Potentials and limitations of *jatropha curcas* for rural energy supply in East Africa: A case study based comparative assessment in Ethiopia, Kenya and Tanzania

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Abstract: Access to affordable, reliable and sustainable energy sources is a key aspect of poverty reduction and rural development in many parts of the world. In recent years, second generation biofuels emerged as a possible alternative energy source. In East Africa, lots of attention was given to *jatropha curcas*, a toxic oil producing shrub, due to its ability to grow in arid areas and on poor soils. But recent research in this region has shown that commercial plot-based *jatropha curcas* production entails serious investment risks, bears considerable opportunity costs of land and is consequently not economically viable for smallholder farmers. However, the question remains whether *jatropha curcas* hedges, which are used traditionally in the region, can play a positive role in enhancing the access of rural households to locally produced energy without threatening food crop production. Based on research conducted in 7 case study areas in East Africa (Ethiopia, Kenya and Tanzania), this paper concludes that *jatropha curcas* hedges have a significant potential for the substitution of kerosene or paraffin for lighting. This would help rural households to save much needed cash resources or to invest them into other farm activities, or into health and education. On the other hand, using *jatropha curcas* hedges to substitute firewood for cooking, presents some serious challenges. *Jatropha curcas* oil cookers are not yet working satisfactorily, are not affordable for many households, and the quantity of oil required for cooking would necessitate more hedges than are needed to fence average plots, which might lead to pressure on land. The use, for cooking, of the *jatropha curcas* seed-cake - a by-product obtained through pressing the seeds - has higher potential. However, adapted high-efficiency cookers and thinning down of the seed-cake with farm residues would be needed to achieve significant contribution to the energy requirements of households. Other challenges include the preservation of existing hedges' ecology, opportunity costs of labour and initial investment requirements.

1. Background and objective

Access to affordable, reliable and sustainable energy sources is a key aspect of poverty reduction and rural development (Eijck et al. 2010). In 2009, globally, two people out of five relied on traditional biomass such as firewood, charcoal or animal dung as a prime energy source. Most of these people live in rural areas of sub-Saharan Africa or Asia (IEA 2006). In East Africa the share of population relying on traditional biomass for cooking is particularly high, with 93% in Ethiopia, 83% in Kenya and 94% in Tanzania (IEA 2011). As a consequence, pressure on natural resources is increasing, leading to land degradation, which makes access to biomass energy even more difficult and costly.

In recent years, second generation biofuels emerged as possible alternative energy source, which could alleviate these problems, while contributing to the reduction of greenhouse gas emissions (Messemaker 2008, Zah et al. 2011). In East Africa, lots of attention was given to *jatropha curcas*, an oil producing shrub, due to its ability to grow in arid areas and on poor soils. But *jatropha* curcas has since been strongly criticized. It is feared that its production will lead to increased pressure on land, competition with food crop production, and more food insecurity (Cotula et al. 2011, FAO 2010, Ehrensperger et al. 2012). Additionally, recent research conducted in East Africa has shown, that commercial plot based *jatropha curcas* production, is not economically viable for smallholders due to low and unreliable yields and unreliable markets (GTZ 2009, Findlater and Kandlikar 2011, Feto 2011, ODI 2011, Mogaka et al. 2012). Also, opportunity costs of land and investment risks are high, as *jatropha curcas* needs around 8 years to reach maturity.

These opportunity costs can be avoided to a great extent if *jatropha curcas* is grown as a hedge or a live fence, to protect crops, or to corral grazing areas. Smallholders in the region have been successfully using *jatropha curcas* as a fencing plant since many years due to its toxicity, thanks to which it is not browsed by animals. However, farmers have, so far, not systematically harvested seeds from *jatropha curcas* hedges, due to the lack of a market and the lack of awareness about its potential for local energy production. Therefore, the question remains whether *jatropha curcas* hedges can play a positive role, not necessarily as a cash crop, but in enhancing the access of households to locally produced energy, without causing opportunity costs of land and labour, while at the same time reducing costs for the purchase of other fuels. This would be a valuable contribution, as it is widely acknowledged that better access to energy, especially to modern energy services, is leading to an increase in the access to information, health and education services (van Eijck et al. 2010).

