009)														√		detoxifying
14	(Rakshit et al. 2008)			√													For the production of biodiesel alkali catalysis (KOH) are commonly used. It is however also possible to use enzymatic transesterification. This has several advantages over alkali catalysis, namely reducing process operations in biodiesel fuel production and an easy separation of the glycerol byproduct. Until now the price of the lipase enzyme is the main obstacle for a commercially feasible enzymatic production of biodiesel fuels
15	(Fukuda et al. 2008)			√													Enzymatic transesterification
16	(Balat and Balat 2010)			√													Dilution, micro-emulsification, pyrolysis, and transesterification


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