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Abstract

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Option for sustainable bioenergy: a jatropha case study

The *Jatropha Curcas* plant provides opportunities to set-up a jatropha bioenergy production chain that fulfils the sustainability criteria of the Cramer Commission of 2006.
The plant produces oil, and the extraction of this biofuel is not at the cost of food production. Jatropha can grow in places where no food can be cultivated.

A team of representatives of SenterNovem, RIVM and the Ministry of VROM has investigated two jatropha production chains in Tanzania which offer commercial prospects. Two cases are considered, firstly for jatropha integrated in smallholdings as hedgerows around small plots of agricultural land where maize is grown and secondly a plantation where jatropha is grown as a mono-culture. The oil can be used for the production of electricity in the Netherlands and the vegetable wastes can be used locally as fuel or as a fertilizer to increase the texture of the soil. The application as a hedge has the advantages that it protects the maize against vermin and the soil against erosion.

The extent to which jatropha can contribute to a decrease in greenhouse gas emission, without shifting negative consequences towards the producing countries has been examined. The project is meant to be a reaction to activities whereby economic gain is favoured above socio-ethical and ecological values. For example as a result of deforestation for the production of biofuels ecosystems disappear with the concomitant loss of biodiversity.

Key words:
biofuel, jatropha, Tanzania, sustainability, greenhouse gas balance

Rapport in het kort

Shinda Shinda (Win Win)
Optie voor duurzame bioenergie: de casestudy jatropha

De *Jatropha Curcas*plant biedt mogelijkheden om een productieketen voor biobrandstoffen op te zetten die voldoet aan de duurzaamheidscriteria van de Commissie Cramer uit 2006. De plant levert olie op, en de winning van deze biobrandstof gaat niet ten koste van de voedselproductie. Jatropha gedijt namelijk op plekken waar geen voedsel kan worden geteeld.

Een samenwerkingsverband van SenterNovem, het RIVM en het ministerie van VROM heeft twee productieketens van jatropha in Tanzania onderzocht die commerciële perspectieven bieden. Het gaat om een kleinschalige aanplant als heg langs kleine maïsakkers en om een plantage waarop uitsluitend jatropha wordt verbouwd. Met de gewonnen olie kan in Nederland elektriciteit worden geproduceerd. De restproducten zijn in het land van herkomst beschikbaar als brandstof of als mest waarmee de structuur van de grond kan worden verbeterd. Het gebruik als heg heeft als voordeel dat de plant de maïs beschermt tegen ongedierte.

Nagegaan is of jatropha kan bijdragen aan een lagere uitstoot van broeikasgassen, zonder negatieve consequenties voor de producerende landen. Het project is bedoeld als reactie op activiteiten waarbij economisch gewin ten koste gaat van sociaal-ethische en ecologische waarden. Door bijvoorbeeld regenwouden te kappen om biobrandstoffen te produceren, worden ecosystemen en biodiversiteit vernietigd.

Trefwoorden biobrandstof / jatropha / broeikasgasbalans / duurzaamheid / Tanzania

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Preface

In spring of the year 2007 a project called *Positive Aspects* was started. The project addressed irresponsible activities in which social-ethical and ecological values were neglected in favour of economic benefits. One of these is the deforestation for the production of biofuels imposing a enormous threat on ecosystems and causing a tremendous loss of biodiversity.

When the progress report of the *Environmental Agenda* was written, it was thought that economic activities should come together with an increase in ecological as well as with an increase in social-ethical values. In this way the sustainability dimensions of economy, ecology and society would increase. It was a challenge to achieve this enlargement.

A team of representatives of SenterNovem, RIVM and the Ministry of Environment choose to study the cultivation of jatropha in Tanzania and the export of the oil of jatropha to the Netherlands, in particular a project which already is in a pre-commercial situation. In this chain already Dutch enterprises and NGOs are active and currently certification is being considered to give an added value to the use of the oil of jatropha. In this chain the oil can be used for the generation of electricity and heat in the Netherlands, whereas the residues can be used locally in Tanzania. With the biomass also fuel for transportation can be produced.

The project was carried out together with all stakeholders involved. Two workshops took place in the Netherlands and one in Tanzania. In total three missions were organized: two in Tanzania and one in the Netherlands.

The results of the project confirm the feasibility of introducing a biomass-chain which enlarges the three dimensions of sustainability at the same time.

Per dimension the following illustrations can be given:

1. Ecological dimension
   - More biomass on land is generated. This leads to a very positive greenhouse balance;
   - The residue can be digested. This leads to the formation of biogas which can be used in kitchens as a fuel. The nutrients from the digesting can be used in agriculture as a fertilizer.
   - Less firewood is needed which leads to less damage on biodiversity.
   - The oil from jatropha is important for the development of climate neutral transportation.
   - The production of jatropha can be done by means of intercropping. This means that there is a win-win-situation between the production of jatropha and the production of food.
2. Economic dimension
   - More inhabitants of Tanzania get access to energy services, which is of major importance for the development of the country.
   - More investments will be done in infrastructure, in facilities for the treatment of jatropha and in irrigation. This leads to more economic activities and more important knowledge is generated.
   - Carbon credits can be generated.
3. Social/ethical values

- The income of farmers will increase. This money can be used for schooling of children and for buying more food.
- The local people will get a role in the primary processes of the biomass-chain, and therefore an access to the market.

In conclusion, the jatropha biomass chain is *feasible*. The project was *pleasant and exciting*, because new personal contacts and new social networks were formed. Also new ideas, new possibilities and expectations for the future have been generated. And it is *necessary*.
The development of a biomass-chain without any negative impact for future generations and other places of the world is possible. More than that, the possibilities for developing countries and for the future can be enlarged.

Ir. Geert van Grootveld
Project Leader “Positive Aspects”
Ministry of Housing, Spatial Planning and the Environment

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Summary

A case study was conducted on the sustainability of cultivating *Jatropha curcas* in North Tanzania for biofuel export to the Netherlands. The case was tested against the framework of the Cramer Commission. The greenhouse gas balance and the social-economic impacts were evaluated for two cases: 1) for jatropha integrated in smallholdings as hedgerows around small lots of agricultural land where maize is grown and 2) a plantation where jatropha as a mono-culture is considered.

Jatropha is a wild species. It is native in tropical America but now found in tropical areas in Asia and Africa. It is drought resistant and toxic and has drawn attention as an energy crop. Because it is not a plantation species reported data on fruit harvest may vary widely without an agronomical rationale. As a consequence, the evaluation of the greenhouse gas (GHG) balance, i.e. the reduction of CO_2 emission compared to an equivalent amount of fossil fuel, is not possible. Agronomical data of traditional food and feed crops are used to compute the GHG balance of biofuels derived from maize, soy, sugar cane etc. These data are not available for *Jatropha curcas*. Without these agronomical relationships the production of biofuel from this plant can not be tested with respect to Cramer's first criterion. Therefore we developed a simple model to estimate the harvest from nitrogen inputs. This model provides an opportunity to estimate the GHG balance as a function of agricultural inputs (environmental effects) and the harvest (socio-economic effects).
The harvested seeds are thought to generate three flows of biofuels (oil, shells and seedcake) and three systems to produce electricity and heat are considered:

1. Co-firing of jatropha oil with fossil oil
2. Co-firing of jatropha seed cake and shells with coal or wood
3. Co-production of electricity and heat by combustion of jatropha oil in a CHP (combined heat and power installation), optionally combined with the generation of electricity from seed co-firing seed cake and shells.

In the specific situation of the case study, the jatropha production takes place in an area consisting of agricultural land or shrub land, where in the last decades the original bush savanna is affected to a high extent by selective deforestation. Introduction of jatropha leads to carbon storage due to land use change. Calculations based on the model mentioned above indicate that reduction of greenhouse gas emissions may be more than 100% (in a range of 100-300%). Even if these positive effects of land use change are not accounted for and only the use of oil, shells and seedcake are taken into account the reduction in greenhouse gas emission is still around 60%. Most likely, this figure represents an underestimation, due to conservative assumptions in the calculations.

For smallholdings the hedgerows will improve the rural environment as it is effective in the combat against erosion. On the long term it may also have a positive effect from a social perspective as the soil structure of the land may be improved by a raster of jatropha hedges. This will counteract further destruction of the amenities because since many decades the rural area is noticeably affected by nutrient depletion.
Jatropha seems to have more positive than negative social effects, though the revenues for the smallholder are marginal if compared to the minimum wage, even when it is adjusted to the rural share of the GDP.

For the plantation case the social implications are yet unclear. On one hand jatropha plantations may revitalize the agricultural sector in the region; on the other hand it has to be proved that there is no competition between a jatropha plantation and subsistence farming. The toxicity of jatropha has been

brought forward as a safeguard against competition between food and biofuel, but this is a precious argument. Although jatropha can survive droughts and shortage of nutrients, it requires land and a considerable amount of water to produce a fair yield. The limiting factor in the Makanya region is water and therefore, competition for productive land can not be excluded. If however, the irregular and intense rainfall which runs off from a large area is harvested, both interests could be protected and unemployment alleviated. Research initiatives by the Technical University of Delft are focussed on hydrological interventions that are effective because they are compatible to local circumstances.

1 Introduction

Biofuel is categorized as renewable because the carbon dioxide, emitted by the conversion of biomass into energy, is recycled by the photosynthesis to an equivalent amount of new biomass. Its “carbon dioxide neutrality” is a major argument to replace fossil fuels with biofuels. Although it has attractive features, the production bio-energy is also a continuous source of scientific dispute itself because it has some troublesome aspects:

- The emission of greenhouse gases in the life cycle of some biofuels may approximate or even exceed the CO_2 emissions of an equivalent amount of fossil fuels.
- Land cleared to set up a biofuel plantation may cause CO_2 emission that is difficult to overcome by biofuels produced on that area.
- Both energy security and food security are at stake. Although bioenergy has been proposed to reduce the risk of energy shortage, there is however a risk of competition with food production or other essential elements of the livelihood.
- Land needed for energy crops may push aside ecosystems so reducing biodiversity.
- Large scale biofuel production may affect the rural community in an adverse way.

A project was initiated by the Dutch government, SenterNovem and the National Institute for Public Health and the Environment (RIVM) concerning a bioenergy chain based on first generation technology. The project includes technologies for direct electricity and heat generation in the Netherlands; biofuel for vehicles is not taken into consideration. The purpose of this study was to give an illustration of a bioenergy production chain that complies with “people, planet, profit” principles of sustainability by comparing the results of the analysis to the ‘Testing framework for sustainable production of biomass’ (Cramer Commission, 2007). Six themes have been identified by the Cramer Commission (2007) with respect to large-scale production of bioenergy:

1. Greenhouse gas emissions: how much life-cycle greenhouse gas emission is avoided?
2. Is there competition with food and other local applications?
3. Is there loss of biodiversity?
4. Environment: are there any effects of the use of pesticides and fertilizers?
5. Prosperity: does the production of biomass contribute towards the local economy?
6. Social well-being: does the production improve the social living conditions of the local population and employees?

Aim of the project

The purpose was to explore, in collaboration with external partners, the possibilities of bio-energy production that is beneficial from an ecological, economic and social point of view. A biofuel production chain in North-Tanzania is examined to illustrate this triple benefit and to identify modes of optimisation.

The biofuel production chain

The choice of the production chain was inspired by the initiative of Diligent to introduce hedgerows of jatropha trees around smallholdings in the agricultural region near Arusha (see Figure 1). Diligent delivers the sowing seeds to the farmers for free and the seeds harvested from those living fences can be sold to Diligent to provide the smallholders an additional income. Two Dutch companies Diligent Energy Systems and Eneco have participated in this project. Eneco was already active in other parts of Tanzania but showed interest to collaborate with Diligent to explore land in North Tanzania for the production of larger amounts of jatropha.

In part of the programme, also two other organisations participated. ICCO and the Max Havelaar Foundation (see Annex E) welcomed the opportunity of a first practical orientation on international jatropha chains. Together with Eneco they are studying the feasibility of bringing jatropha under international fair-trade certification. The envisaged fair-trade standards for jatropha will encompass the Cramer criteria, but, in accordance with the mission of fair-trade, they will complement those criteria with more and stricter requirements with regard to the socio-economic benefits for small producers and their local communities, For ICCO and the Max Havelaar Foundation this project provides an interesting basis for more profound socio-economic research than foreseen in the context of this project, followed by the further development of fair-trade criteria.

In the biofuel production two main production units/sites can be distinguished:

- Small scale
- Large scale

Small Scale:
This method of producing jatropha is mainly focussed on smallholders, local farmers, who grow jatropha as a side crop on their production plots. This can be done by using jatropha as a fence or by using jatropha as a crop between other crops as for example maize, also referred to as intercropping. In this case study jatropha used as a fence is evaluated.

Large Scale:
Nowadays a number of NGO's distribute jatropha seedlings to the local communities, creating opportunities for smallholders to use jatropha as hedgerows or intercropping.
It is inevitable that when a market is ready and jatropha seems to be profitable the production will move from small production units to larger production units. Therefore it is interesting to look at the large scale implications of the production of jatropha. Different ways of organising large scale production units can be distinguished:

- Large scale production through plantations owned by a company, plantation model
- Large scale production through plantations owned by the local community organised in a cooperation, the cooperative plantation model
- A combination of both, in which a core is owned by a company, surrounded by the local entrepreneurs, the nucleus model

However in this report large scale production is referred to as plantation chain.