Hence, the **objective** of this paper is to gain an overview of rural households' current energy strategies and to assess the potential of *jatropha curcas* hedges to substitute the most important (primary) fuels for cooking (firewood) and lighting (kerosene / paraffin) in smallholder communities in East Africa. A quantitative evaluation of the substitution potentials was conducted on the basis of hedge length of average plot sizes. Therewith, the paper proposes a qualitative discussion of the potentials and challenges of *jatropha curcas* hedge production for local energy supply in East Africa, in order to guide policy debate and development interventions.

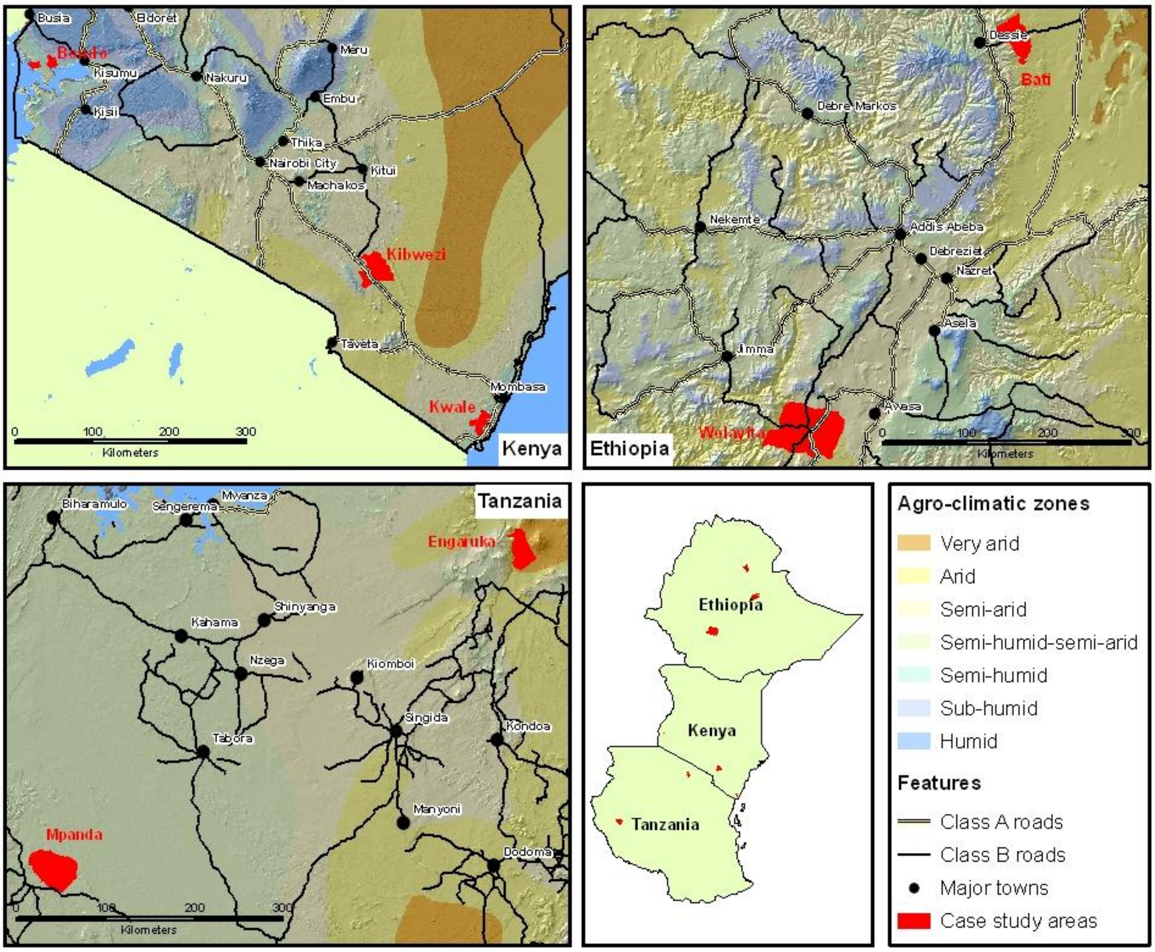

Figure 1: Geographic location and agro-climatic zones of the selected case study areas in Ethiopia (Bati and Wolayita), Kenya (Bondo, Kibwezi and Kwale), and Tanzania (Engaruka and Mpanda).

2. Research Design and Methodology

This study was conducted within the framework of the ERA-ARD funded (www.era-ard.org) *Bioenergy in Africa* (BIA) project (www.bioenergyinafrica.net), which was implemented between 2009 and 2011 in East Africa and Central America. Institutions from 5 European, 3 African and 2 Central American countries collaborated on identifying potentials and risks of *jatropha curcas* and related crops for the rural poor. Different disciplines, including environmental, political and economic sciences, as well as geography, agronomy and engineering were represented, making the BIA an interdisciplinary initiative. Results presented in this paper only cover a part of the research activities undertaken in the frame of the BIA project.

In East Africa field work was conducted in 9 case study areas in Ethiopia, Kenya and Tanzania. These areas were selected to cover different agro-climatic zones, farming systems and *jatropha curcas* production types, such as large-scale monoculture plantations, out-grower schemes with either mono- or intercropping systems, and *jatropha curcas* hedges. Out of these, 7 were selected for this study on the potential of *jatropha curcas* for local energy supply (see Figure 1).

