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Human energy requirements in Jatropha oil production for rural electrification in Tanzania

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ABSTRACT

Mini-grids connecting households to a generator can be a solution for providing rural communities in developing countries with electricity. Substituting diesel with locally produced Jatropha oil can improve economic and environmental sustainability of rural electrification. Jatropha is known as a labor intensive crop, but little is known about how inclusion of human energy input will affect the energy balance of production of Jatropha oil. In this study we investigate human labor requirements in rural electrification with Jatropha oil. Jatropha in this study in Tanzania was grown as living fences and provided multiple benefits. An energy flow chart of generation of electricity from Jatropha oil is presented, and it is shown that human energy expenditure in production of Jatropha oil is small relative to the overall energy in the system. Time consumption however is extensive, and 7.5 hour work is required to harvest and de-hull Jatropha fruit equivalent to 1 kg Jatropha oil. 1 kg Jatropha oil can in turn provide the community with 2.5 kWh electricity through a Multi Functional Platform connected to a local grid. Potential income from harvesting Jatropha is considered so low in the study area that farmers are reluctant to venture into it. Poorer people and children in the community are allowed by the farmers to harvest for free. Collection of seeds for Jatropha oil depends on the availability of labor willing to work for an income of approximately 0.9 USD/day. Social and economic sustainability of rural electrification based on Jatropha oil can be enhanced through generous subsidy.

Introduction

Electrification of rural areas in developing countries is considered fundamental to reduce energy poverty and to meet the Millennium Development Goals (Modi et al., 2006). In Tanzania 86% of the population does not have access to electricity from the grid (OECD/IEA, 2011), most of these live in rural areas. Provision of electricity to rural areas through national grids is costly per unit of electricity because rural consumers are more scattered and typically buy less electricity per consumer compared to urban consumers. Instead of bringing the national grid to rural consumers, community scale electricity production units may be a more realistic solution for supplying electricity at a reasonable cost per kWh (OECD/IEA, 2010), and biomass-based electricity generation in sub-Saharan Africa is deemed to have potential (Dasappa, 2011).

A simple diesel engine providing mechanical power to run a generator connected to a local electricity grid (mini-grid), as well as machines such as for de-hulling maize and pressing oil from oil seeds, is often referred to as Multi Functional Platforms (MFP). These can be run on diesel, but using fossil fuels for running generators may be expensive and causes emission of greenhouse gasses. An alternative solution for rural electrification is using locally produced straight vegetable oil instead of diesel for running the generator. This has been tried in countries such as Mali (Bouffaron et al., 2012), India (Gmünder et al., 2010) and Tanzania (TaTEDO, 2008).

Jatropha curcas, commonly known as Jatropha, belongs to the family *Euphorbiaceae* and is native to tropical America, but grows throughout the tropics (Heller, 1996). Jatropha seeds contain 27–40% inedible oil, which can be converted into biodiesel (Lu et al., 2008) or be used straight or as blends in appliances ranging from stoves (Wagutu et al., 2010) to engines (Agarwal and Agarwal, 2007; Forson et al., 2004; Haldar et al., 2009; Pramanik, 2003). It can be used as a fence to protect crops from grazing livestock, and if planted as hedges it does not compete with food production over land (Heller, 1996). Planting as hedges also has lower negative impact on biodiversity than if planted as plantations (Achten et al., 2007). From a development perspective, decentralized production and use of Jatropha oil from low-technology processing and use for provision of electricity is appealing (see e.g. Practical Action Consulting, 2009). The idea with having an MFP running on Jatropha oil is that the community can be self supplied with fuel for providing electricity and mechanical power for grinding maize and pressing oil seeds, thereby increasing local energy security. It would also provide farmers with an additional source of income. As long as the Jatropha

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is planted on marginal lands, electrification with Jatropha oil can be beneficial to the environment as well (Gmünder et al., 2010).

But fuelling MFPs with Jatropha oil has not been as straightforward as initially suggested. In Mali there were plans to run a large number of MFPs on Jatropha oil, but in the end none did (Nygaard, 2010). Low profitability of producing Jatropha oil during the time of the project was blamed for the failure, and it is suggested that use of Jatropha as a fuel in the MFPs was founded on optimistic calculations (Nygaard, 2010). Another recent study based on the data from Mali concluded that 'Jatropha SVO based electrification projects are balanced on the threshold of economic competitiveness' (Bouffaron et al., 2012). Still, the idea of rural electrification with Jatropha oil is alive. In Tanzania the first MFPs were built in 2007 in Leguruki and Engaruka Juu by the Non-Governmental Organization TaTEDO. These were built as pilots, and TaTEDO has received funding for building a substantial number of new MFPs in remote areas of Tanzania. Findings in previous research suggest the importance of having a good understanding of potentials and pitfalls of the solution for rural electrification.

Although important lessons have been learnt from previous research, little attention is given to the fact that the Jatropha fruits need to be picked manually since convenient technology yet is to be developed for harvesting. The fact that MFPs were promoted as a means of empowering, and reducing the burden on women (Nygaard, 2010) emphasizes the importance of this aspect. Technology for de-hulling of the fruits exists (FACT, 2010), but is still at a research-stage and is not available in rural markets in developing countries. Although there is a general awareness that this is a labor intensive crop (Achten et al., 2007), there are few reports of the actual time and energy required to maintain and harvest the crop, although some recordings from plantations exist (FACT, 2010). Studies of energy balance and life cycle analysis of production and use of Jatropha have been conducted (Gmünder et al., 2010; Prueksakorn and Gheewala, 2008), but they do not include human energy expenditure.