Two locations were chosen differing in altitude and climate. The life cycle analysis includes export of biomass to the Netherlands for combustion in Dutch power plants to generate energy. Two different sites were selected to explore the potentials of sustainable biofuel production (Figure 1):

- Oilseeds collected from jatropha hedgerows around small lots of agricultural land owned by families in the region of Arusha, referred to as "smallholders chain",
- Jatropha oilseeds harvested from plantations in the savannah region of Makanya ("plantation chain")

The approach
Information through literature research and internet was collected on:

- environmental aspects of the chosen region
- socio-economic characteristics
- properties of jatropha

A mass balance model was developed for the harvest of jatropha seeds to be able to:

- calculate the greenhouse gas balance

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- estimate the profits of cultivating jatropha

Two visits to Tanzania and one visit to the Netherlands were paid to gain insight into:

- Willingness of small farmers to grow jatropha integrated in subsistence farming
- Policy of the Federal Government with respect to jatropha plantations
- Opinions and activities of NGOs.

Figure 1 Locations chosen to evaluate jatropha production by smallholdings (Arusha) and plantations (Makanya)

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2 Description of the two locations in North Tanzania

North Tanzania is merely a semi-arid region where the native tropical woodland has undergone a rapid conversion into agricultural land. According to the IPCC’s *Guidelines for National Greenhouse Gas Inventories* (2006) the major part of the region is characterized as tropical shrub land and near the high mountains (Kilimanjaro and Mount Meru) as tropical Mountain Systems. Especially the latter region is densely populated and a large fraction of the land has been changed into agricultural land. The bush savannah is to a high extent affected by selective deforestation because more than 90% of the people in Tanzania depend on fuel wood. It has resulted in drastic ecological changes.
Agro-ecosystems in North Tanzania do not differ much from most countries in East Africa (Annex A) where the sector is typically dominated by subsistence agricultural production. Most of the land suffers from nutrient depletion, being a major cause of soil degradation. This is largely attributed to socioeconomic and biophysical factors. Whereas in Europe terrestrial eutrophication is a major environmental stressor (high emissions of NH_3 and NO_x due to energy production, traffic and agriculture), in Sub Saharan Africa (SSA) the reverse, i.e. nutrient depletion, causes damage to the environment. In general, tropical soils are poor in nutrients and most often rely on recycling of nutrients from soil organic matter to maintain productivity, however most of the subsistence farmers are too poor to fertilize their land. Nutrient depletion prohibits sustainable development in the region; erosion causes ecological damage and deteriorates the infrastructure. Decreased soil fertility is a major cause of low agricultural productivity (Sanchez, 2002) which perpetuates marginal living.
Although the average precipitation rate suggests that rain fed growth of jatropha is feasible (Annex C), the spatial variability is high. Some areas may have less than 600 mm/yr and there is a decreasing trend. The rain pattern in North Tanzania is bimodal.

2.1 Agricultural area cultivated by smallholders near Arusha

The densely populated Arusha region is located in the northern Tanzanian dry belt around 36° 40′ east and 3° 21′ south. The topography of the area is characterized by vast plains at 1400 m above sea level. Mean annual precipitation ranges between 500–1000 mm. The mean annual temperature is 20° C. The soils of the area are classified as chromic luvisols according to FAO/UNESCO (1988) with a sandy-loam texture and reddish colour. In the cultivated fields, maize and beans are grown without nutrient inputs. Few crop residues remain on the fields and are incorporated into the soil but often complete residue removal for fodder and fuel. This contributes to the depletion of soil organic carbon.
The road from Arusha to the main seaport in Dar es Salaam is approximately 600 km long and in a good condition, also transport by freight rail is possible.

2.2 Bush savannah in the catchment area of Makanya

This region is located south of the town of Same and in between the Masaai Steppe and the South Pare Mountains. Makanya is a village of 8000 inhabitants (37° 50′ east, 4° 21′ south) near a main road and a rail road connecting Arusha with Dar es Salaam. Currently, the railroad is not frequently used (once a month), but in a fair condition. The Makanya catchment has an area of 320 km^2 and is populated with 35,000 inhabitants. The altitude of the Makanya area is approximately 600 m and although the tropical regime is suitable for growing jatropha, the average rainfall seems to be too low (between 400 and 700mm). From interviews and comparison with data from a nearby meteorological station by Mul et al.

(2006) the suggestion is raised that the Makanya River at the railroad bridge has changed from a perennial river in the 1950s to an intermittent river in the 1990s and that its flow into the River Pangani ceased, turning the seasonal wetland into a steppe terrain. On the sub-catchment scale, flows from the mountains have reportedly dried up and the base flow decreased significantly. Decreasing rainfall amounts have been mentioned as the predominant cause of these changes. A 7 km wide strip west of the rail road, south west of the catchment area is called the flood plane and has a surface area of approximately 400 km^2 . The soil properties do not seem suitable for water demanding agricultural activities. The surface structure which determines the soil depth, water holding capacity and root depth, allows only a small fraction of the water to infiltrate into the soil. Rain water almost entirely runs of leaving too little for growth of a crop like jatropha. Beyond that strip, the soil is better capable to retain the water, which is discernable from significantly higher plant productivity. If the water of flash rains which precipitates on the impermeable area could be harvested with so-called charco-dams (a primitive micro-dam), a simple irrigation system is feasible that may be sufficient for a jatropha plantation. Sufficient labour force is available in the Makanya area. Many labourers are dependent on agriculture, working at the sisal estate or in the gypsum mines. The jobs available are mostly on a daily bases as unemployment is widespread in the surrounding areas (the Same district). Currently there is a large sisal estate in Makanya, since 2002 owned by Muhamed Enterprises. This company is partly funded by the World Bank. The transport distance to the main seaport is 350 km (road or rail).

3 Characteristics of the jatropha biofuel chain

3.1 The plant

Jatropha curcas belongs to the Euphorbia family. It is a big shrub or a small tree and has recently received attention as an energy crop because it is less demanding with respect to water and nutrients. At present it is still a wild plant - it is not cultivated through variety research. Openshaw (2000) presented a survey on the properties of this perennial and its potentials to play a role in mitigating greenhouse gas (GHG) emission. Nowadays, jatropha's reputation as a valuable plant in the combat against GHG emissions has reached the Dutch daily newspapers. Biofuels from jatropha belong to the first generation. In contrast to traditional food and feed crops, essential information of its performance in agricultural production systems is still lacking. jatropha is toxic and has been ignored by agricultural engineers. With respect to cultivation not much is known and improvement of the jatropha plant is likely to occur. Being an uncultivated wild-species, it is not known what the environmental and the genetic influence is on oilseed production. jatropha production rates vary greatly and profitable claims are made, however, well-founded proof or reliable sources of information are lacking. More information on productivity, oil contents, growth conditions, agronomic practices, propagation methods and sensitivity to pests and diseases, is needed to understand success or failure.
Its toxicity has been considered a safeguard against unsustainable biomass production because it can not compete with food and feed production. However, large scale production of biofuel from jatropha will occupy land and requires water that may be also needed for food and feed production.

3.2 From seeds to biofuel

The fruit contains a coat which can be removed during harvesting and left on the ground as an organic fertilizer. The relative composition of the fruit is 30% coat and 70% seeds. The water content of the coats is 26% but the seeds contain only 6.8% water. Recent data reported by Jongschaap et al. (2007) are used in the calculations in this study.
The jatropha seeds can be treated to give three different kinds of feedstock and are presumably processed into three streams of biofuels: the liquid oil and the solid substances shells and seedcake (composition of the seeds, see Table 1). Shells are removed from the seeds leaving the oil containing kernels. After extracting the oil from the kernels the residue is seedcake, also called press cake, which contains a minor share of oil. It also contains a lot of nutrients. The three types of biomass can be utilized in different ways (Table 1) but because some key data are lacking only the bold printed applications are analyzed in this study.

Table 1 Components of jatropha seeds after processing (removing shells and pressing oil)

Biomass	Phase	fraction	Utilization
Oil	Liquid	37%	**Biofuel**, soap production, insecticide, medical use
Shell	Solid	23%	**Combustibles, organic fertilizer**
Seedcake	Solid	40%	**Organic fertilizer**, **combustibles,** biogas production, fodder (after detoxification)

To our knowledge the use of pesticides in the commercial production of jatropha oil has not been documented. The FAO has recently finalized a study on environmental impacts of large scale energy

crops production, with special emphasis on jatropha (UN Energy, 2007). Table 2 lists some properties and claims that have been attributed to jatropha.
It is expected that research activities will improve the jatropha plant and that insight will be gained on the circumstances that enhance the yield. An average lifetime of 40 years for a jatropha tree is assumed, although based on vague data. Probably this will be shorter as poor performing trees will earlier be replaced with improved varieties. Figure 2 shows that we assume a lifetime of 20 years.

Table 2 Characteristics ascribed to jatropha as an energy crop

Property	**Opportunity/Impact/Produce**
Perennial	CO_2 fixation, positive effects on hydrology
Soil treatment	Ploughing not required
Shrub	Does not require tillage; intercropping possible
Toxic	No competition with food/feed
Drought resistant	Can survive dry periods
Low requirements of nutrients	Low impact on biogeochemical cycles
Low requirements soil quality	Use of “waste”, “marginal” or “idle” land
Seeds contain oil	Pure Plant Oil (PPO) and bio diesel

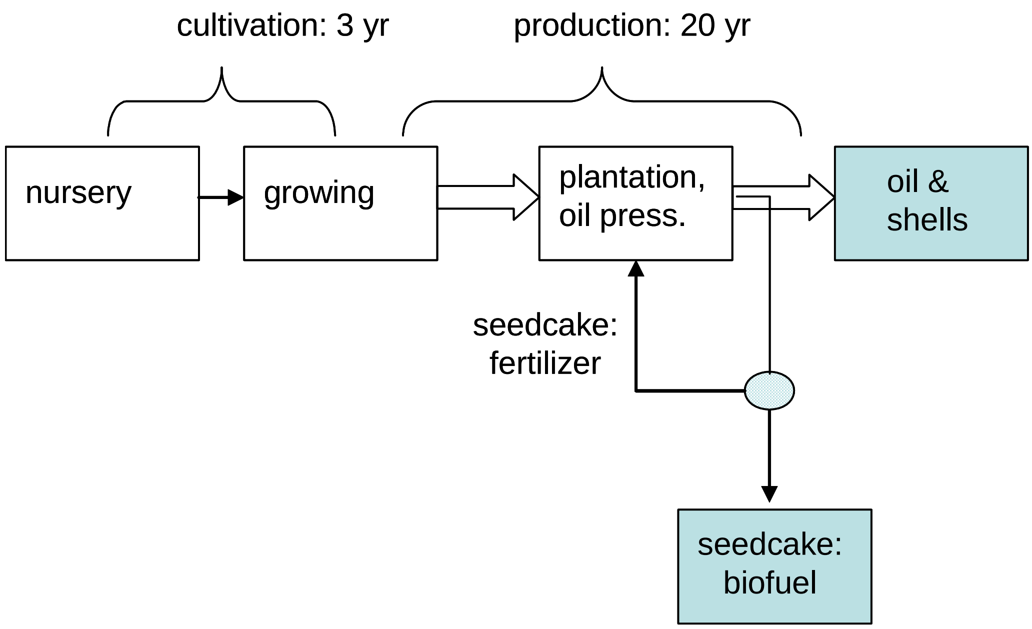

Figure 2 The jatropha biofuel system

The agricultural part of the production chain is given by Figure 2. In a jatropha biofuel chain many combinations of cultivation and utilization of the biomass are possible. For example, intercropping and biogas production from seedcake and subsequent utilization as cooking fuel in local households so avoiding deforestation in Tanzania. However, within the time constraints of this project it appeared not feasible to collect the required data. Moreover, the aim of the study is to *illustrate* that jatropha biomass can be converted into energy in a sustainable manner. The selection of the most sustainable variant requires considering of more possible combinations of cultivations and utilization of jatropha biomass than possible within the framework of this study.

4 Methodology

4.1 Prediction of the yield

Jatropha is a wild species and it is not surprising that reported yields of seeds vary an order of magnitude. These differences are poorly understood and can not be attributed to agronomical input-output relations because they are lacking. It is yet uncertain, whether jatropha is appropriate for agricultural production. Information such as “jatropha is less demanding with respect to water” and “can grow on marginal lands” is only qualitative. To be able to evaluate the expected yield or the GHG balance - both are elemental for a sustainability assessment at the profit and planet level - numbers are required.
Empirical relationships between supplied fertilizer and harvest have a preponderant influence on the GHG balance. For agricultural commodities (among others) maize, soy, palm oil and sugar cane) input-output relationships can be applied to compute the GHG balance. For wild species such agronomical relations are usually not available.
It was necessary to develop for jatropha a surrogate nutrient-yield relationship which is not demanding with respect to input data. The model however, should also account for the environmental restraints that are typical for the region in order to avoid shifting the burden.