In each case study area, a household survey was conducted in 2010 by local MSc students and research assistants, using a comprehensive questionnaire. Prior to the survey, all MSc students participated in a methodology workshop organised through the BIA project in Nairobi to guarantee equal standards. In all sites nearly equal numbers of *jatropha curcas* growers and non-growers were interviewed. Additionally, at least one focus group discussion with local elites, governmental actors, traders and investors was carried out in each site. Data collected was compiled and analysed with SPSS, and complemented with data from literature. The following analysis steps were undertaken for this paper:

1. An assessment of current energy consumption patterns was performed on the basis of the questionnaire data, with a focus on estimating amounts and costs of primary and secondary energy carriers used.
2. An assessment of the share of available income spent for energy was performed on the basis of questionnaire data and literature data on household economics in the region.
3. Average land availability per household was compared with the length of *jatropha curcas* hedges required to substitute primary fuels (kerosene and firewood), as a way of estimating their potential.

Data quality: Some respondents were not able to provide precise information on their own *jatropha curcas* production. This is mainly due to farmers' lack of experience, as *jatropha curcas* is a relatively new (commercial) crop in East Africa. It was especially difficult to obtain reliable data on yields from *jatropha curcas* hedges, as farmers usually do not record their yields, productivity or length. Also, in some instances, adopters did not harvest *jatropha curcas* at the time of the field work, due to unavailability of a market or because of insufficient yields in young *jatropha curcas* plantations or hedges. For this reason, only reliable figures from the case study areas were included in the analysis and supplemented with literature data and a BIA project meta-analysis on *jatropha curcas* yields in East Africa (BIA 2012).

3. Results

In order to evaluate the potential of *jatropha curcas* hedges for local energy supply in smallholder communities, the current energy strategies of households in these communities were assessed and entry points for the use of *jatropha curcas* oil and press cake as a local energy carrier identified.

