Potential of Sustainable Jatropha Oil Production in Tanzania. An Economic Land Evaluation Assessment

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Introduction

Energy crops for biofuel production have received a lot of attention in recent years. So far, production has been limited to a few countries and regions only (the USA, Brazil and Europe alone account for over ninety percent of the global supply, IEA, 2010). However, as land resources dwindle, other countries are projected to increase their share of production and trade as well. One of the East-African countries that have attracted many investors' interest is Tanzania. As a politically stable economy with a long tradition of commodity exports, both national and international stakeholders have started promoting and taking up biofuel activities. The expectations are high; ninety percent of the rural households still depend on traditional biomass sources such as firewood and charcoal. A better access to modern biofuel applications could therefore reduce deforestation and health problems related to e.g. indoor air pollution. Further, domestic production is a way to cut expenditures on expensive oil imports, which are currently growing at double digit rates. Finally, increased domestic and foreign demand for agricultural products could offer a possibility to boost rural development and growth (Martin et al., 2009).

On the flip-side, pressure groups from both the civil society and the scientific community have questioned the sustainability of the biofuel production (see e.g. Sulle & Nelson 2009; WWF, 2008; Habib-Mintz, 2010). Major concerns regard possible negative impacts on water, soil and biodiversity as well as food security and land rights. The importance of sustainability has also been recognized on a global level, what have led to the development of various certification schemes. For example, the European Union (EU) has introduced environmental criteria tied to its obligatory blending targets. Further biofuel certification initiatives include for instance the more far-reaching *International Sustainability and Carbon Certification* (ISCC), which is already operational and has been approved to satisfy the EU criteria as well. These systems may, on the one hand, go hand in hand with the Tanzanian aspiration to a sustainable biofuel development. On the other hand, more environmentally and socially sound production systems may also impose higher costs.

This paper aims at assessing the potential and impact of Tanzanian energy crop production, first with regard to national consumption and second considering exports on the basis of the European biofuel standard. We choose to concentrate our research on oil from the perennial shrub *Jatropha curcas L* (in the following "Jatropha"), as it represents the most common feedstock among investors (Maltsoglou & Khwaja, 2010). Especially in the beginning it was promoted as a non-edible feedstock with a relatively low negative impact on the environment. Following this line of argument, the adaptation to comply with sustainability criteria should be relatively straightforward. The paper is divided into 5 sections; the first section presents a short review of previous literature followed by an outline of the method in Section 2. Section 3 goes into the data collection and assumptions on the farming system. In Section 4, results on the economic, environmental and social sustainability of conventional and certified production are discussed. Finally, Section 5 provides a conclusion and an outlook for further research.

1. Literature

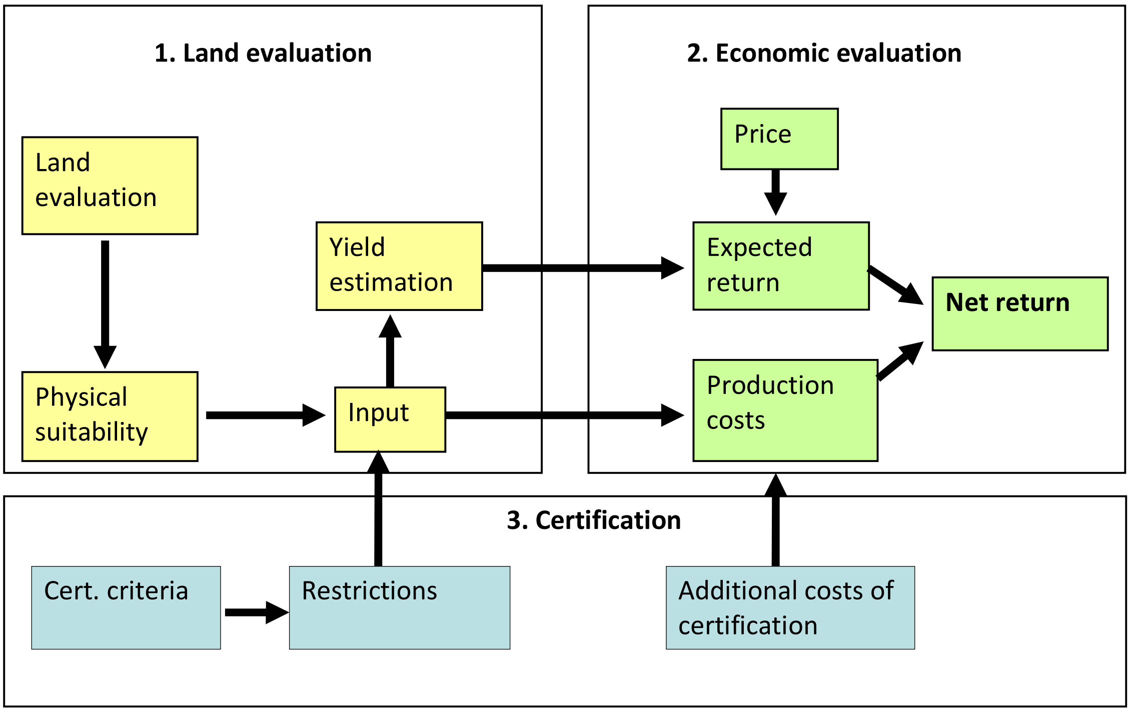
A couple of studies have intended to quantify the economic impacts of biofuel certification in the past. Focus was on identifying major cost factors when improving the sugarcane ethanol value chain in Brazil (Smeets et al. 2008) and the short rotation wood value chain in Ukraine and Brazil (Smeets et al. 2005). Former found that the introduction of certification criteria may raise costs by 37 percent. Yet, since Brazilian sugarcane belongs to the most cost-competitive feedstocks in the world they argued that the increase would not be unbearable (Smeets et al. 2008). For the short rotation crop analysis, Smeets et al. (2005) estimated that certification may incur a cost increase of 35-88 percent in Brazil and 10-26 percent in Ukraine. Also in this study the authors predicted that the biofuels in question would be able to compete with the fossil equivalent both with and without certification, as long as the transport costs could be held down. A crucial factor however was good land suitability.

Considering Tanzania and Jatropha, some surveys have looked into the financial returns of small- and large-scale systems (cp. Wiskerke et al., 2010; Wahl et al., 2009; Mulugetta, 2009; Maltsoglou and Khwaja, 2010). Key factors of profitability were identified as low labor costs, low revenues of alternative crops and high diesel and vegetable oil prices. Yet, while these studies provided an insight in the cost-efficiency of Jatropha, none of them made a direct link between the economic dimension, sustainability and certification. Similarly, there are publications assessing various sustainability issues without incorporating economic costs and benefits (see e.g. Ndong et al., 2009; Hoefnagels et al., 2010).

2. Method

In order to fill this gap of research and establish a connection between agronomic data and economic data, we conduct our analysis in three steps. First, we estimate the physical suitability of the study site by means of a land evaluation approach. On the basis of this, we derive the necessary inputs to obtain certain levels of yields. Second, we look at the optimal input-output level with regard to economic costs and benefits. Finally, we introduce certification criteria to see where input restrictions may appear. In terms of costs and benefits of certification, we therefore have to include both compliance costs related to changes in the production system and direct certification fees (see Figure 1).

Figure 1 Methodology



In total, three scenarios are considered; (1) Jatropha oil production for own consumption as complement to other farming activities; (2) Jatropha oil for export to countries without mandatory certification; and (3), Jatropha oil for export to the EU when taking the criteria of the ISCC into account.