4.1.1 The nutrient-yield relationship

Considering East African agricultural soils, it is essential to take into account the removal of nutrients by harvesting (Annex A). Assuming a steady state mass balance, the amount of nitrogen in the harvested jatropha biomass is taken as a starting point for estimating the demand of “fixed N”. The calculation is based on the assumption of maintaining a constant nitrogen concentration in the harvested fruit over time. The removal rate of nitrogen (in kg N/ha/yr) can be calculated by multiplying the harvest (in kg biomass/ha/yr) of nitrogen containing jatropha fruit with the nitrogen content of the fruit (in kg N/kg biomass). This should be balanced by replenishing the soil by the input of nitrogen (kg N/ha/yr). The same applies to phosphor and potassium however in this mass balance model nitrogen is considered the nutrient that limits the growth of fruit. The reason for this choice is that the GHG emission due to the supply of nitrogen is substantial whereas GHG emission attributed to phosphorus or potassium is small. First, the amount of N-containing fertilizer is higher and the production process is much more energy consuming. Secondly (and more importantly), due to biotic processes a fraction of the nitrogen is released as nitrous oxide (N_2O) which is a strong greenhouse gas. In this model the harvest of jatropha fruit is limited by the supply of nitrogen while all other inputs, i.e. light, CO2, water and other nutrients do not limit the yield.
Insert 1 demonstrates how a reduction of fertilizer input can be achieved if coats, leaves and cuttings are left on the soil and if the seed-cake is applied as organic fertilizer.

Insert 1. Example of nitrogen limitation
Assume that the uptake efficiency of N fertilizer is 50% and the N content of jatropha fruit is 2%. If the fertilizer input on an agricultural soil is 57 kg N/ha/yr, the maximum yield of jatropha fruit can be estimated. When 50% of the N supply is completely transferred to the harvest (neglecting that stem, roots and leaves also require this nutrient, although considerably less than the fruit that is harvested on a regular basis), the harvested fruit per ha can never contain more than 28.6 kg N. This is 2% of the mass of the jatropha harvest and as a consequence the total amount of fruit can never exceed
50 x 28.6 = 1,430 kg. After removal of the coats (30% of the fruit) this leaves 1000 kg seeds from which 375.7 kg oil can be extracted. For this example data on the composition of jatropha fruit and seeds of Jongschaap et al., (2007) are used. The oil has a very low content of nitrogen compounds. After pressing the oil from the seeds most of the nitrogen remains in the seed-cake which is rich in proteins. The seed-cake can be applied as fertilizer and so half of the applied N fertilizer is used again. In the next cycle in stead of 57 only 29 kg N fertilizer has to be supplied to the soil. This may change the GHG reduction but also agricultural management.

4.2 The evaluation of the GHG balance

The evaluation of the greenhouse gas balance is elemental for the comparison with Cramer's first criterion. The GHG balance indicates the reduction of GHGs when fossil fuel is replaced with an equivalent amount of biofuel. Although the definition of the GHG balance is straightforward and not intricate, methodological issues arise when emissions related to the production process of biofuels have to be assigned. If and how some processes evoke greenhouse gas emission that should be included in the GHG balance computation, is still a matter of debate[1] . The biological production model described in the former paragraph implies that the outcome of a GHG balance calculation is rather sensitive for the presumed N content of harvested biomass. Furthermore, the GHG balance also depends on the chosen value of the N uptake efficiency and the emission factor (fraction of fertilizer N that is emitted as N_2O).

4.2.1 Functional unit

In the goal and scope definition phase of an LCA it is common practice to select a functional unit. For energy derived from biomass, obviously, the functional unit is in units of energy. For example, the functional unit may be one kWh of electricity delivered to the customer. In combined processes such as combined heat-power installations (CHP) electricity and heat are generated in a certain ratio. For these processes a combined functional unit (kWh energy) is defined including both heat and electricity. The GHG balance is a dimensionless ratio of greenhouse gas emissions (in CO_2 equivalents) per functional unit.
For some purposes it may be convenient to compute the GHG reduction per ha of land per year because it has a closer relation to agricultural practice, usually expressed in terms of biomass production (yield) per ha per year or bio-energy per ha per year. It represents a kind of a "footprint" of the biofuel.

[1] Dutch consultancy bureaus and institutes (CML, Ecofys and CE) are still working on methods to calculate the greenhouse gas reduction of biofuels. Although a year ago the final version of the Cramer report (March 2007) announced publication shortly after the summer of 2007, methods referred to as "CO_2 tools" or "Greenhouse Gas Calculator", were not yet published when this study was performed.

4.2.2 Accounting for land use change in the GHG balance

At this moment it is still undecided how land use change should be accounted for in the GHG balance equation. One of the methodological obstacles is that it requires an accurate assessment of the carbon stocks of the land that is assigned to produce biofuels although there are cases with a clear evidence of carbon loss. Obviously, a change from rain forest to agricultural land would always give a negative C balance as estimates of above-ground biomass range from 11 ton ha-1 on agricultural land to 120 to 400 ton/ha-1 in tropical humid forests (Vågan et al., 2005). Changes in the biomass stock above and below the soil surface is included in the GHG balance. If it is not included in the GHG balance equation and the energy crops add more carbon than was removed by clearing the vegetation, the difference can be computed separately as fixation rate of CO_2. This may be profitable if for example, the aim is to receive carbon credits. Thus the GHG balance is modelled either for steady state processes or for both steady state processes and CO_2 sequestration averaged over a period of time of 20 years. Annex D schematically represents the geometry of smallholdings in Likamba near Arusha. Only two sides of the parcel are assumed to have a hedgerow and if the adjacent smallholdings have a similar arrangement and geometry each lot of land is surrounded by jatropha. When all hedges have a width of 2 m this raster covers 7.3% of the agricultural area with jatropha. In order to function as a fence the space between jatropha trees is between 0.3 and 0.5 m. This is significantly less than the spacing between jatropha trees on a plantation where that distance is 2 m or more. As a consequence, the maximum biomass a tree can attain is also different for both systems. On a plantation, where there is sufficient space (for example in a grid of 2 x 3 m), a jatropha tree may attain a weight of 50 kg after 20 years, provided that the tree is properly pruned during the first three years. In a fence the tree has less space and pruning will be carried out in a different manner. It is assumed that the final weight of a hedge jatropha is proportional to the distance between the trees. It is scaled according to 16 kg (0.3 m distance) and a maximum value of 50 kg (2 m distance between the trees).

The plantation near Makanya is assumed to replace degraded savannah vegetation. In the semi-arid part of northern Tanzania, most of the acacia trees in the savannah region have disappeared due to selective deforestation for the production of charcoal. A spacing of jatropha trees of 2 x 3 m (1667 trees/ha) would give a maximum biomass density of 2.3 kg below ground and 6 kg above ground per square meter or 83 ton/ha. It is tentatively assumed that the cleared vegetation has a biomass density that is significantly lower.
In case of net loss of carbon it will be accounted for in the GHG balance as carbon dioxide emission due to land conversion. The total emission due to the loss of carbon stocks is averaged over the defined time horizon (20 years).

4.2.3 Calculating the GHG balance

The greenhouse gases (GHG) balance compares the performance of the biofuel chain (emission of GHGs due to the production, processing and transport of biomass) to the reference chain (the emission of GHGs due to the combustion of an equivalent amount of fossil energy). The production of biomass is the result of the photosynthesis and involves extraction of CO_2 from the atmosphere. When the biomass is used to produce energy, the CO_2 is emitted again. Because on a relevant time axis the moment of extraction is close to the moment of emission the feedstock is considered to be carbon neutral and therefore extraction and emission cancel. The emission reduction due to replacing fossil fuel with biofuel is usually expressed as a fraction or percentage and referred to as the GHG balance:

$$GHG\,reduction(i) = \frac{GHG\,emission\,reference\ chain(i) - GHG\,emission\,biofuel\,chain(i)}{GHG\,emission\,reference\ chain(i)}$$

Index i specifies the chain and indicates the feedstock (oil, seed shells and seedcake), its use and in which power plants it is co-fired (Table 3). If the seedcake is not converted into energy it is reused in the field as organic fertilizer.
Many combinations are possible. However within the constraints of this project, the elaboration of the GHG balance is confined to some modes of energy production in Dutch power plants as given by Table 3.

Table 3 Biofuel chains and related functional units

Option	Feedstock	Plants	Functional unit
1	Oil, shells, seedcake	TPP_o TPP_c	1 kWh electricity
2	Oil, shells	TPP_o TTP_c	1 kWh electricity
3	Oil	CHP	1 kWh energy
4	Oil, shells	CHP, TPP_c	1 kWh energy
5	Oil, shell, seedcake	CHP, TPP_c	1 kWh energy

TPP = thermal power plants with co-firing capabilities (o = oil, c = coal); CHP = combined heat and power installation

GHG emissions of the reference chain
This represents CO2 emitted if one kWh is generated with fossil fuel. This term includes CO_2 emission due to extraction and transport of the fossil fuels. The conversion process in a power plant has a significant influence on the reference chain. For most of these processes the Ecoinvent database is used which is a standard LCA database with good data on energy generation processes. Sometimes the reference chain is also denoted as “avoided” or “saved” to indicate that generating 1 kWh of electricity (or heat) from the combustion of biofuels is neutral with respect to carbon. The three biofuels considered here (oil, shells and seedcake) are suitable for three types of power plants: oil for an oil-fired power plant (TPPo) or a combined heat and power plant (CHP) and shells and seedcake for a coal-fired power plant (TPPc).

GHG emissions of the biofuel chain
This is the negative side of the GHG balance and includes GHG emissions due to the production of biomass and subsequent processes. In accordance to the assumptions the nitrogen supply governs the biomass yield. It also determines the release of N_2O, the CO_2 emission due to manufacturing the fertilizers and due to transport of both biomass and fertilizers. All these emissions are proportional to the mass of the harvest or to the area that has produced that harvest (because N:P:K is constant).
In Annex B the GHG emission biofuel chain (i) is evaluated for the production of 1000 kg seeds/ha/yr which is in agreement to the supply of 57.1 kg N/ha/yr (see Insert 1). It can be subdivided in a fossil part (the first two terms) and a biogenic part (the last term):

$$GHG\,emission\,biofuel\,(i) = \sum_{k,m} M_{i,k,m} \cdot L_{i,k,m} \cdot Tr_k + \sum_{l} MF_{i,l} \cdot Fr_l + \sum_{g} MG_{i,g} \cdot GWP_g$$

with

$M_{i,k,m}$	= mass *m* in option *i* transported with transport mode *k*
$L_{i,k,m}$	= transport distance of mass *m* with mode *k* in option *i*
Tr_k	= kg emission of CO_2 for transport mode *k* per ton mass per km
$MF_{i,l}$	= mass of fertilizer *l* in option *i*
Fr_l	= kg CO_2 emission due to the production of one kg of fertilizer *l*
$MG_{i,g}$	= kg GHG *g* (N_2O or CH_4), biogenic emission in option *i*

GWP_g = Global Warming Potential of gas g in kg CO_2/kg N_2O or CH_4

CO_2 emission characteristics for transport, production of fertilizer and emission of N2O are given in Annex B. In Table 4 the most ponderous parameters for the emission side of the GHG balance are given. These values determine the outcome of the GHG balance calculation to a high extent.

Table 4 key parameters for which GHG reduction is highly sensitive

Input parameter	Value
N uptake efficiency	0.5
N_2O emission factor	2%
N content fruit (g/kg)	1.95-2.15

Conversion from hectare year to kWh
For a defined jatropha chain, regardless whether a plantation or a jatropha fence around a smallholding property is concerned, the production of biomass per hectare is evaluated. With conversion factors which are specific for each option i (see Annex B) the emission of CO_2 equivalents per ha per year is transformed into CO_2 emission per kWh. GHG emissions of the reference chain related to area and time (ha·year) is proportional to the emissions related to the functional unit of energy delivered to the customer (kWh) and a similar reasoning applies to the biofuel chain. For combined processes, CHP or a combination of CHP and co-firing in a TPP, the functional unit is kWh energy in different ratios of electrical energy and heat. For option 3 (only oil feeds the CHP) the functional unit is energy (kWh) with an electricity/heat ratio of 48/52 (48%). If the oil fed CHP is combined with conversion of seed shells (option 4) or seed shells and seedcake (option 5) into electricity in coal-fired power plants this ratio increases (see Table 6).

4.2.4 Calculating the difference in carbon stocks

Land conversion causes a carbon stock change. According to the IPCC's *Guidelines for National Greenhouse Gas Inventories* (2006), changes in biomass are estimated according to the so-called Stock-Difference Method. This approach is appropriate if land is converted to a new land-use category. The convention is that all emissions and removals associated with a land-use change are reported in the new land-use category. The method relies on the assessment of carbon stocks in relevant pools at two points in time. From the presumed lifecycle of jatropha in an agricultural environment (20 years) the annual difference in carbon stock is calculated as carbon dioxide emission or uptake per hectare per year. The maximum total weight of a jatropha tree on a plantation has to be known. During the nursery stage the tree is pruned for optimal branching. This determines the shape of the jatropha and improves its yield. Furthermore the height of a plantation tree may not exceed 2 or 2.5 m as harvesting would be too laborious. A maximum value of 50 kg after 20 years is assumed. To check this assumption a visit was paid to a plantation where since 6 years jatropha trees are cultivated.

Sequestered carbon may be eligible for Clean Development Mechanism (CDM) and if not it may by subsidised voluntarily by organisations like Trees for Travel. CDM is an arrangement under the Kyoto Protocol and allows industrialised countries with a greenhouse gas reduction commitment ("Annex 1 countries") to invest in projects that reduce emissions in developing countries. This could be an alternative to more expensive emission reductions in industrialised countries. Carbon fixation may be a clear incentive to use existing arable land and not permanent grassland, savannah or forested land.

It is assumed that on agricultural land, jatropha will grow on bare soil and will not replace existing biomass (see Figure 3). The introduction of jatropha hedges will cause a significant and quantifiable gain of biomass. Carbon fixation can be estimated and converted into financial profits for the smallholders. In environmental impact assessment it is appraised qualitatively for its positive role in the combat against erosion.