3.1. Current Energy Strategies

a) Utilisation of fuels

Primary fuels: According to expert knowledge and literature (e.g. Kiefer and Bussmann 2008), firewood and kerosene are almost as vital for smallholder households in East Africa as food. The key role of these two fuels was verified in this study: In the understanding of respondents throughout the region firewood is the most important and kerosene (or paraffin) the second most important fuel for domestic use. In the considered areas, firewood is almost exclusively used for cooking and kerosene for lighting. In Bati, where average low temperatures in December and January are below 10° Celsius (*www.worldweatheronline.com*; Bach 2012), some households use firewood for heating and lighting. In the Kenyan case study areas, especially in Kwale, a few households use kerosene for cooking. In some households, especially those not having livestock, maize stocks and cobs are also often used as cooking fuel, helping to reduce consumption of firewood, but reducing availability of fodder, or nutrients in the soil.

Secondary fuels: Other fuels have less importance for everyday own energy supply. Charcoal, although produced locally in most areas, is only rarely used by the farmers themselves. Mostly, it is sold to urban dwellers on local markets, or along main roads. Gas is very rarely used; only 8 households out of 857 interviewed indicated using gas for cooking. Batteries are mainly used for lighting (in torches), especially in the Ethiopian case study areas, while their use is rather directed towards communication (radios, mobile phone chargers) in the Kenyan case study areas. Diesel, petrol and electricity from the grid or from a generator are rare occurrences.

Jatropha curcas oil is only used in two case study areas: In Bati *jatropha curcas* seeds are sometimes pinned on wires and used as candles. The high oil content of the seeds (approximately 30%) allows for a constant combustion. In Kwale farmers sell *jatropha curcas* seeds to a local company, which processes the oil and sells it back to farmers at a preferential rate, along with specially designed oil lamps, to replace conventional kerosene lamps. While primary fuels are absolutely crucial, households can more easily cope without secondary fuels, reason for which they are not included in the following analysis of households' energy expenditure.

b) Costs of primary fuels

Firewood: Quantities of firewood used are highly variable depending on the case study area (see *Table 1*). Tanzanian farmers seem to be more economical (2 to 3 loads per week) than Kenyans (3 to 5 loads per week), while in the 2 Ethiopian areas quantities vary widely (1 to 4 loads per week). However, definition of firewood loads could be different depending on the case study area and therefore, comparison of costs is more meaningful: With the exception of Bati, which has significantly higher figures, median weekly costs for firewood per household lie between 0.7 dollars (Wolayita) and 2.5 dollars (Mpanda). Of course, these median figures do not properly take into account the fact, that some households probably gather most of their firewood themselves and therefore do not incur cash expenditures, but higher workload.

Kerosene: Median values for quantities of kerosene used in the selected case study areas are surprisingly consistent. Most households use around 1 litre per week (median value), with the exception of the Ethiopian respondents, who have lower consumption. Median weekly kerosene costs are highly consistent in the Kenyan and Tanzanian case study areas (from 0.7 to 0.9 dollars) and significantly lower in the Ethiopian sites, due to lower per litre costs and lower consumption.

These figures show that households incur monthly energy costs for primary fuels ranging from 4 dollars (Wolayita) to 26 dollars (Bati). The strong variability of results in the Ethiopian sites is mainly caused by the high figures given for firewood in Bati and the low overall figures given in Wolayita. Average expenditures in Kenya and Tanzania are slightly below 10 dollars per month. In view of determining the potential of *jatropha curcas* hedges to contribute to local energy supply, approximate energy costs per household of 10 dollars per month, or 120 dollars per year will be used. This only includes the essential primary fuels. Expenditures for batteries and other energy carriers are not considered.