2.1 Physical land evaluation, fertilization and yield assessment

The physical land evaluation is conducted using the "FAO Framework for Land Evaluation" and the "Booker Tropical Soil Manual". Both approaches are widely used in Tanzania and represent international standard methods. In the course of the land evaluation process, physical parameters influencing soil fertility and yield potential for a specific crop are identified and rated allowing a quantitative appraisal and suitability assessment. Important parameters in this context are soil texture, cation exchange capacity, base saturation, soil pH and soil organic matter content. A comprehensive methodological overview of the rating process of these parameters is given in chapter 7 of the Booker Tropical Soil Manual (Landon, 1991). In a second step the rated parameters are transformed into the FAO land evaluation classification system (see chapter 4, FAO, 1976).

Next to the land evaluation, the FAO simulation software "AquaCrop" is used to determine the influence of the prevailing climate on crop yield potential and thus the ecologic and/or economic feasibility of production (FAO, 2010). Applying the FAO-Penman-Monteith approach, we include standard meteorological parameters (minimum temperature, maximum temperature, wind speed, relative humidity or dew point and solar radiation) to calculate the reference evapotranspiration (ETo) of the crop. Further, to determine the potential evapotranspiration of Jatropha we multiply the ETo with a crop specific factor (Kc value). As this value also depends on crop variety and planting site, this factor is found through field trials. When the ETo is multiplied with the Kc value the result is denoted as the crop evapotranspiration (ETc).

To be able to calculate the actual evapotranspiration, we use data on water availability and water storage capacity of the soil (see also chapter 8, Allen et al., 1998). The crop yield in turn can be assessed using different approaches. Here, we apply a rather simple yield-moisture stress relationship. In line with Doorenbos and Kassam (1979) we apply an empirical and robust linear crop-water production function to predict the reduction in crop yield when crop stress was caused by a shortage of soil water:

$$1-\frac{Ya}{Ym}=K_y\left(1-\frac{ET_c actual}{ET_c potential}\right) \quad (1)$$

where: Ya = actual crop yield; Ym = maximum expected crop yield; Ky = a dimensionless yield response factor; ET_c actual = actual crop evapotranspiration (mm d^{-1}); and ET_c potential = crop evapotranspiration for standard conditions (mm d^{-1}).

Jatropha has been in the focus of agricultural research for a while. Nevertheless only little is known about the interdependency between plant, climatic conditions, farming input level and yield. In this study the research results achieved by the Delft University and the

Council for Scientific and Industrial Reseach South Africa (CSIR) are used (Blesgraaf, 2009).

Moreover, also the appraisal of nutrient demand is crucial not only for economic but also ecologic performance of Jatropha. In this study we assess the nutrient demand relative to the crop's withdrawal of macro-nutrients nitrogen, phosphorus and potassium as well as the nitrogen production function. The calculations are based on results of field trials in India (Kalannavar et al., 2009, Patolia et al., 2008) as well as observations at the site.

2.2 Economic land evaluation

The economic costs and benefits of Jatropha oil production are discounted according to the net present value (NPV) approach:

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} \qquad (2)$$

with NPV = net present value, B_t = benefits in year t, C_t = cost in year t, r = real discount rate, and n = life time of project. To obtain the real discount rate, we divide the nominal lending rate i with the inflation rate π:

$$r + 1 = \frac{1+i}{1+\pi} \qquad (3)$$

Cost items included in the analysis cover the cultivation and processing stage as well as transport to the harbor and export fees. As we base our calculations on a currently inoperative sisal farm, which took up Jatropha production recently, investments in buildings and infrastructure are excluded from the analysis.

3. Data collection and farming system

Data for the farming system were collected from secondary literature and from one plantation in Kilosa, a district of the Morogoro region in the South-East of Tanzania, approximately 300 km from Dar es Salaam (5° 49' 60 S and 37° 46' 60 E). Soil and weather data for the physical land evaluation as well as the yield assessment under rainfed and irrigated conditions were provided by the project “ReACCT”, a partner project working on climate change in the Morogoro area. Below we provide a short description of the farming system and assumptions. For a complete list of parameters and references, see Annex 2.

Cultivation of Jatropha started in 2007 and takes place on 1 hectare for test purposes so far. However, there are plans to increase the planted area within the next 2-3 years. As stated by Brittaine & Lutaladio (2010), Jatropha trees may become up to 30-50 years old. Nevertheless they emphasize that there is little data to confirm this. In order to account for changes in environment and technology, we here consider a productive lifespan of 25 years.

The trees grow with a density of 2x2 meters (2,500 shrubs per hectare). Seedlings from the hybrid clone variety *Vasudha* were imported from India and developed in a nursery through tissue culture. For future expansion, seeds will be propagated directly on the farm. To clear the land, hand hoes were used. Other field preparations (digging pits, planting, pre-irrigation etc) were conducted manually as well.

Manure and single super phosphate[1] were applied in the first year (0.5 and 2 kg/plant respectively), while NPK (15:15:15) is applied annually depending on the nitrogen withdrawal. Yields are still too low for oil production to be profitable. Once oil production starts, we assume that the seedcake is used as fertilizer partially substituting the NPK applications. Some of the diseases and insects prevailing at the location are e.g. the twig borer beetle, fusarium wilt and powdery mildew (Kusolwa et al., 2008). To control this, pesticides (Thionex) are applied three times a year.

The rainy season in this part of Morogoro is bimodal with shorter rains beginning in September/October until December, and the longer rainy season going from March

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[1] SSP is a straight phosphatic multi-nutrient fertilizer which contains 16% water soluble P2O5, 12% sulphur, 21% calcium and some other essential micro nutrients in small proportions.

through May. In total, rainfall is estimated to about 1043mm per year but with high fluctuations depending on the year and month (WorldClimate, 2010). Irrigation is applied once a week using buckets in the dryer months between June and October.

Harvest takes place from January through September. In the second and third years, fruit yields amounted to 441 and 291 kg/ha respectively. The shortfall in the third year can be traced back to the pruning that took place in this period, a higher pest infestation and less rain. In the first quarter of the fourth year, 2000 kg/ha were obtained. Usually in the fifth year after transplanting the yield becomes steady. The results of the physical land evaluation and the AquaCrop model were used to assess the actual yield under rainfed and irrigated conditions in this period.

Processing

Seeds are dried inside. At the moment, they are peeled manually at a rate of 19 kg per person day. To improve the efficiency, we also account for the use of a so called universal nut sheller, which is easy to produce and has been shown to be useful for peeling Jatropha seeds (Heger, 2009). Producers can choose between a cheaper manual ram-press or a mechanical screw-press. It is not recommended storing the seeds for more than 24 months (Mkony, 2010), hence we assume that the yields from the second year are sold on the local market at a price of TZS 200[2]. For the remaining years the seeds are used to produce oil. The cultivation and processing plan is outlined in Table 1.

Experiments have shown that it is possible to blend conventional diesel with up to fifty percent Jatropha oil. For higher blends or straight Jatropha oil, the engine has to be adapted due to the higher viscosity (Eijck van, 2006). It is also possible to convert the straight vegetable oil into biodiesel by a process called transesterfication. Here we assume that the Jatropha oil is used as blend domestically. Since Jatropha oil trade is negligible in Tanzania, we set the price equal to its opportunity costs, i.e. the local diesel price.

[2] Current price at the local market, (Loos, 2009)

Table 1 Cultivation and processing plan

Year	1	2	3	4	5	6	7	8	9	10 and onwards
Raising seedlings	x									
Land preparation	x									
Planting	x									
Fertilizer application	x	x	x	x	x	x	x	x	x	x
Pesticide application		x	x	x	x	x	x	x	x	x
Weeding	x	x	x							
Irrigation	x	x	x	x	x	x	x	x	x	x
Pruning		x								
Sanitation and re-sanitation		x								
Harvesting of pods		x	x	x	x	x	x	x	x	x
Decortication of pods		x	x	x	x	x	x	x	x	x
Seeds sale		x								
Oil extraction					x	x	x	x	x	x

Export and certification

For the export option we assume that the oil is sold to export companies and that the biodiesel production process (if applicable) takes place in the import country. Related costs include transport costs to the harbor in Dar es Salaam and governmental export fees. In lack of data for Jatropha, we base our calculations on data for cashew exports, where farmers pay taxes in the range of TZS 140 per kg (Ministry of Agriculture, Food Security and Cooperatives, 2008). Certification adds to the cost first in terms of compliance costs with sustainability criteria and second as fees and inspection costs for the certification itself.