Figure 3 Settlement of smallholdings in Likamba (Arusha) and its environment

4.3 The socio-economic evaluation

Companies and NGOs were consulted to compare prices farmers receive for jatropha seeds. Federal authorities of the United Republic of Tanzania were contacted in Dar es Salaam to learn their opinion on export of jatropha biofuels to the Netherlands. In a socio-economic evaluation it would be desirable to examine more agricultural management systems than the two described here. For reasons of consistency we evaluate only two systems.

4.3.1 The smallholdings (Arusha)

The small farmers own their land and have a contract with Diligent. As contract farmers ("outgrowers") they obtain information from Diligent on how to grow jatropha. The outgrowers receive the seeds for free and can sell the harvested seeds for an agreed price to Diligent at collection points (in May 2008 the price is Tsh 80 per kg[2]). They are allowed to sell to another company if a higher price is offered. The analysis includes an assessment of the profits for the outgrowers. On the profits side there are the seeds, CDM money and the long term influence of stemming erosion. The latter is, however, difficult to quantify. Only the purchase of fertilizers is on the cost side.

[2] Information from Ruud van Eck of Diligent (26 May 2008)

During the mission in November 2007 Diligent brought the project team in contact with a community of local farmers. The purpose of that visit was to learn the opinion of this community with respect to the introduction of jatropha and to assess physical aspects of subsistence farming, including the infrastructure and availability of irrigation water during the nursery phase of jatropha. Eneco explained their interest to purchase jatropha seeds on the condition that it is also profitable for the rural population.

4.3.2 The plantation (Makanya)

Makanya was visited two times to gain information on the program Smallholder Systems Innovations (SSI) in integrated watershed management. The possibility was examined to set up a jatropha plantation. In this vulnerable semi-arid tropical river basin, water is a limiting factor. SSI is a multidisciplinary project, with participation by several research institutions (SUA, IWMI, and Unesco-IHE). The SSI project is an integrated and applied research program on how to balance water for food and nature. Particular focus is given to investigate the opportunities to upgrade smallholder rain fed agriculture through water system innovations, while securing water to sustain critical ecological functions. One of the challenges is to explore the possibilities to include a jatropha plantation in the SSI program.
The physical constraints for livelihood farming were discussed during a visit to the SUA office on 13 November 2007. The community of Makanya is vulnerable for dry spells and during the 2005 drought food security was at a precarious stage.

During the second mission (February, 2008) information on the economic viability of jatropha bio-energy production was obtained through a visit to Peter Burland. He runs a jatropha plantation belonging to the Kikuletwa farm at TPC, a small sugar estate village not far from Moshi. On this plantation the jatropha trees are more than five years old. The primary goal of this visit was to make a rough estimation of the weight of full grown trees but also to obtain information on agricultural management such as the average yield and the requirements of water, nutrients and pesticides.

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5 Results

5.1 The ecological impact

5.1.1 General

The greenhouse gas reduction accounts for all steady state GHG emissions in the life cycle of the biofuel: processes related to harvesting, biomass treatment and transport, the production of fertilizers and biogenic emissions. The change in soil quality and biodiversity is only qualitatively assessed. Emissions of acidifying, eutrophying and toxic substances are not included. The GHG balance is evaluated for a moderately low supply of fertilizer, corresponding to 57 kg N/ha/yr.

5.1.2 GHG balance for smallholdings

All calculations have been conducted on the assumption that the soil is fertilized only on the strip where the jatropha fence is located. For the smallholding system 7.3% of the area is covered by jatropha and only that part is fertilized at a supply rate of 57 kg N/ha/yr. The whole agricultural area receives 4.2 kg N/ha/yr (7.3% of 57 kg) due to only fertilizing jatropha. The configuration in Annex D pertains to a property with an area of one acre (4047 m^2) which has on two sides a jatropha fence with a tree spacing of 0.4 m. The GHG balance for an export chain of oil, shells and seedcake to conventional power plants in the Netherlands (option 1) is given by Figure 4.

5.1.3 GHG balance for plantations

For a similar fertilizer supply, Figure 4 almost entirely represents the outcome for the plantation system. The small difference is attributed to the small change in transport emissions in the biofuel chain, which in its self is already small. The similarity between smallholding and plantations can be understood from the vertical axis as it is expressed in kg GHG per kWh, irrespective whether the biomass comes from a plantation that is fully occupied with jatropha or only for 7.3%. This assumes that the yield per area covered by jatropha is equal because the N supply rate is equal. In Annex B the results of CO_2 savings and emissions *per hectare per year* are given. This enables a comparison between smallholdings and plantations and illustrates the information loss if CO_2 emission quantified per kWh in stead of per hectare per year.

The change in carbon stock for a smallholding
Unlike a plantation where the biomass per tree - if properly pruned - can be up to 50 kg because there is sufficient space (for example in a 2 x 3 grid each tree has 6 m^2), in a jatropha fence the distance is only 30 or 40 cm with consequences for the maximum weight a tree can attain. In the model the weight per tree is proportional to the distance and in this range a tree is assumed to attain a weight between 14 to 18 kg. In Annex D data for the increase in biomass and carbon fixation per hectare are given.

The change in organic carbon stock on a plantation
Literature data were used because it was not feasible to estimate the above and below ground carbon stock on the chosen location. According to Vågen et al. (2005) the tree savannah in North Tanzanian once had an above-ground stock of 65 (± 35) ton ha^{-1} but decreased to 20 ton ha^{-1} because nearly the whole region has been selectively deforested due to gathering fuel wood. According to UNFCCC (2003) the tree savannah system of Miombo in South Tanzania with trees up to 20 m high, has an

above-ground biomass stock equal to 75 ton ha^{-1} which is close to 65 ton ha^{-1} assigned to tree savannah by Vågen et al. (2005) before encroachment. The difference in carbon introduced by jatropha when replacing the original vegetation and averaged over a period of 20 years can be expressed as *carbon fixation rate*.

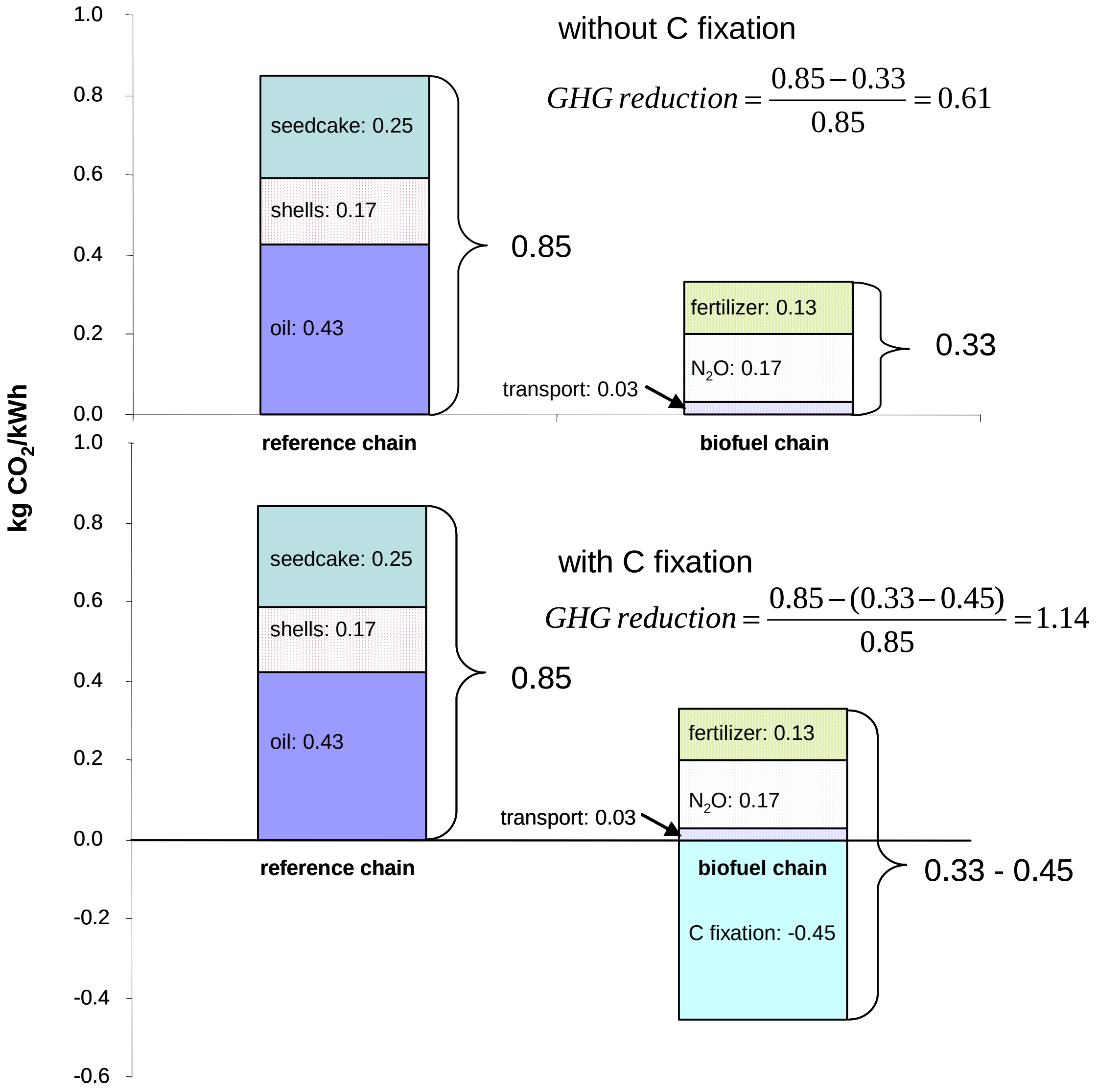

Figure 4 GHG balance for the plantation case calculated from GHG emission (in CO_2 equivalents) per unit electrical energy produced by Dutch TPPs.

The carbon stock on a plantation with a spacing of 2 x 3 m (1667 trees) equals 83.3 ton/ha (dry weight) or 39.6 ton carbon/ha. This is equivalent to 145.1 ton CO_2 stored per hectare. Assuming that 72% is above ground this would correspond to 0.036 ton x 1,667 = 60 ton biomass per hectare. This is in the range between 20 and 65 ± 35 ton/ha, given by Vågen et al. (2005) for *tree savannah degraded* and unaffected *tree savannah*, respectively.

The second mission in February 2008 made possible a better impression of the biomass stands. Beyond the planned charco dam which is approximately 5 miles away from the rail road, the biomass stock is remarkably higher than close to the road but it is certainly less than 83.3 ton/ha. In the vicinity of sisal plantations nearby the road the carbon stock is much lower. Here the plantation was foreseen in November 2007. However then it was not recognized that this strip of land is sparsely covered by bush due to the fact that rain water can hardly infiltrate. It is not clear yet if this type of soil degradation is anthropogenic or natural. Nevertheless, even when it is acknowledged that the location of the second choice is relatively lush, there will be an enhancement of carbon stock if the vegetation is replaced with jatropha trees, although the difference is smaller than if the land close to the road would be designated for a large scale cultivation of jatropha.

Options 2 to 4 represent application of seedcake as fertilizer instead of biofuel. Options 3 to 5 involve energy production from biofuels in a CHP or in a CHP in combination with a coal-fired TPP. Results of GHG reduction for a plantation in Makanya are given in Table 5. For smallholdings the GHG reduction values without CO_2 fixation are only 1% lower which can be attributed to longer road transport. If CO_2 sequestration is included the GHG reduction is higher than 300%.

Table 5 Utilization of biomass in energy production (if seedcake is not combusted it is used as organic fertilizer), percentage electricity of delivered energy and GHG reduction.

Option	Feedstock			Electricity	GHG reduction	
	Oil fired TPP	Coal fired TPP	CHP		Without CO_2-fixation	With CO_2-fixation
1	Oil	Shells, seedcake		100%	61%	114%
2	Oil	Shells		100%	56%	132%
3			Oil	48%	30%	154%
4		Shells		55%	50%	136%
5		Shells, seedcake	Oil	62%	57%	115%

5.2 Social impacts

5.2.1 General

Most people live in rural areas, where adequate energy services are lacking. Nationally, 97% of energy consumption comes from biomass, mainly fuel wood. This creates serious problems, including soil erosion, deforestation and health problems such as respiratory ailments. Of the country’s 39 million people, 36% live below the poverty line. The economy of Tanzania strongly depends on agriculture, which accounts for slightly less than half of the national GDP (see Annex C). Nevertheless, its share of the export is 85% and 80% of the work force depends on agriculture.

5.2.2 The smallholdings

Information is used from an analysis of the prospects of jatropha biofuel for Tanzania according the concept of Strategic Niche Management (Van Eijck and Romijn, 2008). From interviews, they analyzed the conditions that determine the attractiveness of different jatropha uses. The question was how attractive it would be for people to cultivate jatropha, and to press the seeds to obtain oil. From the interviews with villagers it appeared that cultivating jatropha is not very different from current agricultural practices. Farmers prefer to have a fence around their land to protect their crops against animals. However, the yield of staple food (maize) and some vegetables is the main production from which smallholders are dependent. Most of the family members of the smallholdings are used to sell the products on the market. 59% of rural households in Tanzania sell food crops for onward processing (National Bureau of Statistics, 2000). The farmers can not live from solely cultivating jatropha because they can not overcome the nursery period of 2 to 3 years without yield and income. Nevertheless Diligent succeeded to persuade many smallholders to grow jatropha in hedges. In 2007, the number of contract farmers has risen from 300 to 1000.