Firewood

		Loads/week		**Costs/load ($)**		**Costs/week ($)**		**Distance (km)**	
	N	mean	median	mean	median	mean	median	mean	median
Bati	92/100	4.8	4.0	1.4	1.4	6.6	6.4	1.6	1.8
Wolayita	120/120	1.5	1.0	0.6	0.6	0.9	0.7	1.8	1.0
Bondo	54/69	6.3	5.0	0.3	0.2	1.7	1.4	0.1	0.0
Kibwezi	96/109	5.1	5.0	0.4	0.4	1.7	1.4	6.4	1.5
Kwale	83/99	3.8	3.0	0.4	0.4	1.5	1.1	1.4	0.0
Engaruka	120/120	2.1	2.0	0.8	0.6	1.7	1.3	2.8	2.0
Mpanda	137/140	2.9	3.0	1.1	1.3	3.7	2.5	2.5	2.0

Kerosene

		Litres/week		**Costs/litre ($)**		**Costs/week ($)**		**Distance (km)**	
	N	mean	median	mean	median	mean	median	mean	median
Bati	17/100	0.4	0.3	0.4	0.3	0.2	0.1	17.2	16.0
Wolayita	119/120	0.6	0.5	0.7	0.7	0.4	0.3	1.0	0.3
Bondo	60/69	1.9	1.0	0.9	0.9	1.7	0.9	2.5	2.0
Kibwezi	101/109	2.4	1.0	0.8	0.8	1.8	0.8	4.4	3.5
Kwale	83/99	1.4	1.0	0.8	0.7	1.1	0.7	2.4	2.0
Engaruka	118/120	1.1	1.0	0.9	0.9	1.1	0.9	1.4	1.0
Mpanda	136/140	1.0	1.0	0.9	0.9	1.0	0.9	3.2	1.0

Table 1: Expenditures for firewood and kerosene

To evaluate the financial burden of energy supply, the above costs for primary fuels need to be compared to other expenditures incurred by smallholder households, or to these households' purchasing power: In 2007 real annual income per household in Kenya averaged between approximately 640 dollars in the western lowlands and 1600 dollars in the high potential maize zone; the national mean was around 1200 dollars (Suri et al. 2008). However, rural poverty in the East African region is still widespread. According to global statistics (UNDP, CIA, WRI), one third of the population in Tanzania, 40% in Ethiopia and half in Kenya live below the national poverty line, and 80% or more live below the international poverty line of 2 dollars PPP (purchasing power parity) per day.

Taking the latter figure as a representative measure for purchasing power of the majority of households in the rural area, the above estimated energy costs for primary fuels in the selected case study areas represent between 15% and 20% (120 out of 700) of a household's annual income. Energy costs are therefore a non negligible financial burden for rural households, especially for the rural poor. The search for alternatives that can help reducing this burden, while enhancing energy autonomy of rural communities and reducing pressure on natural resources is therefore an important development priority.

c) Priorities for alternative energy sources

In designing their energy strategies, rural households have higher flexibility for cooking. Next to firewood as the main fuel, which can be bought or gathered, they can fall back on maize stocks and cobs, cow dung and other biomass from natural vegetation or farm residues. For lighting, current choices are narrower. Batteries and especially kerosene are the main alternatives. Both are industrial products that have to be purchased. Replacing partly these products, which account for around half of the energy costs, with locally produced fuels could help releasing much needed cash for other uses (health, education, investments), if production and opportunity costs are kept low. The question is whether *jatropha curcas* hedges could be such an alternative. The following analysis will look separately at kerosene and firewood substitution, which each have own requirements and challenges.

3.2. Potential of *Jatropha Curcas* Hedges for Local Energy Supply

a) Substitution of kerosene for lighting

An average kerosene consumption of 50 to 100 litres per year is considered, on the basis of figures in Table 1. Respondents mentioned that less than one litre of *jatropha curcas* oil is needed to substitute one litre of kerosene, because of better burning characteristics and lower volatility of jatropha oil. However, as this information was not verified in the frame of this study, equal amounts of *jatropha curcas* oil are considered for kerosene substitution. Using village based extraction techniques (for example a simple ram press, see Figure 2) an extraction efficiency of about 20% and an extraction capacity of around 3 kg *jatropha curcas* oil per hour can be achieved (Beerens 2007), which means that between 250 and 500 kg of de-husked seeds are needed per household to replace 50 to 100 litres of kerosene. With average seed yields of 1 kg per meter of hedge (BIA 2012), 250 to 500 meters of hedge are needed per household to substitute kerosene for lighting. This corresponds to 50% to 100% of the length of the boundary of two 0.5 hectare plots. As the average surface of land owned in the case study areas lies between 0.5 and 5.2 ha, most households would have sufficient land boundaries to substitute kerosene with *jatropha curcas* oil.