4. Results

4.1 Land Suitability and yields

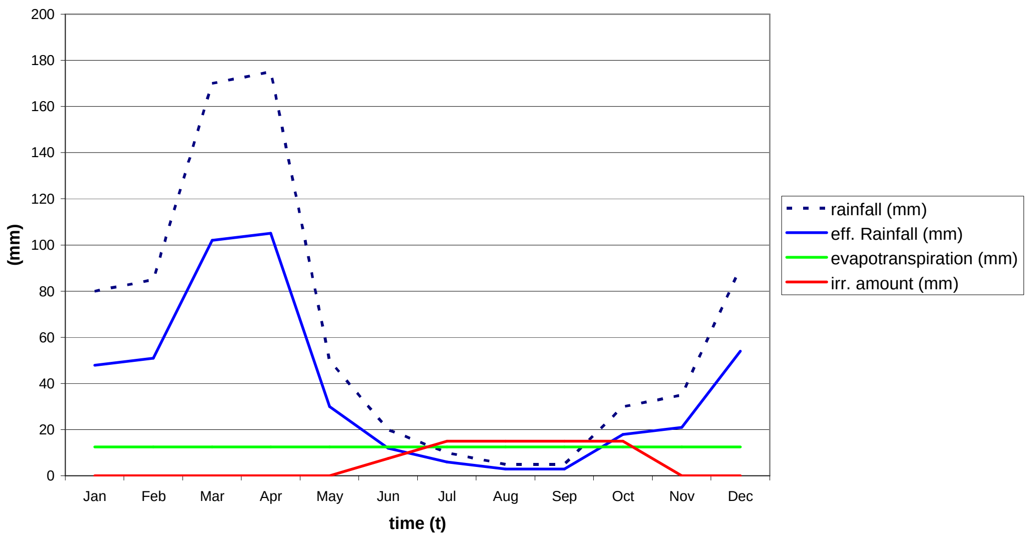
As can be seen in table 2, the results of the land suitability evaluation indicate an overall good potential for the production of Jatropha. The prevailing soils belonging to the fluvisols generally have a high agricultural potential and all key indicators range between highly suitable (S1) and moderately suitable (S2). Consequently there are no constraints for fertilizer and/or irrigation applications even in high input systems.

Table 2 Land suitability classification for a fluvisol at the study site following the FAO framework for land evaluation (FAO, 1976) with S1=highly suitable, S2=moderately suitable, S3=marginally suitable, N1=currently not suitable, and N2=permanently not suitable.

	Land suitability
Soil texture	S2
pH	S1
Soil organic matter	S1
Available soil phosphate	S2
Cation exchange capacity	S1
Base saturation	S1
Slope	S1
Temperature	S1
Rain	S2
Length of growth period	S2
Overall rating	**S1/S2**

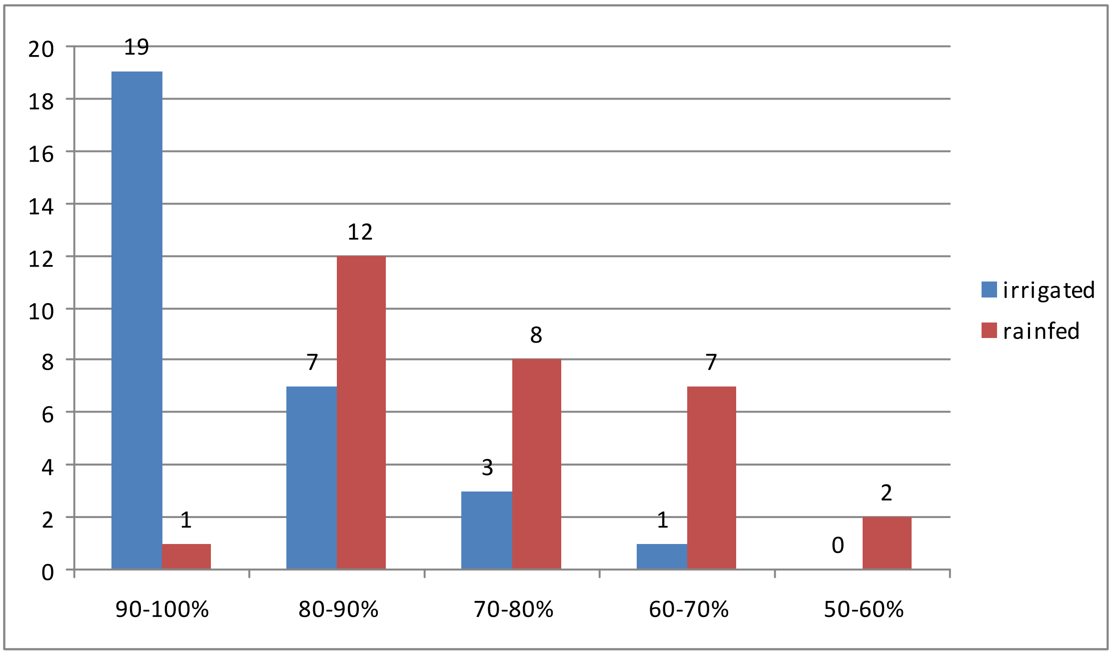
Figure 2 shows the averages of rainfall distribution, effective rainfall (describing the portion of rainfall infiltrating into the plants rooting zone), evapotranspiration of a full grown Jatropha plant and the irrigation amount supplied by the farmer. The figures indicate a sufficient supply of rain water between January (when the first seeds are harvested) and May. By contrast, on average the effective rain water amount falls below the line of the evapotranspiration from June to mid-October. This coincides with the time where irrigation is applied. The last seeds are harvested by the end of October.

Figure 2 Jatropha water balance for Morogoro region including applied irrigation



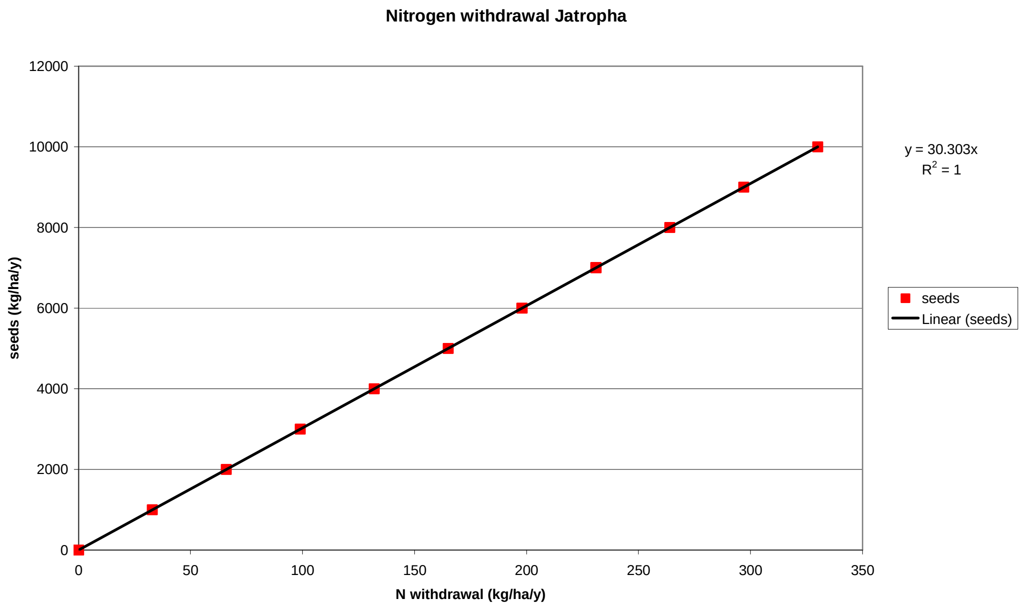
For a more accurate assessment of the influence of irrigation, a more detailed analysis of rainfall distribution and irrigation effects on yield formation was necessary. Based on the findings of Blesgraaf (2009), the AquaCrop model was parameterized to calculate daily actual and potential evapotranspiration for a time period of 30 years (1971 – 2000). The potential and actual evapotranspiration as well as the yield losses due to plant water stress for cultivation with and without irrigation was calculated in two steps. Figure 3 shows a histogram of the distribution of annual yield losses due to plant water stress over a 30 year period. For 26 years the yield level reaches at least 80 percent of the maximum when irrigation is applied. For the rainfed scenario this yield level can only be obtained in 13 years. The average yield loss due to insufficient water supply is 10 percent for the irrigated scenario and 25 percent for the rainfed scenario. Further investigation with more detailed knowledge on Jatropha's response to water stress is needed in order to assess the impact of water saving cultivation techniques such as deficit irrigation. These techniques may improve yield stability and the efficiency of the used inputs.