For the smallholders, the introduction of jatropha hedges has positive impacts from a social perspective:

- no destruction of village or social structures;
- no displacement of people;
- risk avoidance: no dependency of a sole income source;
- contribution to stem erosion.

Erosion has an adverse affect on both the infrastructure and the soil quality. Land degradation erodes resilience of the community because it increases the vulnerability of the local populations that depend on the land for their livelihoods. Although less erosion does not alleviate the poverty immediately, it may help to improve the efficiency of agriculture. On the long term the community will take benefit from the increased water holding capacity of the soil. Although not spectacular on the short term, jatropha fences can contribute to a gradual improvement of the productivity of the land. Together with better maintenance of infrastructure this is a requirement for the community to escape the poverty trap (Lybbert et al., 2004). The poverty trap is the result of a general marginalization of the rural area, manifested by a lack of infrastructure, public services and market access, and by human capability deprivations. Even if the jatropha hedges cause only a marginal supplement to their income, less erosion will have a positive effect on the long term. Moreover, this positive effect is lengthy and differs from other small investments they can afford. Usually these small investments only result in temporal improvements due to internal feed-backs that push the system back.
There are some similarities with experiences in Mali, although environmental conditions are quite different. During the 1970s and 1980s, the Dutch Royal Tropical Institute and local partners encouraged farmers to plant jatropha in hedgerows of their fields and on eroded land. Today, Mali has more than 20,000 kilometres of jatropha hedges which proved successful in combating desertification. These hedgerows were introduced several decades ago only for that purpose but now jatropha seeds are collected for the production of oil.

5.2.3 Plantation

In Tanzania the private sector and NGOs are now executing many activities and programmes which two decades ago were performed by the government. This change has necessitated the private sector and individuals to initiate projects and schemes. A good example is the so-called charco-dam owners of Makanya. Water is the limiting factor in this region and several reports describe attempts to cope with droughts, for example a study on community-driven smallholder irrigation in dryland by Makurira et al. (2007). Harvesting rainwater with charco-dams is an ancient technique that is easy to adopt, accessible, affordable, environmental friendly and suits the local conditions. Although it is understood that harvesting rainwater in semi-arid areas is of vital importance for crops, livestock and domestic uses, the adoption rate is low, probably due to institutional factors, such as land tenure system. While land security may be a precondition for investment in maintaining land productivity, in some settings, investment on land may help farmers to obtain *de facto* right over land. According to Paul M. Kiwele

(Ministry of Energy and Mines of Tanzania) land belongs to the government and is leased for specific time periods to persons/companies (Workshop, Utrecht 11 January, 2008). This reduces the risks of conflicts on land ownerships. Tenure arrangements of marginal lands are not always clear. “Marginal land” or “waste land”, has been defined previously by the colonial authorities (Shiva, 2008). It is to indicate everything without revenue from agriculture (“revenue category of wasteland”). “Idle land” in the Makanya region is officially owned by the Tanzanian government but the poorest people are allowed to use it.

Charco-dams nearby Makanya have been constructed for livestock keeping. This is the only reliable source of water since the Makanya River has run dry. The livestock of agro-pastoralists living in Makanya village relies on harvested water.
A simple irrigation system that suits local circumstances can also be applied to jatropha plantations in this region with the advantage that it would create employment for the numerous day labourers who now depend on risky jobs. It may generate income of local people and if successful it may revitalize the local agricultural sector.

Jatropha can survive drought, however water (rain or irrigation) is needed for sufficient oil production. There is a risk for competition on water, since all (local) activities require water in the same dry period of the year. A jatropha plantation should not compete with farmers who also need water for their cattle (Mul, 2008). During the short visit in February 2008 it was observed that the land several miles remote from the main road is not unused. Five miles west from the road the bare soil changes into a more lush area because rain water can penetrate into the soil. Here a charco-dam is foreseen to irrigate the plantation. The small charco dam that is already there was without water during the visit because it was at the end of the dry period. Earlier in the dry season it could have been a water source for the herds of cattlemen. During the visit of one hour two groups were encountered pasturing their cattle. It should be investigated, whether the introduction of plantations may be in conflict with their interests as less land will be left. Pasturing cattle on this vast land is a traditional way to spread the pressure by humans on dry land. The negative effects can be counteracted if additional measures are taken to improve the hydrological conditions. Rainwater may be harvested in a more efficient way for the benefits of the whole community, including the cattlemen. In cooperation with other Dutch partners, the Technical University of Delft (the Netherlands) is developing a research project on this interesting opportunity.

5.3 Economic impacts

5.3.1 General

The model, used for the GHG balance calculation was also applied to predict the yield of jatropha seeds. The fertilizer supply and yield of jatropha seeds are converted into costs and benefits, respectively. There is a great difference between the price per kg seeds the small farmer receives and the price on board of an oceanic tanker in Dar es Salaam.

5.3.2 Costs of fertilizer and irrigation

According to Diligent the smallholders are often too poor to purchase fertilizers and they use it occasionally if they have the financial means. The nutrient depletion problem in SSA has been attributed to the high prices smallholders have to pay (Sanchez, 2002). In Sub Saharan Africa fertilizers cost two to six times compared to Europe, North America, or Asia. According to Sanchez (2002) a metric ton of urea costs in Europe about $ 90 (free on board) but $ 120 delivered in the ports of

Mombasa (Kenya). However prices are soaring due to transport and reach $ 400 in Western Kenya (700 km away from Mombasa). The difference of $ 280 is the financial burden of all processes involved in the transfer of one ton fertilizer over a distance of 700 km in a region with a poor infrastructure. Apparently, it adds $ 0.40 per ton for every km of transport to the price of urea fertilizer. As Arusha is located approximately 350 km west of Mombasa, the price of urea for smallholdings is estimated to be $ 260/ton. From the nitrogen content of urea (0.466) the price per kg nitrogen can be estimated. Smallholders are assumed to pay this price to replenish their soil with nitrogen when cultivating jatropha. Table 6 gives the price in Tanzanian shilling (Tsh) per kg N per hectare agricultural land. The nitrogen supply corresponds to 57.1 kg N per hectare land that is fully covered by jatropha, giving a yield of 1000 kg seeds. Because this is at the lower end of the range of the yield of jatropha seeds we also calculate a scenario for a relatively high yield as is indicated in Table 6. The high yield scenario relates a supply rate of 171.4 kg nitrogen per ha to a yield of 3000 kg seeds. Makanya is 140 km south of the town of Moshi and also approximately 350 km away from Mombassa and also 350 km remote from the main port (Dar es Salaam). The main road from Dar es Salaam to Makanya (and also from Makanya to Arusha) is in a good condition and the costs given in Table 6 for the plantation scale are probably lower. These figures should be interpreted as worst case. In this estimation the costs of other fertilizers (P and K) are ignored. Agriculture near Arusha is assumed entirely rain-fed.

Table 6 Costs of nitrogen fertilizer for the farmers in Tanzanian shillings (Tsh). The currency ratio is 1200 (Tsh/$)

Jatropha system	agricultural scale	smallholding		plantation	
	option	1	2	1	2
% land covered by jatropha		7.3%		100%	
N supply (kg N/ha/yr) **low yield**		4.2	2.1	57.1	28.6
Costs N supply (Tsh/ha/yr) **low yield**		2,809	1,405	34,831	17,446
N supply (kg N/ha/yr) **high yield**		12.59	6.30	171.4	85.7
Costs N supply (Tsh/ha/yr) **high yield**		8,428	4,214	114,746	57,373

5.3.3 Revenues

The smallholdings

Seeds are sold at prices in the range of 100 and 400 Tsh per kg. According to information received in November 2007 Diligent was prepared to collect the seeds at points near the smallholdings at a price of 100 Tsh/kg, provided that the water content of the seeds is not too high. At the same time the NGO Kakute was prepared to pay 200 Tsh/kg during the high season when supply is high and up to 400 Tsh during the low season. Kakute uses the seeds for the manufacturing of soap exclusively. According to Diligent this price can not be maintained and only be offered because Kakute receives subsidies. Diligent provides the outgrowers with sowing seeds for free and guarantees to buy the harvested seeds for a fixed price (100 Tsh/kg) at collection points in the neighbourhood.

During the visit in February 2008 it appeared that there is a run on jatropha seeds because the tree has gained popularity over the last year. Almost all seeds are now sold as sowing seeds which has pushed up the prices. It is now difficult to fix the price of the seeds, as outgrowers are enticed to sell the seeds to an organisation for a relatively high price which is temporary. Kakute admitted that the high price they offer will decrease soon. Considering the keen competition between Diligent and Kakute, currently on the occasion that jatropha seeds now come from a cash crop rather than an energy crop, and the expectation that the price of energy feedstock in the future will rise, a price of 200 Tsh/kg for jatropha seeds is assumed.

At this moment CDM (Clean Development Mechanism under the Kyoto protocol) only supports carbon sequestration by forestry plantations. It is yet unclear if carbon fixation by jatropha hedgerows, *as a measure to stem erosion*, is qualified to benefit from CDM. Trees for Travel, a Dutch a charity, is specialised in forestry projects in developing countries. Among other projects this organisation is organizing the planting of jatropha hedges in Mali in order to sell CO_2 sequestration as carbon credits. The smallholdings in the Arusha region may be eligible in the future. Here we calculate with a presumed remittance of $ 20 per ton CO_2 sequestered (which is now an optimistic estimation). The revenues from the seeds and carbon sequestration are compared in Table 7.
In Table 8 the net revenues are summarized per acre and compared to the minimum wage. One acre (0.4 ha) was taken as the area of a subsistence farm of one family. The minimum wage is taken as a reference, which appears to be $70 per month, whereas the unions argue that $ 280 is a fair wage. This information was obtained from Tatedo, an NGO in Dar es Salaam.
Jatropha seeds can only provide additional income. The revenues are too low for the farmer to serve as main income. Although other crops are grown on subsistence farms, the smallholder typically depends on the production of maize which is staple food in the region.

Table 7 Benefits per hectare; for CO_2 sequestration a spacing of 0.4 min the fence is assumed; price per kg seeds is 200 Tsh; currency Tsh/$ = 1200

Benefits	Yield (kg/ha/yr)	Revenues (Tsh/ha/yr)
Yield low	1000 (seeds)	15,754
Yield high	3000 (seeds)	47,262
Carbon sequestration	595 (CO_2)	36,302

Table 8 Revenues per smallholding of 1 acre (0.4 ha); price and currency ratio of Table 8 are assumed. Percentages are with reference to the minimum wage. For CDM $ 20 per ton CO_2 absorbed is assumed.

Income	$	Tsh	Additional income
Minimum wage/year	840	1,008,000	-
Net revenues jatropha low yield	4.37	5238	0.5%
Net revenues jatropha (C seq.) low yield	16.27	19519	1.9%
Net revenues jatropha high yield	13.10	15,715	1.6%
Net revenues jatropha (C seq.) high yield	25	29,996	3.0%

An increase between 0.5 and 3% with respect to the minimum wage is low, however, 93% of the land is still available for food production and better protected against animals and erosion. Moreover, it is questionable if the minimum wage is an appropriate reference for the average income of a smallholder. The differences in incomes between urban and rural Tanzania are great as can be deduced from the urban share of the GDP earned by only 20% of the population (Table 9). Agriculture employs 80% of the work force but contributes only 43% to the GDP. Corrected for this difference the “GDP per urban capita” would be $ 3140 or 2.6 times the GDP per Tanzanian capita ($ 1100). For rural regions these figures are respectively $ 589 and 0.54 times the GDP. For urban people a minimum wage of $ 70 is probably a factor 2.6 too low whereas in agricultural regions $ 38 (= 0.54 X $ 70) would be more appropriate as a reference to put the additional income from jatropha in a more appropriate perspective. Table 10 indicates that jatropha may increase a “typical smallholdings income” by 3% if no carbon sequestration subsidies are acquired.

Table 9 Allocation of gross domestic product (GDP)

People (39 million)	Fraction
Urban	20%
Rural	80%
GDP ($ 1100/capita)	
Urban	57.2%
Rural	42.8%

Table 10 Revenues per smallholding of 1 acre (0.4 ha); price and currency ratio of Table 7 are assumed. Percentages are with reference to assumed rural minimum income. For CDM $ 20 per ton CO_2 absorbed is assumed.

Income	$	Tsh	Additional income
Minimum rural income/year (12 x $ 38)	453	544,320	-
Net revenues jatropha low yield	4.37	5,238	1.0%
Net revenues jatropha (C seq.) low yield	16.27	19,519	3.6%
Net revenues jatropha high yield	13.10	15,715	2.9%
Net revenues jatropha (C seq.) high yield	25	29,996	5.5%

<u>Plantations</u>

A harvesting rate of 5 kg seeds per hour is reasonable (information from Diligent) which is somewhat lower than estimations by Peter Burland who considers jatropha not an appropriate plantation species. One labourer is expected to collect 100 kg of fruit (= 70 kg seeds) per day.

Today jatropha seems a cash crop rather than an energy crop as its reputation as a very promising oil producing shrub has spread out. As a consequence, the current price per kg seeds is much higher than justified by the price if it would replace conventional oil. For starting a plantation (1 ha) at least 2 kg seeds is required (1 kg = 1500 seeds).

Table 11 Financial data of a plantation of one hectare. L/H = low/high fertilizer use (57.1/171.3 kg N/ha/yr); labour costs are $0.05/kg seeds. The price of seeds and seedcake are 0.33 and 0.06 $/kg, respectively.