Hence, households would be in a position to eliminate their expenses for kerosene purchase, which amount to 50 to 100 dollars per year by using home grown *jatropha curcas* oil from hedges instead. As average prices for *jatropha curcas* seeds range between 0.1 and 0.2 dollars per kg, the income from selling *jatropha curcas* seeds would be comparable to the reduced expenditure from purchasing kerosene, minus the investment cost (see below). Thus, farmers would need to choose, depending on the market value for *jatropha curcas* seeds, between cutting down expenses for kerosene purchases through substitution with *jatropha curcas* oil on the one hand, and on the other hand financing kerosene purchase through selling *jatropha curcas* seeds.

b) Substitution of firewood for cooking

There have been few attempts to develop cooking stoves that can be fuelled with *jatropha curcas* oil. These prototypes either did not work or were not competitive (GTZ 2009, Eijck et al. 2010). Additionally, using *jatropha curcas* oil for the substitution of both kerosene and firewood would mean that more meters of hedges are needed per household. If opportunity costs of land have to remain low, this would only be possible for households owning more land. Therefore, at the present time, the potential of *jatropha curcas* oil as a substitute for firewood has to be considered as low. However, if *jatropha curcas* oil is used as a kerosene substitute as suggested above, a non-negligible amount of seed-cake will be available as a by-product, which can either be used directly in adapted stoves, or processed into briquettes or bio-char. Hence, the potential of this by-product has to be assessed as well.

Respondents indicated using between 1 and 5 loads of wood for cooking per week (median values). Though the definition of loads is not univocal, some sources (e.g. Openshaw in FAO 1983) mention an average weight of 25 kg per head-load in East Africa. Hence the total annual consumption of fuel wood could be ranging from 1300 kg to 6500 kg per household. This seems high, but is still much lower than the estimate of Kiefer and Bussmann (2008) of 430 kg per week (= 22’360 kg per year) for the Kakamega area of Kenya, not far from the Bondo case study area. In comparison, 200 kg to 400 kg of seed-cake can be obtained from the above mentioned 250 m to 500 m of *jatropha curcas* hedges (around 80% of the seed biomass). The energy density of *jatropha curcas* seed-cake is around 18 MJ / kg (Achten et al. 2007 and 2010), which is, according to Smil (2008), comparable to wood (16 to 21 MJ / kg). Therefore, when assuming similar cooking efficiency, the seed-cake would not last more than a few weeks per year. Higher contribution can be expected, if stoves with improved efficiency are used and/or if the seed-cake is thinned down, for example with farm residues, rice husks, or cow dung. However, only little experience is available with this technology. Jatropha Products Tanzania Ltd. (JPTL) is promoting an improved seed-cake stove (figure 2), the efficiency of which is said to be much higher than with open wood stoves (but no concrete figures were mentioned). However, such a stove costs around 12 dollars, which is a significant investment for a low-income household.