Figure 3 Distribution of yield level between 1971 and 2000 for irrigated and rainfed scenario



Besides water, fertilizers are important inputs for a high yielding Jatropha cultivation system. Figure 4 shows the nitrogen withdrawal of full grown Jatropha plants based on the field trials of Kalannavar et al. (2009). According to his findings 30 kg of seeds withdraw 1 kg of nitrogen from the soil. The experimental farm in consideration aims at a maximum yield of 5000 kg ha^{-1} y^{-1}. Consequently the plants take up nearly 170 kg ha^{-1} y^{-1} nitrogen from the soil. Accounting for the very high amount of fertilization demand in combination with the tropical soils and the acidifying effect of the mineral nitrogen fertilizers commonly used in Tanzania, it is obvious, that a sustainable Jatropha cultivation is only feasible on soils belonging to the suitability classes 1 and 2.

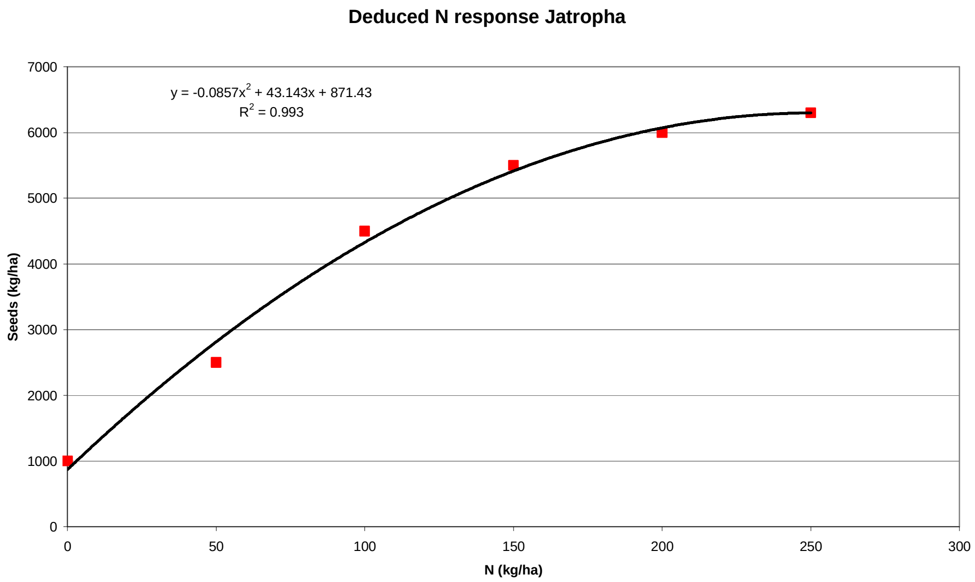
Figure 4 Calculated nitrogen withdrawal of Jatropha in a high input system



Whereas the nitrogen withdrawal of the plants is a linear function, the plants’ response on nitrogen fertilization is nonlinear. So far only a few results of field trials including information of Jatropha fertilization on different fertilizer levels are available. Analyzing the result from Kalannavar et al. (2009) and Patolia et al. (2008) together with the yield experience at the site a nitrogen response function is deduced (see Figure 5).

The maximum obtainable yield is 6300 kg ha^{-1} y^{-1}. Using the actual applied nitrogen amount by the farmer in Kilosa which is 95 kg ha^{-1} y^{-1}, a seed yield of 4000 kg ha^{-1} y^{-1} is possible. These figures correspond well with findings of recent research.

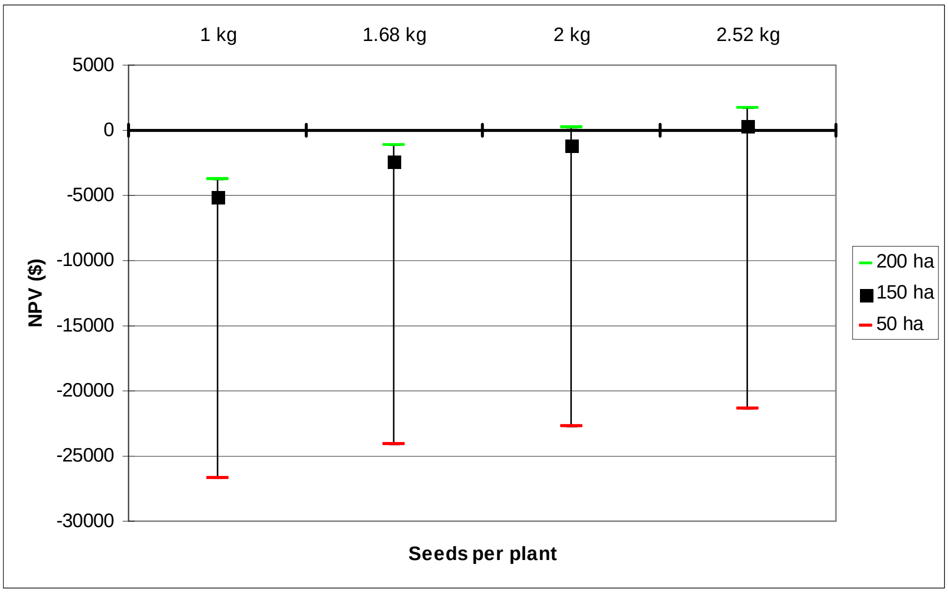
Figure 5 Deduced nitrogen response function of Jatropha



4.2 Costs and Benefits for Local Consumption

Net present values of Jatropha oil production for 50, 150, and 250 ha are given in Figure 4. Local consumption would be viable from approximately 120 hectares and upwards in the high-yield scenario. For lower yields, the cultivated area has to be substantially larger (400 hectares for 1.68 kg seeds $plant^{-1}$). Oil production with trees yielding only 1 kg seeds or lower never become feasible in this system.

Figure 4 NPV (in USD) for different seed yields per plant and 50, 150 and 250 hectares. Real discount rate: 7.54 percent.



Revenues are optimized when the oil production begins in the fifth year. As a result, fixed costs for the processing equipment increases in this year, while the use of the seedcake for fertilizers makes input cost go down.

As a labor-intensive crop, Jatropha has been highlighted as particularly suitable for developing countries where labor is often the cheapest factor of production. As a matter of fact, labor constitutes around 38.5 percent of total costs even when including mechanical peeling and expelling (see Figure 5). Hence, in spite of Tanzanian labor costs being low, the future feasibility of Jatropha production is likely to depend on the development of less labor-intensive cultivation and processing systems. For example, manual peeling would have raised costs by 24 percent for the high-yield option compared to the universal nut sheller. The same is true for the manual ram press, which would have required 1.5 hours per liter of oil compared to 4.5 min with the mechanical expeller (Henning 2004).