Input/output	Costs ($)	Benefits ($)	Net result ($)
Maintenance	150		
Labour (L)	50		
Labour (H)	150		
N fertilizer (L)	31.87		
N fertilizer (H)	95.62		
N fertilizer (L)*	15.94		
N fertilizer (H)*	47.81		
Seeds (L)		333	101
Seeds (H)		1000	604
Oil (L)*		345	113
Oil (H)*		1033	685

* Seedcake is used again as organic fertilizer, therefore less fertilizer has to be purchased but it can not be sold for $0.06/kg

According to Peter Burland a jatropha monoculture is vulnerable to pests. Herbicides necessary to control weed and to protect the green parts of the plant, fungicides and insecticides would be indispensable. He runs a plantation with irrigation but surprisingly without using fertilizers.

Furthermore, the harvest has to be protected against pigeons eating the seeds. Approximately $ 150 would be required for the maintenance of one hectare.
To be able to conduct the calculation we have used the numbers obtained from Burland because other data were not available. We are aware that the information obtained from Burland may be biased and it certainly does not provide a bright perspective. Therefore, the outcome of the cost benefit analysis should be considered worst case.

The labour costs were estimated from the assumption that one person is able to collect 70 kg seeds per day in 20 days per month. The labourer is supposed to earn a minimum wage. One hectare produces between 400 L of oil (or 1 ton seeds, low scenario) and 1200 L (3 ton seeds, high scenario). The prices of seed and seedcake (in $ in Table 11) are based upon 400 Tsh/kg and 72 Tsh/kg, respectively.

6 Discussion

6.1 Assumptions

Ecological and economic impacts of jatropha cultivation in North Tanzania were assessed from a mass balance model. As a continuous production chain of jatropha biomass is concerned, the mass balance assumes steady state conditions and predicts the yield of jatropha from one agronomic input parameter: the nitrogen input supplied as fertilizer. The assumption of biomass production that is limited by the nitrogen input is pivotal in the model. Crucial for the model are data with respect to the distribution of nitrogen over the distinguished parts of the plant and the concentrations. Information was derived from a recent survey on jatropha by Jongschaap et al. (2007).

In the model it is presumed that the removal of nitrogen per ha per year due to harvesting, due to direct and indirect emission, due to transport processes such as surface run-off and leaching from the soils, be equal to replenishing the soil with N nutrients. This approach may be considered a realistic worst case; it avoids implausible combinations of low fertilizer and high yields. It is also preferable from the precautionary principle because a high GHG balance is misleading and unsustainable if it is based on a virtually zero nitrogen input *and* a high yield of oil. A high oil yield is inextricably bound up with a high production of seedcake which is rich in N containing proteins and other compounds.

6.2 Environmental impacts

6.2.1 The GHG balance

The GHG reduction is highly sensitive for the parameters of Table 4. Besides the nitrogen concentration of the harvested jatropha fruit, it is the uptake efficiency of jatropha and the emission factor of N_2O. The latter two have no dimensions: they are fractions of the N supply.
The emission factor for N_2O of 2% consists of direct emission (1%) and indirect emission (also around 1%), the uncertainty envelope though is high: from 0.1% to 5% (Mossier et al., 1998; Croeze, 2007).
For the nitrogen uptake efficiency the fraction of 0.5 was chosen. This is on the lower side of the range in between 0.4 and 0.8. Low and regular precipitation allows the crops to take up a relatively high fraction as the residence time at the root zone is rather long. For high rain rates a lower value is more appropriate.
Despite these rather conservative choices, the greenhouse gas balance (without C-fixation due to land use change effects) is positive and between 30 (if only oil is used) and 61% (if oil, shells and seedcake are used).
The nitrogen limitation in the calculation implies that for a given option, the greenhouse gas balance is virtually independent of the nitrogen fertilizer supply. Both the avoided CO_2 emission (the “reference chain”) and the emission of GHGs due to the production of biofuel (the “biofuel chain”) are both proportional to the N supply.

6.2.2 Uncertainties in cultivating jatropha

In estimating of the harvest a moderate supply rate of fertilizer is assumed (57.1 kg N/ha/yr) which corresponds to a yield of seeds of only 1000 kg/ha/yr. Jatropha is a rather new crop to cultivate and the plantation of Burland was the only one found with full grown jatropha trees. Nutrient depletion on the long term was not considered by Burland, neither the possibility of an improved yield if nutrients are supplied. This underscores the need for more research to improve the yield. The plantation was visited to observe full grown jatropha trees that have been optimally pruned during the nursery stage in order to estimate the biomass of a plantation tree. The weight of 50 kg per jatropha which was used in the calculation of the carbon fixation rate is probably an underestimation.

Improvement programs may develop varieties of jatropha with other properties. For example, if jatropha varieties originate with a concentration of nitrogen in the fruit equal to 1.5 in stead of 2% and the N uptake would be more efficient (0.6 in stead of 0.5), the GHG reduction would increase to levels of 55 and 75% depending of the chosen option. Moreover, with the 57 kg nitrogen/ha/yr the harvest of seeds would increase from 1,000 to1,600 kg. If 120 kg N/ha/yr would be supplied the yield improves to 3,300 kg/kg seeds.

There are no indications that cultivating and processing the seeds has a negative impact either on the regular food crops or the environment when jatropha is planted in hedges. The increase of water holding capacity of the soil will counteract erosion and improve the quality of the soil. This would require however, that the distance between the jatropha trees is only 0.3 m in stead of 2 m. This is far from optimal in agronomic terms and in such an arrangement it is doubtful if the nitrogen input - yield relationship we used to calculate the GHG balance is still valid to predict the harvest.

6.2.3 Carbon stocks

Conversion of natural ecosystems into agricultural land has been put forward as a major objection against biofuels. It may cause 60% depletion of organic carbon pool in soils of temperate regions and 75% or more in cultivated soils in the tropics (Lal, 2004).
The opposite of carbon loss (carbon sequestration) is beneficial, which means the transfer of CO_2 into long-lived terrestrial pools (trees and soils) and storing it securely so it is not immediately reemitted. Recently, Fargione et al. (2008) argued that unlike food-based biofuels in Brazil, Southeast Asia, and the United States which create a “biofuel carbon debt”, biofuels made from waste biomass or from biomass grown on abandoned agricultural lands planted with perennials incur little or no carbon debt and offer immediate and sustained GHG advantages. Here we have demonstrated that this is also true for jatropha fences around existing subsistence agricultural land. But also for the plantation case we calculated a net carbon gain in spite of the worst case assumptions with respect to the existing vegetation in the Makanya region. Although further investigations are needed to confirm this, a so-called carbon dept as recently described in alarming reports on biofuel production is unlikely if land in this region is changed in a jatropha plantation.

6.3 Social and economic impacts

At first sight the vast areas of “unused” land in Tanzania seems promising for the production of biofuels. Topography and climatic conditions, however, are rather limiting for the cultivation of crops. Only 4% of the land area is cultivated to feed 39 million people (CIA Factbook, 2008) and

approximately 30% of the area is national park or otherwise protected. A significant part of the land is inappropriate for cultivating crops but used for pasturing.
The search for a good location brought the project team to an area near the village of Makanya. In November 2007, along the main road vast areas of land near Makanya were noticed over a length of 60 km. This land is merely void with some sisal plantations of which some were thought to be “abandoned”. However, sisal has a cycle of almost ten years and there are episodes in which the plantation has an abandoned appearance. The hydrological properties of this region drove the project team to explore an area 7 km away from the road for better conditions. That land is also used by cattlemen to pasture their livestock as was observed when the project team visited the charco-dam. This however, would not necessarily be in conflict with the exploitation of a jatropha plantation of 300 ha. Water management can be improved by harvesting the intense and intermittent rainfall in a more effective manner. Recently, a research initiative for sustainable water management was taken to investigate the potentials to integrate a jatropha plantation in this area at the benefit of both farmers producing food and other people using the land.

Economic benefits from jatropha hedges seem negligible if we assume a price per kg seeds offered to the smallholders. In November 2007 a price equal to 100 Tsh/kg was mentioned by Diligent. This is equal to € 0.057 per kg and is not far from € 0.04 per kg which is the price that small farmers in Indonesia receive. They complain about these marginal profits from jatropha compared to other crops. A fast rising oil price may change this picture within a year.

6.4 Sustainable livelihood approach

The introduction and promotion of jatropha in Tanzania should be seen in the context of a sustainable livelihood approach. This approach provides a holistic and analytical understanding of the things that the poor might be vulnerable to, the assets and resources that help them thrive and survive, the policies and institutions that have an impact on their livelihoods and what sort of outcome they aspire to. All these aspect should be taken into account in the context of stimulating jatropha production. By doing so, better outcomes can be expected in terms of sustainable use of the natural resources base, more income, increased well-being, reduced vulnerability and improved food security.

7 Conclusions from testing the results against the Cramer principles

The Cramer criteria mentioned in the introduction have been elaborated into nine principles (Cramer Commission, 2007). Here we compare the principles with the outcome our project.

Principle 1 The greenhouse gas balance of the production chain and application of the biomass must be positive.
In spite of conservative assumptions on some key parameters in the GHG emissions calculation (N_2O emission factor of 2% and a nitrogen uptake efficiency as low as 0.5), the balance is higher than 60%. The conclusion is that this is in accordance to the criteria.

Principle 2 Biomass production must not be at the expense of important carbon sinks in the vegetation and in the soil.
This principle is certainly fulfilled for the smallholding chain; it adds even carbon to the soil. For the plantation chain this is less pronounced, although loss of carbon is unlikely. For confirmation, a refined assessment is preferred according to the decision tree in Figure 3. In this specific case, where the plantation is situated in degraded shrub lands we calculated a net carbon gain in spite of the worst case assumptions with respect to the existing vegetation in the Makanya region.
Conclusion: for smallholdings as well as for the plantation case the criteria are fulfilled.

Principle 3 The production of biomass for energy must not endanger the food supply and local biomass applications (energy supply, medicines, building materials).
Again for the smallholding chain the outcome is positive although land occupation of 7.3% implies that this fraction is lost for food production. However, improved soil structure and less erosion will probably more than compensate this. The livelihood of a farmer will significantly improve if additional financial means allows the application of fertilizer for the food production.
Conclusion smallholding case: this criterion is met.
For the plantation chain this is less univocal. On one hand the intended land is not used for food crops, neither is the water that is supposed to be harvested by means of charco dams. On the other hand the land is extensively utilized by Masaai cattleman. Masaai people are for their food almost entirely dependant on their cattle. If less area is available, the possibility of overgrazing increases. However, as no research is carried out yet to assess the situation, there is too little information available to draw any meaningful conclusion.
Conclusion plantation case: no conclusion possible yet.

Principle 4 Biomass production must not affect protected or vulnerable biodiversity and will, where possible, have to strengthen biodiversity.
At first glance this principle seems not applicable to the smallholding chain. However, wide spread jatropha fences will stem erosion and may improve the conditions on locations which are not used, so increasing biodiversity.
Conclusion smallholding case: meet.
For the plantation chain, the consequences land use change from degraded bush savanna into jatropha plantation should be assessed. A first step is to quantify the fraction of land use with respect to the whole area. Degradation of the biodiversity has taken place already The layout of plantations with specific corridors might improve biodiversity in the area under consideration
No conclusion is possible with respect to the plantation case.

Principle 5 In the production and processing of biomass the soil and the soil quality are retained or improved.
The concept of nitrogen limitation of jatropha cultivation in the model calculations is a safeguard against “high yield - low input” scenarios which ultimately will cause nutrient depletion. The positive GHG balance is based on replenishing the soil.
Conclusion: the criteria are fulfilled.

Principle 6 In the production and processing of biomass, ground and surface water must not be depleted and the water quality must be maintained or improved.
For the smallholding chain this is evident, also for the plantation if sustainable water management is implemented.
Conclusion: meets the criteria for smallholder, can technically be attained for the plantations if the right management is chosen.

Principle 7 In the production and processing of biomass the air quality must be maintained or improved.
If applicable the air quality is at least maintained.

Principle 8 The production of biomass must contribute towards local prosperity.
Smallholdings will have only a marginal benefit. The economic viability of a jatropha plantation in the Makanya region depends on the success to achieve domestication of jatropha and the possibilities to improve it. If varieties originate that produce a significant higher yield it might be financially interesting for the local community. Higher prices for fossil fuels will stimulate the development. Also the application of certification of biofuel production may positively influence the local prosperity.
Conclusion: Uncertainty whether Cramer’s criteria are met.

Principle 9 The production of biomass must contribute towards the social well-being of the employees and the local population
No attention has been paid to this aspect in this report and therefore no conclusions can be drawn.

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Annex A: Depletion of nutrients as an environmental and social problem in East Africa

Soil degradation is common in sub-Saharan Africa (SSA). Nutrient depletion is widespread in East Africa is a major cause of soil degradation and can be attributed to both socioeconomic and biophysical factors.