Figure 2: Left: Ram-press for extraction of jatropha oil from seeds. Right: Improved jatropha curcas seed-cake stove of Jatropha Products Tanzania Ltd. (JPTL). (Photos: Ehrensperger 2011, Arusha, Tanzania)

3.3. Challenges

Aside from the above outlined potentials, a number of challenges are linked to the use of *jatropha curcas* hedges for local energy supply in rural East Africa:

Initial investments: Oil extraction requires at least a simple ram press and a gravity filter. In Tanzania, the former costs around 150 dollars and the latter around 6 dollars, but needs to be replaced every month (annual costs of 70 – 75 dollars). Additional costs include 6 dollars per year for the oil container and 12 dollars for heavy wood beams used to fix the ram press. Most households are not in a position to make such an investment and therefore, local energy production with *jatropha curcas* will only work if processing can be organised and done at community level. Investment for an improved seed-cake stove could also put off households with very tight financial resources. Community based micro-financing schemes could help to overcome this challenge.

Hedge ecology: This study did not investigate other functions of non-*jatropha curcas* hedges (medicinal, food, fodder and fibre), which might get lost if all non-*jatropha* hedges are replaced with *jatropha* hedges. Context specific analysis of these other functions should be done prior to promoting *jatropha curcas* production in hedges, and maximum replacement rates defined accordingly. Biodiversity value of non-*jatropha* hedges has to be taken into account as well in view of avoiding loss of important genetic resources and ecosystem services.

Technology: Technical challenges are low for the substitution of kerosene. Simple oil lamps made from recycled tins can be used. The only modification needed, is a copper tube to conduct heat from the flame into the oil reservoir to reduce viscosity (Figure 3). Such lamps cost around 1 dollar in the Arusha region, in Tanzania. Simple floating wick lamps basically only necessitate a glass and a wick would be an even cheaper alternative. Technical challenges for the substitution of firewood are more important. *Jatropha* oil stoves do not yet work properly (van Eijck et al. 2010, GTZ 2009). Press-cake stoves work well, but combustion produces a lot of smoke, which necessitates either outdoor use or the adding of an exhaust pipe. Further improvement of this technology is therefore needed. The technology for processing of seeds is available and satisfactorily operational. Improvements of pressing efficiency and affordability could certainly still be achieved, but additional research and innovation is needed in this field.

Figure 3: Jatropha oil lamp manufactured from an old tin. A copper tube has to be used to conduct the heat from the flame into the oil reservoir, in order to reduce the oil's viscosity (Photo. Ehrensperger 2011, Arusha, Tanzania)

Labour requirement: While opportunity costs of land are very low with *jatropha curcas* hedges, opportunity costs of labour can, in some cases, present a challenge, as *jatropha* harvesting is labour intensive. However, respondents severally mentioned that *jatropha curcas* harvesting usually does not clash with other farm activities. Furthermore, some respondents mentioned that *jatropha* fences help reducing work load for fencing, which is usually done with dry thorny wood and therefore needs to be replaced frequently.

4. Conclusions

The above assessment shows that, when integrated into smallholder production systems in the considered case study areas, *jatropha curcas* hedges could play a significant role in substituting kerosene for lighting. This would help households to save between 50 and 100 dollars per year, which is not negligible for a household living at or below the international poverty line of 2 dollars per day (730 dollars a year). In some cases farmers might be more inclined towards selling *jatropha curcas* seeds than using the oil themselves. This would be the case especially if they are unable to invest in *jatropha curcas* processing and utilisation devices and if seeds can be sold for at least 0.1 or 0.2 dollars per kg, which would be comparable to the value of the substituted kerosene.

The potential of jatropha to substitute firewood is currently limited in the considered case study areas in East Africa. Cooking stoves fuelled with jatropha oil are not yet reliable and affordable for most rural households in East Africa. The use of jatropha seed-cake for cooking is technically doable but only partly affordable, as improved stoves are needed. Furthermore, the available seed-cake biomass gained from fencing average farm sizes only allows covering a fraction of a household's needs for cooking fuel. Higher contribution could be reached if using economical stoves and if thinning down the seed cake with farm residues like rice husks, or cow dung. However, this should not be done at the expense of the nutrient balance on the farms, in order not to threaten farm yields, or to increase the need for fertilizers, as both would have a negative impact on households' economic situation.

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