Figure 5 Distribution of costs for 2.52 kg and 150 hectares.

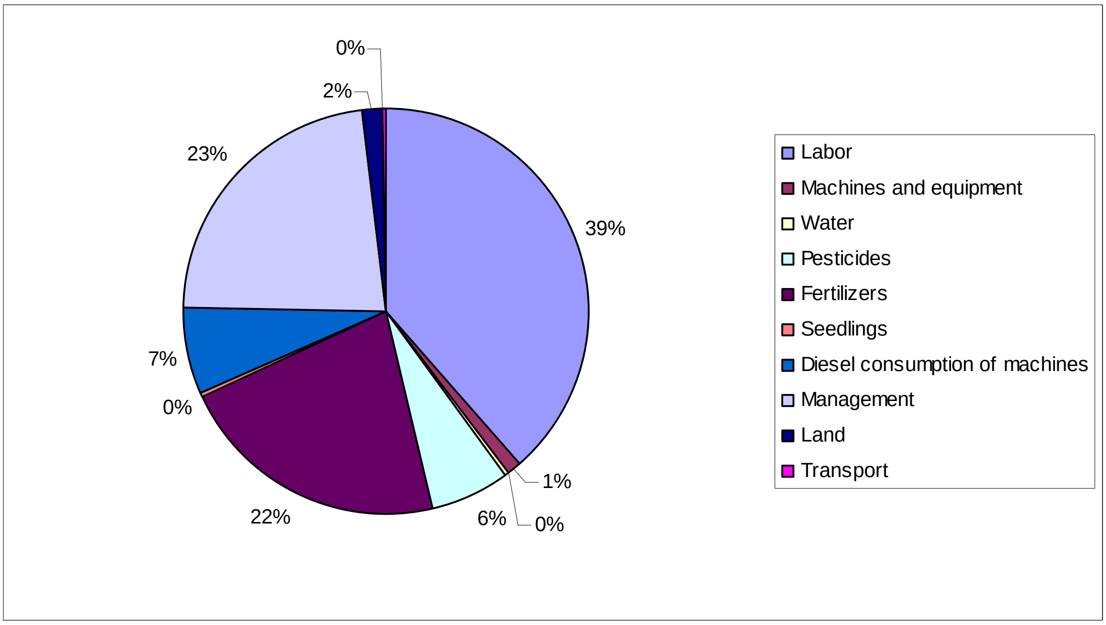
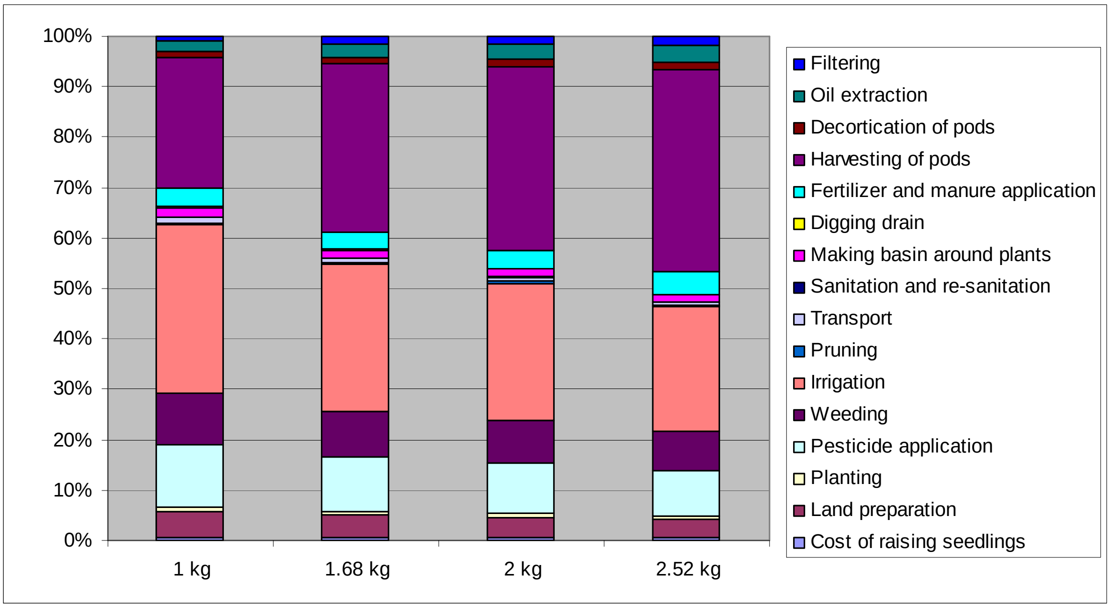
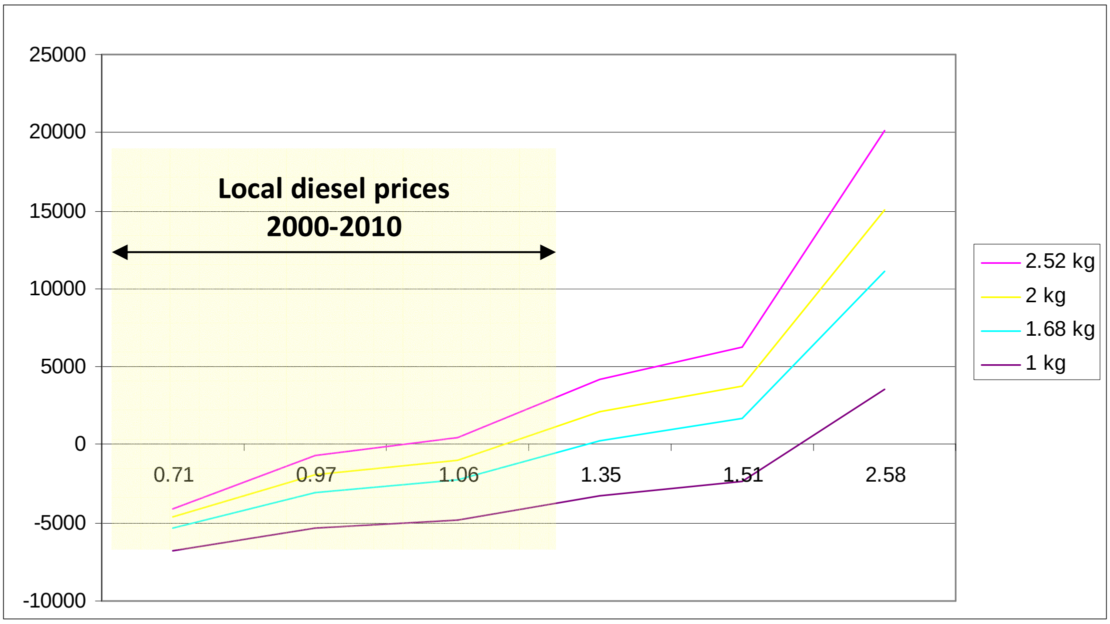


Figure 6 Break down of labor costs relative to yields (kg/plant). In percent.



The probably most important driver of producing Jatropha oil for local consumption is high fuel prices. Even though the diesel price has been steadily growing in the last years, the energy markets are exposed to strong fluctuations. In Figure 7 the NPV is plotted against the diesel prices of the last ten years and the break-even diesel prices of the different yields. Production with yields of 2.52 and 1.68 kg per plant is viable from USD 1.03 and 1.32 respectively.

Figure 7 NPV of different yields and diesel prices. The yellow box represents average pump prices for diesel fuel in USD, which have ranged between 0.61 and 1.30 in the last 10 years (World Bank, 2010). In the last 12 months the average in Kilosa has been USD1.21 (standard deviation 0.04) (EWURA, 2010).



4.3 Exports and Certification

The ISCC standard refers to social and environmental criteria on the one hand and greenhouse gas emissions on the other hand. In the following we aim at estimating additional costs of certifying the Jatropha oil before exporting it.