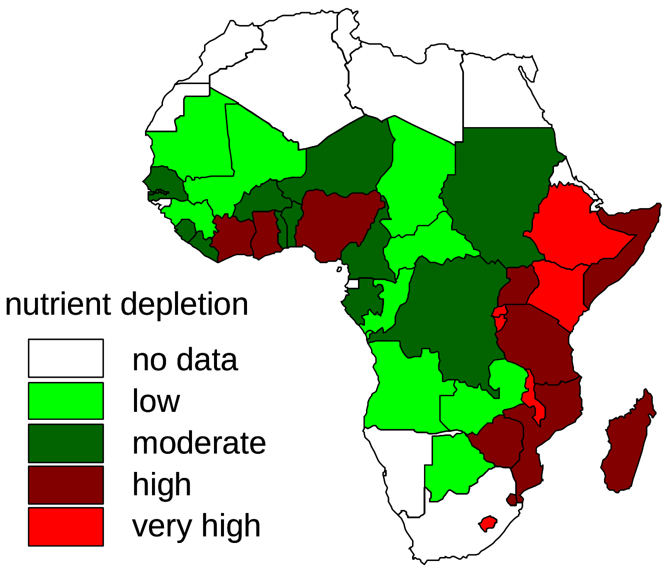

Figure A1 Lack of fertilizer replenishment in East Africa (Smaling et al., 1993)

The decrease of soil fertility and nutrient availability is closely related to mineralization of soil organic carbon (SOM). As plants and crops are used to mine nutrients by dismantling humic substances, the soils are not only depleted from nutrients but also from SOM. Reduced water holding capacity and fertility make the soil prone to erosion. Insufficient replenishment by nutrients is causing environmental damage. This situation is an obstacle for sustainable development, not only from an ecological point of view but also socio-economically. With respect to agricultural soils, depletion of soil fertility is a major cause of low per capita food production (Sanchez, 2002), caused by the breakdown of traditional practices and the low priority given by governments to the rural sector. Over decades, small-scale farmers have removed large quantities of nutrients from their soils without using sufficient quantities of manure or fertilizer to replenish the soil. This has resulted in an average annual depletion rate of 22 kg of nitrogen, 2.5 kg of phosphorus, and 15 kg of potassium per hectare of cultivated land over the last 30 years in 37 African countries (Sanchez, 2002). Nutrient depletion is most severe in East African countries, especially in Ethiopia, Kenya, Rwanda, Burundi and Malawi but also in Tanzania, Zimbabwe and Mozambique (Figure A) and the nitrogen depletion rate in North-Tanzania is probably even higher than 22 kg N/ha/yr. These extractive practices perpetuate marginal living and poverty as cultivating marginal soils with marginal inputs produce marginal yields. As a source of nutrients for growing crops, the SOM pool is a mean of production in subsistence farming systems. Soil degradation and erosion may be withstood by replenishing the soil with manure or fertilizer in combination with growing perennials.

Annex B: Evaluation of the different options

Evaluation of the reference and biofuel chains for energy conversion in thermal power plants, (option 1 and 2)

Calculation of reference and biofuel chains based on CO_2 per ha per yr
When a feedstock derived from jatropha, for example the seed shells with an energy content of 22 MJ per kg, is processed in a Dutch coal-fired power plant, the efficiency of the energy conversion is 35.3% (Table B1). In this power plant, the production of one MJ of electrical energy causes a GHG emission equivalent to 0.279 kg CO_2. The production of this amount of electrical energy avoids the emission of 0.279 kg CO_2. This would have been emitted if (fossil) coal were used as fuel. Further data with respect to the other biofuels obtained from jatropha seeds are given in Table B1.

Table B1 Data for calculating the reference chain (jatropha biofuels for Dutch power plants). [1] Jongschaap et al. (2007); [2] Openshaw (2000), [3] Knops (2008), [4] SimaPro (2007)

biofuel (% w/w)[1]		energy content (MJ/kg)	efficiency energy production (%)[4]	GHG fossil (kg CO_2/MJ)[4]	power plant
oil	37.6	40.7[2]	44.2	0.197	TTP oil-fired
oil	37.6	40.7[2]	82	0.09	CHP
shells	23	22[3]	35.3	0.279	TTP coal-fired
seedcake	40.4	19.3[3]	35.3	0.279	TTP coal-fired

The reference chain is first evaluated for the harvest of one hectare of jatropha trees which are arranged according to a grid 2 x 3 m. In the model the agricultural practice is fixed by the chosen nitrogen supply. For this illustration the N supply corresponds to a harvest of one ton of jatropha seeds per hectare per year. The avoided CO_2 per hectare per year can be calculated using data in Table B1. The results for the reference chain are listed in Table B2 which is a simplified representation (avoided emissions due to extraction of transport of equivalent amounts of fossil fuels are included but not listed separately).

Table B2 Results for the reference chain (two Dutch power plants): CO_2 avoided by the biofuel yield of one hectare (1 ton jatropha seeds/yr, see also Table B7)

biofuel	mass biofuel (ton/ha/yr)	energy biofuel (GJ/ha/yr)	electricity produced (GJ/ha/yr)	CO_2 avoided (ton/ha/yr)
oil	0.376	15.30	6.764	1.3325
shells	0.23	5.06	1.786	0.4976
seedcake	0.404	7.80	2.753	0.7673
		conversion factor (i = 1) =	0.00032 ha·yr/kWh	sum (I = 1) = 2.566
		conversion factor (i = 2) =	0.00043 ha·yr/kWh	sum (I = 2) = 1.798

For option 1 (all biofuels transported to the Netherlands and combusted in two TPPs) the avoided CO_2 amounts 2.566 ton/year. For option 2, the avoided CO_2 is equal 1.798 ton/year.

Calculation of reference and biofuel chains based on CO_2 per kWh electricity delivered
The conversion factors below Table B2 are calculated as follows. For i = 1, the three terms of produced electricity are added (11.1 GJ/ha/yr) and converted in 3093 kWh/ha/yr. Then the reciprocal is taken (0.00032 ha·yr/kWh). If i = 2 (seedcake is utilized as fertilizer) the conversion includes only two terms

and will be higher than for i = 1. The conversion factors are necessary to calculate savings and the emissions in kg CO_2 per kWh in stead kg CO_2 per hectare per year. A conversion factor (i = 1) equal to 0.00032 ha·yr/kWh has the meaning that 3.2 m^2 of agricultural land is required to deliver 1 kWh electrical energy if 3 biofuels are utilized (if 57.1 kg N/ha/yr is supplied giving a yield of 1 ton seeds). Obviously, if only 2 biofuels are used for the production of electrical energy more area is needed: 4.3 m^2.

Values needed for the reference chain and the biofuel chain are shown in Tables B3 and B4. GHG emissions of the biofuel chain depend on the fossil fuel input required for production and transportation of fertilizers. Also transport of biomass requires fossil fuel input. N_2O emission depends on N supply.

Table B3 Parameters used in the GHG balance calculations (Ecoinvent 1.2, 2007).

CO_2 emission	units	Value
Transport road (32 ton truck)	kg CO_2/ton/km truck	0.159672
Transport rail	kg CO_2/ton/km rail	0.035782
Transport sea	kg CO_2/ton/km rail	0.005387347
Fertilizer nitrogen	kg CO_2/kg N fertilizer	6.69
Fertilizer phosphorus	kg CO_2 /kg P fertilizer	0.71
Fertilizer potassium	kg CO_2/ kg K fertilizer	0.46
GWP N_2O	kg CO_2/kg N_2O	296

Table B4 Parameters of a jatropha plantation

Quantity	Units	Value
N supply (variable)	kg N/ha/yr	57.1
P supply (depend. on N supply)	kg P/ha/yr	19
K supply (depend. on N supply)	kg K/ha/yr	9.5
Yield (depend. on N supply)	kg seeds/ha/yr (dry matter)	1000
Emission N_2O in CO_2 eq. (dep. on N)	kg CO_2/ha/yr	531.6

The consequences of N limitation for the calculation of the GHG balance

The assumption of nitrogen limitation implies that the yield of biomass is governed by the supply of nitrogen: the harvest of jatropha seeds is proportional to the nitrogen fertilizer supply. This means that the "savings" of CO_2 per hectare is also proportional to the nitrogen input as well as the negative side of the balance, i.e. emission of GHG gases due to manufacturing of N-fertilizer (and other fertilizers which are assumed to have a fixed ratio with nitrogen), emission of N_2O (proportional to N input) and all transport emissions (biomass, bio-fuel, fertilizer). As a consequence, regardless whether the GHG balance is computed in terms of GHG avoidance/emission per functional unit (kWh) or in *production unit*, which is one hectare that is occupied for one year (ha·yr), the calculation produces identical results. For a given bio-fuel export chain with identical characteristics with regard to agricultural practice and related yield of biomass, chosen transport modes and conversion processes in power plants, the equation is:

$$GHG\,reduction = 1 - \frac{GHG\,emiss.biofuel\,chain^{fu}}{GHG\,emiss.reference\,chain^{fu}} = 1 - \frac{GHG\,emiss.biofuel\,chain^{pu}}{GHG\,emiss.reference\,chain^{pu}}$$

In the first part of the equation the quotient refers to the emission/avoidance ratio evaluated for one kWh energy (*fu = functional unit*) produced at the end of the chain. Calculation from biofuel(s) yearly harvested from one hectare land (*pu = production unit*) is at the beginning of the chain (Table B5). Both the nominator and the de-nominator are linearly related to the output (the flow of biofuels to be co-fired) and to the input (f.i. fertilizer supply).
Avoided CO_2 or release (emission) of GHGs per ha per year can be compared to other processes that require land. Also the consequences of choosing option *i* can be analyzed. Thus the variables with subscript *fu* in this equation can be compared with saved and emitted CO_2 of other energy production systems that use land area (f.i. other bio-fuels or wind energy). It also enables the evaluation of "carbon dept" of land conversion as recently introduced by Fargione et al. (2008). Figures B1 and B2 illustrate this. If the GHG balance is computed in terms of CO_2 per kWh, there is hardly any difference between smallholding and plantation if we look at the nominator (or if we inspect the de-nominator). Figure B2 shows that although the outcome of the GHG reduction is identical to Figure B1 (which can be considered a consistency check), the absolute values differ between smallholding and plantation.

Table B5 Avoidance (reference fuel chain) and emission of CO_2 (bio-fuel chain)

CO_2	Meaning	Units
reference chain^{fu}	CO_2 saved per unit electrical energy delivered by TPP	kg/kWh
bio-fuel chain^{fu}	CO_2 emitted per unit electrical energy delivered by TPP	kg/kWh
reference chain^{pu}	CO_2 saved per hectare per year	kg/ha/yr
bio-fuel chain^{pu}	CO_2 emitted per hectare per year	kg/ha/yr

Another characteristic of nutrient limitation is the independence of jatropha arrangement on a plantation. The yield is fixed for a given supply of nitrogen fertilizer (and so P and K as it has a fixed ratio with N) regardless whether the trees are arranged along a grid of 2 x 3 m distance (1667 trees/ha) or 2 x 2 m (2500 trees/ha). In the latter the yield per tree will be lower as the yield per hectare is fixed. This is in reasonable agreement with field observations by Van Eck (2007) and Openshaw (2000) who report that wider spacing gives larger yields of fruit per tree, at least in early years, which may compensate the reduction due to a lower number of trees.

Evaluation of the reference and biofuel chains for energy conversion in thermal power plants, (option 3 to 5)

Results for the reference chain for oil to a CHP (*i* = 3), oil to a CHP and shells to a Dutch coal-fired TPP (*i* = 4) and oil to a CHP and shells and seedcake to a coal-fired TTP (*i* = 5).

Table B6 CO_2 avoided by the biofuel yield of one hectare (1 ton jatropha seeds, see also Table B7). Data of Table B1 were used.

biofuel	mass biofuel (ton/ha/yr)	energy biofuel (GJ/ha/yr)	electricity produced (GJ/ha/yr)	CO_2 avoided (ton/ha/yr)
oil CHP	0.376	15.30	12.483	1.1228
shells	0.23	5.06	1.783	0.4976
seedcake	0.404	7.80	2.750	0.7673
	conversion factor (*i* = 3) =		0.000294 ha·yr/kWh	sum (*i* = 3) = 1.123
	conversion factor (*i* = 4) =		0.000257 ha·yr/kWh	sum (*i* = 4) = 1.620
	conversion factor (*i* = 5) =		0.000215 ha·yr/kWh	sum (*i* = 5) = 2.388

Table B7 Parameters in the GHG balance calculation

Input parameter	Value
Water content fruit	15%
Water content plant	15%
Water content seeds	6.8%
Fraction coats	0.3
Fraction oil in seeds	0.375
Fraction shells of seeds	23%
Fraction C biomass	0.475
Spacing plantation (m,m)	2, 3
Biomass jatropha (kg) above	35
Biomass jatropha (kg) roots	15

Table B8 Fixed parameters

Parameters	Value
N:P:K	6:3:1
Energy content oil (MJ/kg)	40.7
Energy content shell (MJ/kg)	22
Energy content cake (MJ/kg)	19.3