4.3.1 Greenhouse gases and biodiversity

Based on the target of the EU, the ISCC criteria foresee a greenhouse gas (GHG) reduction of at least 35 percent compared to fossil fuels. For some feedstocks there is a possibility to use the default values listed in Directive 2009/28/EC **(**European Parliament & Council, 2009**).** Yet, Jatropha is not included in this catalog and the GHG emissions of cultivation and processing have to be determined for the farm directly.

Even though it is difficult to generalize as emissions depend on site-specific characteristics (agro-chemicals and organic fertilizers, seed yields and by-products, energy consumption, waste etc), most studies find that Jatropha oil and biodiesel have a good reduction potential. Struijs (2008) considered Jatropha oil production on abandoned sisal land in the North of Tanzania. Assuming that the oil is used for electricity generation in a Dutch combined heat and power plant, he found a GHG reduction potential of 30-61 percent. Taking into account the CO_2 fixation of Jatropha trees the savings could grow up to 154 percent. Another study on GHG emissions from Jatropha biodiesel produced on former cotton fields in West Africa was carried out by Ndong et al. (2009). Similar to the before-mentioned authors, they concluded that the consumption may lead to GHG emission savings of 72 percent compared with conventional diesel.

Acting on the assumption that there is no need to make significant changes in the production process in order to meet the 35 percent-criterion, the main cost of this criterion is related with performing the GHG-calculation itself. For a specialist on the crop and region, it may take a couple of hours to provide this information. Nonetheless, it is difficult to find such an expert and a more realistic assumption for the first year would be 7 working days of a post-doctoral consultant. In the forthcoming years, we estimate the need for a consultant to one day per year.

Apart from greenhouse gases, the ISCC criteria rule out the use of land with high biodiversity value or carbon stock. This includes primary forests and the like, protected areas, grassland with high biodiversity and areas with high carbon stock (such as wetland and continuously forested areas). Given that the plantation has existed for many decades already, none of the former categories apply. Still, the estate is in the vicinity of the Miombo woodland, a unique biome of grass- and scrublands. If the cultivation would expand outside the farm boarders this could have negative impacts on land pressure, biodiversity and emissions from land use change. For example, Romijn (2009) found that production in the Miombo biodiversity hotspot would implicate a carbon debt of more than thirty years. To analyze the environmental and economic dimensions of land-use change would go beyond the scope of what is possible in this paper. Yet, for future expansion of energy crop production in Tanzania, this could become a relevant issue, both in terms of local impacts of deforestation and access to foreign markets.

4.3.2. Environmental sustainability

Soil, fertilizers and pesticides management

As could be seen in Table 2, the results of the land suitability evaluation indicate an overall good starting point for Jatropha. Existing luvisols and fluvisols both have a high agricultural potential and all key indicators are in a good range. Accordingly, there is no need to change the input quantities because of the certification; production is sustainable and resilient, even on a high input level, as long as the detracted nutrients are replenished and the organic matter content is maintained. Nevertheless, there are restrictions related to the choice and handling of agro-chemicals. For example ”Thionex 35 EC”, a widespread pesticide in Tanzania, is used to control insect pressure. Yet, the active agent Endosulfan is highly toxicant and it was prohibited by the EU in 2007 (Watts 2008). For the certified option we therefore substitute this pesticide for Dimethoat, which is considered less harmful and is slightly cheaper.

Workers further apply agro-chemicals without the proper equipment. Adequate protective utensils (sprayer, gloves etc) would add to the expenditures but be within reason. Also some smaller investments may be needed such as an annual calibration of application machinery. We calculate one day work of a technical specialist for this. Both pesticides and fertilizers should be kept in a closed, well-ventilated room. Moreover, facilities to handle spillage and accidents (such as running water) should be available. Finally, a minor must relate to non-chemical interventions against pest such as integrated pest management (IPM). Based on estimations of Larcher (2005), we calculate that the reconstruction of storage rooms and IPM trainings would raise costs by slightly more than 1 percent.

Environmental impact assessment

Larger agricultural projects (>50 ha) in Tanzania are obliged to accomplish an environmental impact assessment (EIA). Even so, except for aid-funded development projects the implementation has been fairly poor (Mwalyosi et al. 1999; Andersson & Slunge 2005). In other words, it seems reasonable to assume that an EIA will not be performed automatically and meeting this criterion would generate additional costs. However, as shown by Mercier (1995), financial costs of conducting an EIA are generally low ranging between 0.05 and 0.5 percent of total project costs in Sub-Saharan Africa. In view of the scale of this project, the lower estimate of 0.05 percent seems to be more adequate, which would correspond to about USD 1000 or employing an environmental expert for 1 month.

Irrigation and waste disposal

With regard to irrigation, the ISCC criteria require that the withdrawal of groundwater should not come at the cost of human consumption. Besides, the abstraction should be in line with existing water rights.

The plantation uses about 600 m^3 irrigation water in the drier months of the year. Covered by the Mkata and Wami River flood basins the district has abundant ground-water resources and the Morogoro region on the whole ranks among the three regions with the highest irrigation potential in the country (Nkongo, 2009; Ministry of Agriculture and Food Security and Cooperatives, 2009). In addition, the private water provider, Kimamba Water Supply Company, has registered water rights and drought exposure is low also in the drier months (Ministry of Water and Livestock Development, 2010). Accordingly, the two major criteria regarding irrigation and water availability are already met.

Producers are further required to set up a waste action plan including equipment to guarantee the safe disposal of plant protection products and waste-water treatment facilities. As was indicated by Larcher (2005), Tanzanian fruit producers certified to EurepGap pay ca USD 800 in the first year and USD 50 in subsequent years to meet this criterion. The author further calculates risk assessment expenditures to an initial USD 1,500 and further USD 300 per year. We use these estimates as approximation for the ISCC-certification.

4.3.3 Social sustainability

The most expensive cost of compliance relates to a raise of wages to the official minimum wage level (from TZS 60,000 to 65,000 per month). The increase would translate into increased production costs of almost 6 percent. Other social benefits may include for example bonus payments, a more appealing working place, medical care and the support of food production e.g. through plantation machinery. Adding a minimum health insurance package for the workers and the workers' family would cost TZS 5,000 extra per worker and year (0.5 percent of total costs).

Further social issues included in the ISCC list are difficult to measure in monetary terms (e.g. that no person should be discriminated, freedom to join labor organizations etc). At this point we do not include these criteria in our economic calculation, even though we recognize their importance for the overall acceptability of large scale Jatropha production.

4.3.4 Direct costs of certification

Currently, there is no local company that certifies biofuels in Tanzania. The organic certifier TanCert was accredited by IFOAM in 2008 (TanCert, 2010). We base our calculations on their fees but stress that the use of certification bodies based in Europe, which are generally connected with higher costs both in terms of daily rates and travel expenses, may be necessary.

Direct certification costs are highest for the first year where the applicant has expenses for preparations (including external consultants and internal audit costs) as well as the inspection and certification itself. In both cases, costs of accommodation and transport have to be accounted for. In successive years, the inspection effort and fees will decrease. The certificate needs to be renewed every five years.

4.3.5 Costs of export and certification

The export itself adds to the costs in relation to the total produce as it is calculated according to weight. All in all, the net present value of production costs would increase from USD 1.03 to USD 1.25 per liter of oil for 2.52 seeds per plant. Certification would imply an increase in total production costs of another 5-9 percent where the high-yield alternative is relatively more expensive to certify due to the higher labor intensity (see also Table 3 for the cost distribution of the first four years).

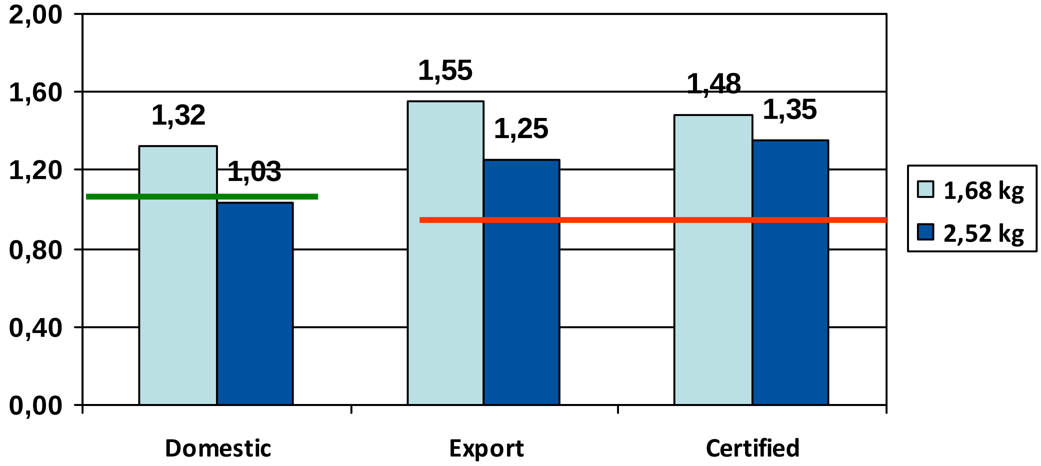
Table 3 Costs of Jatropha certification (2.52 kg plant^{-1} hectare^{-1}). All units in TZS.

Operation	1	2	3	4	5
Direct certification costs					
Application fee	76000	0	0	0	0
Inspection fee	2508000	2052000	2052000	2052000	2052000
Certification fee	152000	0	0	0	0
Cost of accomodation and overhead for consultants	1672000	684000	684000	684000	684000
Transport costs	600000	300000	300000	300000	300000
Internal audit with managers	187500	125000	125000	125000	125000
Consultant preparation	7370	0	0	0	0
Total direct costs	**34859.229**	**21178.7**	**21178.7**	**21178.7**	**21178.7**
Indirect certification costs					
Fertilizer management	25460	7638	7638	7638	7638
Pesticide management	105913.6	12730	12730	12730	12730
Protective clothing	7708.35	304.85	304.85	304.85	304.85
First aid kit	3040	0	0	0	0
Exchanging pesticides	0	-17550	-17550	-17550	-17550
Consultant GHG	4690	670	670	670	670
Consultant EIA	10184	0	0	0	0
Waste & pollution management	8147.2	509.2	509.2	509.2	509.2
Written risk assessment and accident procedure plan	15276	3055.2	3055.2	3055.2	3055.2
Minimum wages	66250	92917	65625	53542	89375
Health insurance	10000	10000	10000	5000	10000
Total indirect cost of certification	**256669**	**110274**	**82982**	**65899**	**106732**
Total certification costs	**291528**	**131453**	**104161**	**87078**	**127911**
Total costs of production	**2433340**	**2406304**	**2063673**	**1664237**	**2111864**

As can be seen in Figure 8, both the non-certified and the certified export alternative are well above the equivalent price of rapeseed oil, which we may consider the ceiling price for exports to the EU; in order to be competitive on the European market in 2009/10, the oil price in Dar es Salaam would have to stay below USD 0.90/l[3]. In the last 20 years, Jatropha oil exports would have break even only during the vegetable oil price hikes in 2008.

[3] The average rapeseed oil price corresponded to USD 897/MT in 2009/10 (IMF, 2010). Considering a specific gravity of 0.917 and transport costs from Tanzania to Rotterdam harbor of USD 0.08/l (CIF) (Felix et al., 2010), we obtain a threshold price in the Tanzanian harbor of USD 0.9 per liter of jatropha oil.

Figure 8 Production cost of one liter Jatropha oil (in USD) for 150 hectares. The green line indicates the local diesel price of USD1.10, and the red line the rapeseed oil price equivalent of USD0.90



5. Conclusion and outlook

We have shown that conventional cultivation of Jatropha may be viable for own consumption only when keeping the fixed costs low (expanding production to at least 140 hectares). Crucial for the profitability are low labor costs, as many steps in the production process are still conducted manually. In addition to this, the feasibility hinges on high volumes of seeds. According to our yield assessment, seed yields in the range of 1 to 2.52 kg per plant are possible, where the upper boundary would only be reached with high levels of fertilization. Under worse soil suitability and less advantageous climatic conditions, the yields are likely to be lower.

With regard to exports, production costs of Jatropha oil are too high to be able to compete with other vegetable oils on the global market. Hence, even though the cost increase of certification of ca 9 percent may be considered comparatively low, neither export nor certification seems very attractive. On the other hand, many of the sustainability criteria are already met, which would indicate that a formal certification process may not be necessary to make the Jatropha production sustainable. Even so, environmental sustainability is strongly related to site-specific factors. Accordingly, for large-scale projects stricter enforcement of environmental impact assessments should be in focus of national biofuel policies. Further, attention should also be paid to compliance with laws related to social standards (minimum wages, health protection etc).

Our analysis has provided a valuable insight in the costs of production and certification of Jatropha oil, but is by no means complete. More empirical evidence is needed to analyze the impact of input on yields and environment. In addition, development of new technologies to mechanize production will probably be necessary to set a long-term incentive for Jatropha production.

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Annex 1 ISCC Principles

Requirements regarding greenhouse gas emissions as listed in ISCC 201 System Basics for the certification of sustainable biomass and bioenergy (ISCC, 2010b, p.12):

The produced liquid biomass respectively biofuel must grant greenhouse gas emission savings of 35 percent

Sustainability requirements as listed in ISCC 202 Sustainability Requirements for the Production of Biomass (ISCC, 2010, p.3):

PRINCIPLE 1: Biomass shall not be produced on land with high biodiversity value or high carbon stock and not from peat land (according to Article 17, 3. of the Directive 2009/28/EC and § 4 to 6 of the German BioSt-NachV and BioKraft- NachV). HCV areas shall be protected
PRINCIPLE 2: Biomass shall be produced in an environmentally responsible way. This includes the protection of soil, water and air and the application of Good Agricultural Practices
PRINCIPLE 3: Safe working conditions through training and education, use of protective clothing and proper and timely assistance in the event of accidents
PRINCIPLE 4: Biomass production shall not violate human rights labour rights or land rights. It shall promote responsible labour conditions and workers' health, safety and welfare and shall be based on responsible community relations
PRINCIPLE 5: Biomass production shall take place in compliance with all applicable regional and national laws and shall follow relevant international treaties
PRINCIPLE 6: Good management practices shall be implemented

Annex 2 Data, Assumptions and References

For one hectare.

Item	Value	Source	Comment
General			
Lifetime of project (years)	25		Own assumption
Nominal discount rate (%)	15.50	World Bank (2010)	Average 2005-2008
Inflation rate (%)	7.40		Consumer prices, average 2005-2009
Land rent (TZS/ha)	30,000	Kadigi et al. (2008)	
Manager salary (USD/year)[3]	41,100	Beerens (2007)	
Yields			
Number of plants (ha)	2,500	1	
Spacing (m x m)	2	1	
Seed weight (of total pod)	63.51%	1	Average of seeds
Yields in the first 4 years (kg/year/ha)	0, 280, 185, 2,000	1	For 2008, 2009 and beginning of 2010 respectively.
Yields (low) (kg/year/ha)	2,000, 2,500	Estimate	For the 5th year and the 6th year onwards
Assumed yields (medium) (kg/year/ha)	4,000, 5,000	Estimate	For the 5th year and the 6th year onwards
Assumed yields (high) (kg/year/ha)	4,000, 6,300	Estimate	For the 5th year and the 6th year onwards
Seedlings			
Cost of seedlings (TZS)[4]	6,301,875	1	
Import duty (TZS)[4]	29,750	1	
Import permit (TZS)[4]	2,250	1	
Cost of seeds on local market (TZS/kg)	200	Loos (2009)	
Seeds for planting (kg/ha)	3	van Eijck (2006)	
Fertilizers and pesticides			
Single Super Phosphate (P_2O_5) (kg/plant)	0.50	1	At planting
Manure (kg/plant)	2.00	1	At planting
NPK (15:15:15) (kg/plant)	0.25	1	Annually
Price Single Super Phosphate (P_2O_5) (TZS/50kg)	10,000	Observed	Price in Morogoro, July 2010
NPK (15:15:15) (TZS/50kg)	30,000	Observed	Price in Morogoro, July 2010
Manure (TZS/ha)	1662.62	Akyoo & Lazaro (2008)	
Nutrient content seed cake (NPK per 1000 kg seeds)	(29:12:10)	Estimate	
Application of pesticides (ml/plant)	1.00	Estimate	Thionex
Application of pesticides (l/ha)	2.50	Estimate	3 applications per year
Cost of Thionex (TZS/l)	14,500	Observed	Price in Morogoro, July 2010