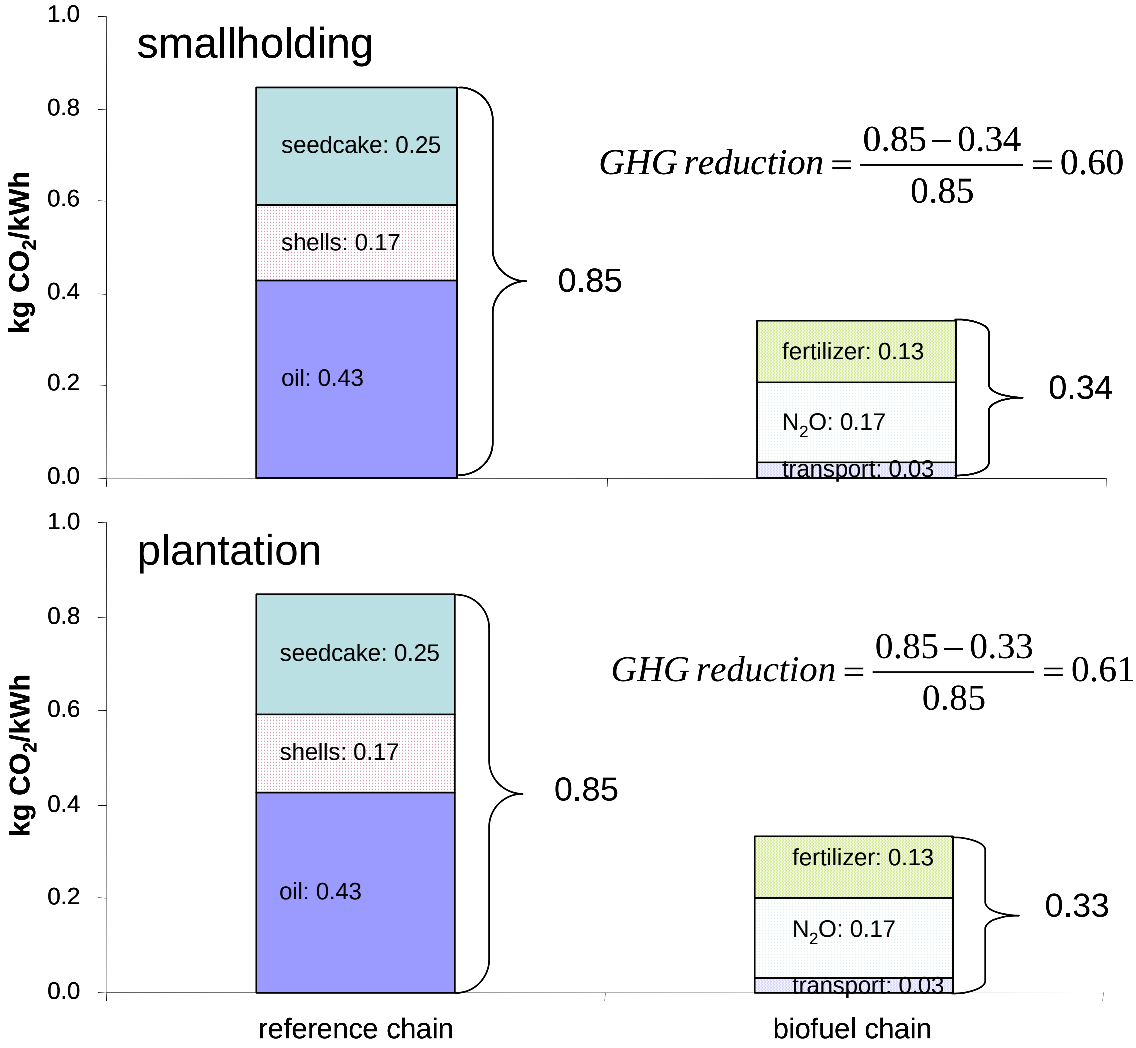

Figure B1 Representation of the GHG reduction calculated from CO_2 emission per the functional unit (kWh)

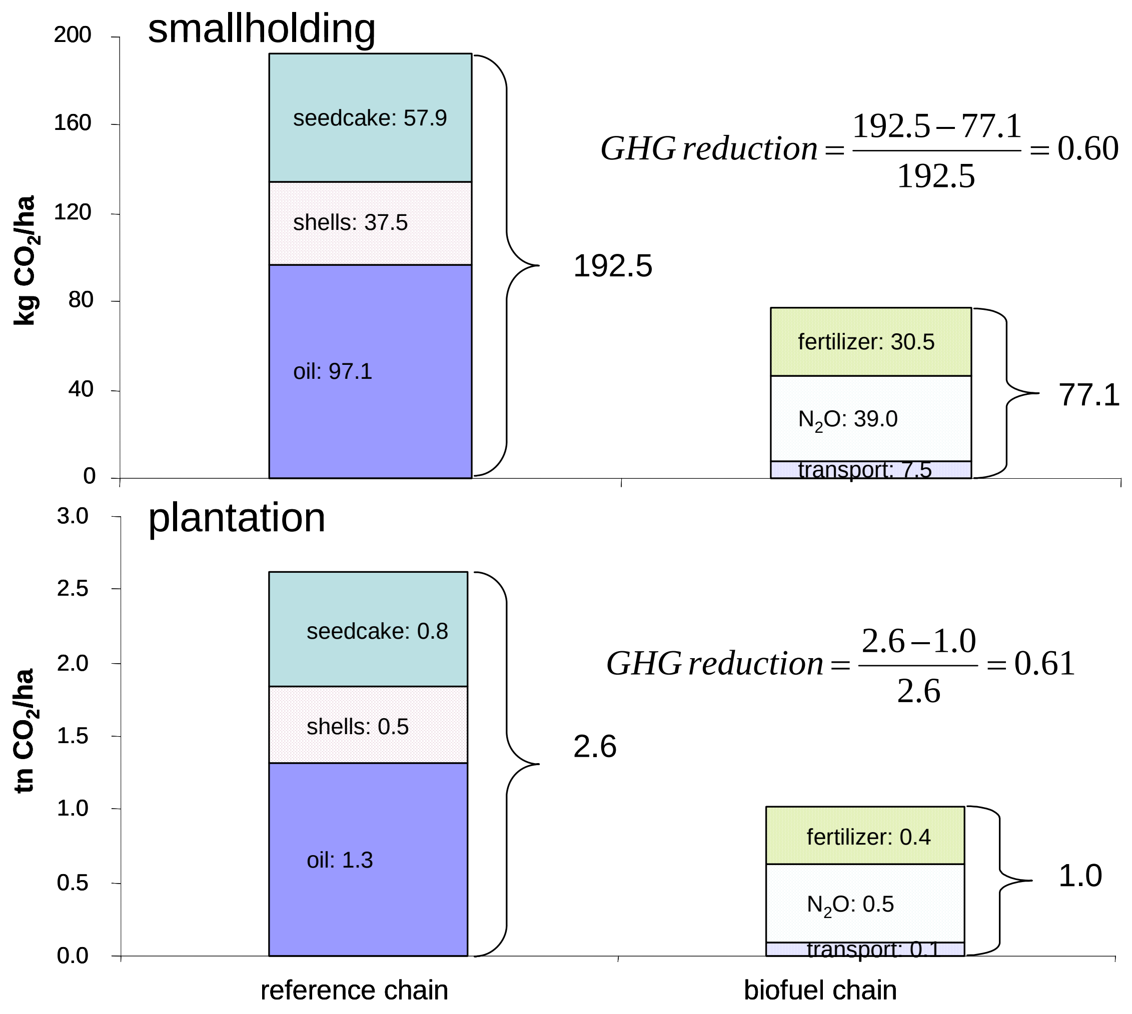

Figure B2 Representation of the GHG reduction calculated from CO_2 emission per hectare per year. Note the difference in scale on the vertical axis between smallholding and plantation

Annex C: General information on Tanzania

Most of the data on the Federal Republic of Tanzania given in Table 4 are derived from CIA Factbooks website. The current land tenure system limits cultivated crops to only 4% of the available land area.

Table C1 Physical and social geographic data on Tanzania

Surface	945,000 km^2
Arable land/permanent crops	4.23%/1.16%
Irrigated	1840 km^2
Inhabitants	39,384,223
Precipitation rate	1,100 mm/yr
Total internal natural water resources[1]	88 km^3/yr
Water dependency ratio[1]	10%
Renewable water per capita[1]	2591 m^3/capita/yr
Gross Domestic Product[2] (GDP)	$ 1100/capita
Corruption Perception Index (CPI)[3]	2.9 – 3.4 (> 3 means corruption is challenge)
Minimum wage	$ 70/month
Below poverty line	36%
Labour force in agriculture	80%
% GDP in agriculture	43%

[1]The UN World Water Development Report, “Water for people, water for life”, UNESCO, 2003.
[2] CIA Fact Books (9 April, 2008)
[3] Transparancy International

Annex D: The smallholder property

Chain A: the smallholding property of one acre (4047 m^2) with a jatropha fence

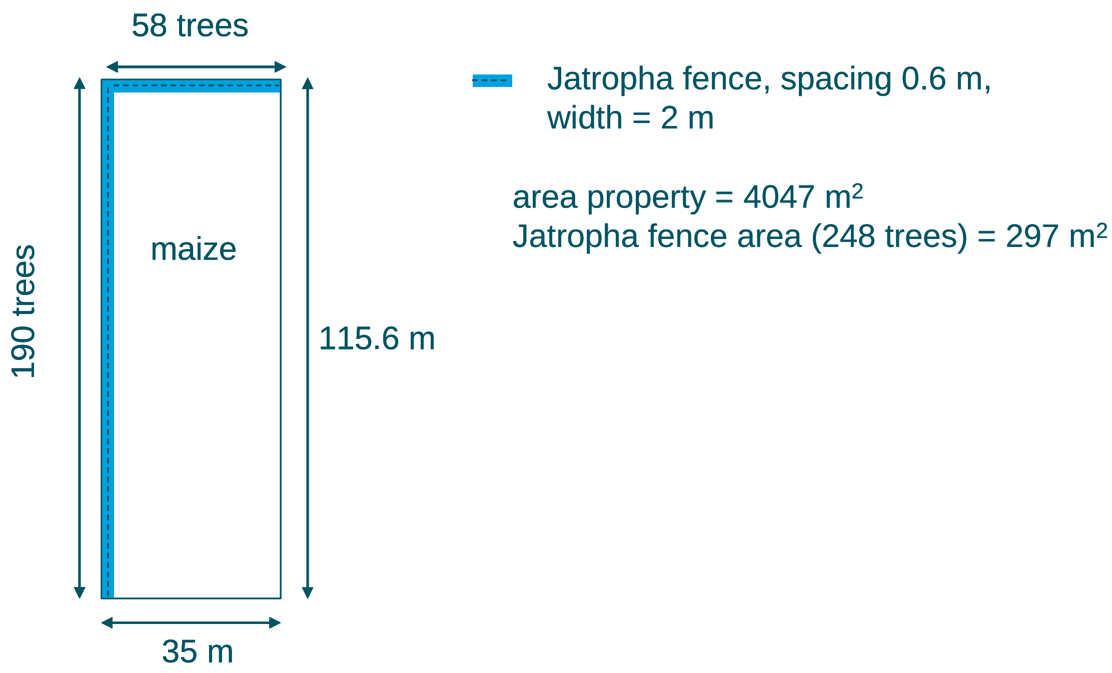

Table D1 Carbon stored in a jatropha hedge depends on spacing

Distance between trees	30 cm	40 cm	50 cm
Fraction root	40%	40%	40%
Water content	15%	15%	15%
Mass per tree (dry weight)	14.5 kg	16 kg	17.5
Number of trees/ha	1224	918	735
Biomass/ha	17.8 ton/ha	14.7 ton/ha	12.9 ton/ha
Carbon sequestered/ha*	8.4 ton/ha	7.0 ton/ha	6.1 ton/ha
CO_2 uptake/ha	30.9 ton/ha	25.6 ton/ha	22.4 ton/ha
CO_2 uptake rate/ha**	1.5 ton/ha/yr	1.3 ton/ha/yr	1.1 ton/ha/yr

* fraction C in biomass is 0.475 (UNFCCC, 2003); ** life cycle of a jatropha is 20 yr

Annex E: Parties involved in the project

Dutch companies

Eneco
Eneco is the third energy supplier in the Netherlands. ENECO Holding N.V. is a non-listed public limited liability company with its official seat in Rotterdam. Through its wholly-owned subsidiary ENECO Energie, the company supplies gas, electricity, and heat to retail and business customers throughout the Netherlands. Other activities revolve around the leasing of hot water and central heating and cooling systems, sustainable energy, public lighting, and traffic control systems. As one of the top three network operators in the Netherlands (along with Essent and Nuon), ENECO serves about 2 million customers. ENECO also owns electricity suppliers ONS Energie and Echte Energie.

Diligent Energy Systems
Diligent Energy Systems is a company that produces biofuels from *Jatropha curcas* and from waste of coffee production in Colombia. Diligent is based on the campus of the Technical University of Eindhoven, and collaborates closely with renowned research centres.
Diligent wants to contribute both to reduction of global warming, and to creation of employment in developing countries.

Dutch NGOs

Max Havelaar Foundation
Max Havelaar Foundation strives towards fair and just relations worldwide. Central to its policy is sustainable production, trade and consumption. Its goal is offering access to international trade with good conditions for farmers and workers in disadvantaged parts of the Third World so that they can build a better future for themselves. This means customers and retailers must also pay enough to cover social and environmental costs. To this purpose the Max Havelaar Foundation issues a label with the same name, which expresses that the labelled product complies with international fair-trade standards concerning the way it was produced and traded.

ICCO
ICCO's mission is to work towards a world where poverty and injustice are no longer present.
The work of ICCO (Dutch abbreviation of interchurch organisation for development co-operation) consists in financing activities which stimulate and enable people, in their own way, to organise dignified housing and living conditions. Together with partner organisations in Africa, Asia, Latin America, Eastern Europe and the Middle East, ICCO works towards a world without poverty, injustice and unsustainability. ICCO’s partner organisations comprise of local faith-based and secular, non-governmental development organisations. Annually, ICCO spends over € 100 million on support to development programmes of these organisations. ICCO seeks on one hand to make a relevant contribution to structural poverty alleviation in developing countries, and, on the other hand to promote structures, systems and processes that contribute globally to a more equitable distribution of prosperity and power.

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