Water			
Water needed for pesticides (l/ha/year)	3,750	Estimate	2 ml Thionex/l water required, i.e. 1250l/ha and time
Quantity needed for irrigation (l/plant)	15.00	1	10-15 liter per plant
Times (per year)	16.00		1x weekly from mid-Jun to mid-Oct
Fixed water cost (TZS/month) [3]	600	Ministry of Water and Livestock Development (2010)	House connection fee of Kimamba Water Supply Company
Tools			
Planting tools (TZS)	10,000	Loos (2009)	Depreciation time five years
Universal nut sheller (TZS) [3]	50,600	Rijssenbeek & Galema (2010)	USD 30 for material and two working days of craftsman
Capacity of nut sheller (kg seeds/h)	150	Heger (2009)	
Labor			
Raising seedlings in nursery (person/day/year)	169	1	
Land preparation (person/day/year)	125	1	Only first year. Includes labor for field layout, making holes and pegs, land clearing, making rows, and pre-irrigation
Planting (person/day/year)	24	1	Only first year
Fertilizer (person/day/year)	36	1	Only first year. Includes labor for weighting and mixing of fertilizer, fertilization of soil and reffling pits as well as application in the first year
Irrigation (person/day/year)	14	1	Only first year
Application of fertilizer remix (person/day/year)	3-11	1 and estimate	From second year onwards. Low yield: 3; Medium yield year 1-6: 3; year 7-25: 5; High yield: 1-6:3; year 7-25: 11
Transport fertilizer (person/day/year)	2	1	
Mixing of fertilizer (person/day/year)	2	1	In second year and onwards
Digging drain (person/day/year)	8	1	Only second year
Pruning (person/day/year)	11	1	Only second year
Sanitation and re-sanitation (person/day/month)	6	1	Only second year
Making basin around plants (person/day/month)	2	1	Only second and third year
Weeding (person/day/year)	34-156	1	Year 1: 24; Year 2: 156; Year 3: 96; Year 4-25: No need
Application of pesticides (person/day/year)	24	1	
Harvesting of pods (person/day/year)	59, 76	1	For the second and third year respectively
Harvesting of pods (kg/person/day)	42.60	Estimate	From the fourth year onwards
Irrigation (person/day/year)	75	1	In second year and onwards
Manual peeling of seeds (kg/person/day)	19	1	
Semi-manual peeling of seeds (kg/person/day)	1,200	Heger (2009)	Using universal nut sheller
Labor oil extraction (h/l)	0.05	Eijck van	

		(2006)	
Purification/Filtering (min/l)	1.5	Henning (2004)	
Wage (TZS/person/day)	2,500	1	
Oil extraction and filtering			
Cost of transport of expeller[3]	300,000	Estimate	From Morogoro to estate
Cost of mechanical screw-press (TZS)[3]	3,700,000	Henning (2007)	Sayari expeller
Cost of manual ram press (TZS)	400912.00		FACT, 2008
Raw oil recovery factor (l oil per 100 kg)	35	Beerens & van Eijck (2010)	Average during the first 3 years
Clean oil recovery factor (l oil per 100 kg)	26.5	Beerens & van Eijck (2010)	25-28 liter clean oil after filtering
Diesel consumption of expeller (l/h)	1.25	Eijck van (2006)	1-1.5
Extraction capacity of expeller (kg seeds/h)	70	Beerens & de Jongh (2008)	
Production rate of expeller (l/h)	20	Eijck van (2006)	
Depreciation time of expeller (years)	6	Eijck van (2006)	8 hours a day, 50% of the year
Specific gravity of oil (kg/l)	0.92	Odetoye et al. (in press)	
Export			
Governmental fees (TZS/kg)	140	Ministry of Agriculture, Food Security and Cooperatives, (2008)	Refers to cashew nuts
Transport costs to harbor[3]	300,000	1	Cost from estate to harbor in Dar es Salaam
Exchange rate (USD/TZS)	1,520	XE (2010)	02. Aug 10
General			
Diesel price Morogoro (TZS/l)	1,650	Observed	In Morogoro, July 2010
Certification			
Application fee for certification (USD)[3]	50	Akyoo & Lazaro (2008)	Based on fees of Tancert
Inspection fee (USD/day)[3]	150	Akyoo and Lazaro (2008)	Based on fees of Tancert
Re-inspection (USD/day)[3]	150	Akyoo and Lazaro (2008)	Based on fees of Tancert
Certification fee (USD)[3]	100	Akyoo and Lazaro (2008)	Based on fees of Tancert
Days for inspection (days)[3]	11	Vis et al. (2008)	Every five years
Days for re-inspection (days)[3]	9	Vis et al. (2008)	Every five years
Preparation of consultant (days/year)[3]	11	Vis et al. (2008)	First year only
Internal audit with managers (days per year)[3]	7.5, 5	Vis et al. (2008)	7.5 days in the first year, 5 in the following years
Cost of hotel (USD/night)[3]	50	Observed	
Transport cost audit (TZS)[3]	600,000,	Estimate	Trip of certifier only: 300,000, trip of

	300,000		certifier and consultant (every five years): 600,000
Cost of consultant (TZS/day) [3]	100,000	Vis et al. (2008)	
Minimum wages (per month and worker)	60,000	ILO (2010)	
Health insurance (per year and worker)	5000	2	For worker with family
First aid kit (USD/piece)	2.00	Sundara (2007)	Lifetime of five years
Greenhouse gas analysis (TZS/day) [3]	100,000	Estimate	For first year 7 days needed, subsequently 1 day per year
Crop protection (USD/year) [3]	10,400, 1,250	Larcher (2005)	
Protective clothing (TZS)	7,708, 305	Observed, estimate	First year including pesticide sprayers, masks and protective gloves: 7,708. Subsequent years only masks and protective gloves: 305
Dimethoat (USD/l)	20	Estimate	
Dimethoat application (l/year)	3	Estimate	
Environmental impact assessment (USD) [3]	1000	Observed, estimate	1 month's salary of consultant on post-doc level; only first year
Written risk assessment and accident procedure plan (USD/year) [3]	1,500, 300	Larcher (2005)	First year: 1,500; subsequent years:300
Waste and pollution management (USD/year) [3]	800, 50	Larcher (2005)	First year: 800; subsequent years:50

1. Based on data collected in a Jatropha farm in Kilosa
2. Based on survey conducted in Rural Morogoro District in spring 2010
3. Proportionate share in costs depending on total hectares
4. Costs of seedlings per hectare are calculated according to the formula $S_i = \frac{S_{im}}{HA} + 3S_{op}$ with S_i cost of seedlings for hectare i, S_{im} cost of imported seedlings, import duty and import permit, HA total number of hectares and S_{op} cost of own propagation, which we sets equal to the opportunity cost of selling the seeds on the market.