Measurement of energy balance in biofuel production involves accounting for the amount of energy used in the production and comparing it to the amount of energy contained in the resulting biofuel. If the production of oil from the Jatropha plant is heavily dependent on human energy input, then it is likely that the human energy input will be a major contributor in an energy balance analysis. Various methods have been used for estimating human energy expenditure in agriculture (see for example: Pimentel and Pimentel, 2008), but have been criticized for oversimplifying energy use by using average energy expenditures per day as basis (Pradhan et al., 2008), as opposed to calculating with specific energy expenditures for specific tasks. Loake (2001) used an approach where a nutritional model developed by FAO/WHO/UNU (2004) was applied to compare human energy expenditure in conventional and organic agriculture. The model allows for energy needed by individuals and populations to be estimated for activities to a detailed level. It has been argued that since the human energy input is usually marginal relative to other energy inputs, it might as well be excluded from energy balance analyses of biofuel production (Pradhan et al., 2008). We still deem it important to include the human factor when evaluating labor intensive agricultural production typical for developing countries since human energy in agriculture concerns not only the balance of calorific expenditure and consumption, but also the negative health effects associated with high levels of energy expenditure and effort (Loake, 2001). Degree of work intensity can be related to quality of life, and work in rural areas in developing countries is typical for its labor intensity (Palmer-Jones and Jackson, 1997).

In this paper we present an energy balance analysis which includes human energy and a brief discussion of the economy in rural electrification with Jatropha. It was hypothesized that the human energy input would be extensive, and that biofuel-based rural electrification schemes are dependent on labor willing to work for little income.

Materials and methods

Study site

The study was conducted in Engaruka Juu village (S 2° 58′ 60″, E 35° 57′ 0″) in Monduli district, Arusha region, Tanzania. Engaruka ward has a population of 7295 according to the National census in 2002, and its population is pursuing pastoralism, agriculture and trade for a living. The area has a dry climate, and receives short rains in November and December and long rains from February to April. Engaruka ward has a complex system of irrigation channels providing water from nearby mountains throughout the year for watering cattle and crops. Engaruka is situated in the Rift Valley and the soils are slightly basic volcanic sandy loams and loamy sands. A Multi Functional Platform (MFP) with a mini-grid connecting about 50 households and shops was raised in Engaruka Juu by the Tanzanian organization TaTEDO in 2007 with the intention of running it on locally produced Jatropha oil.

Cultivation

Engaruka Juu seems to have suitable growth conditions for Jatropha. High solar insolation in combination with irrigation, and temperatures within ranges suggested in literature (Heller, 1996), are important factors. The soils found in Engaruka are sandy and well-drained with good aeration, and although slightly basic it does not exceed pH 9 which has been reported as inhibiting the growth of the Jatropha plant (Achten et al., 2008). Jatropha is grown in hedges along irrigation channels and around fields, and has an important function as fence to protect food and cash crops from livestock, since livestock are brought to Engaruka Juu for watering. The hedges are typically between 2 and 4 meter tall, and between 2 and 3 meter wide. They are planted and maintained by using cuttings. Pruning is done once or twice per year when preparing fields for other crops, since overgrown hedges would shade over the crops. When pruning, the cuttings are replanted to fill in gaps in the hedge. Weeding under the hedges is done while preparing the field for cultivating crops.

Harvesting and de-hulling

Harvesting is done between February and May. Fruits are collected in the morning while it is still cool, and de-hulling is done in the afternoon. Fruits are collected by hand. A pole is used to pull down branches to reach the high-hanging fruits. Children climb to collect fruits. De-hulling of the fruits can be done in various ways. If the fruits are yellow and soft, the seeds can be squeezed out by spreading them on a plastic sheet and stepping on them. If the fruits are dried they can be peeled by hand or they can be put in a bag and beaten. Seeds and fruit coats are then separated by hand. Seeds are dried for a day in the shade before being ready for selling to local business people. Fruit coats are not utilized.

To calculate energy content in products and by-products from the production process, volume and weight of the different fractions were measured after sun drying in the shade for one day. Energy content of the fractions were obtained from literature and own measurements of calorific value.

Time required to harvest Jatropha fruits was measured by recording time required by three persons to fill three buckets with fruits each. De-hulling time was estimated by recording time required to de-hull Jatropha fruits to fill a measure. Several repetitions were made. The persons involved in the experiment occasionally made some money from collecting and selling Jatropha seeds.

Multi Functional Platform

The MFP in Engaruka Juu is built based on Multi Functional Platforms installed by UNDP in Mali (TaTEDO, 2008). Several components, for example maize mill, maize de-huller, oil-expeller and generator can be connected to a diesel engine functioning as a mechanical power source. The engine can be run on plant oil instead of diesel with only slight modifications; two-tank system. In this study we have chosen only to include units on the MFP relevant to electrification with Jatropha oil.

Engine

The engine installed on the MFP in Engaruka Juu is a 10 HP Lister engine. It is a single-cylindered, four-stroke engine with indirect injection and water cooling. To run on Jatropha oil, a two-tank system is installed: the engine is started on diesel. When the engine is warm, Jatropha oil can be fed to it from a second tank. The Lister engine has a specific fuel consumption (engine operating at maximum capacity) of approximately 1.9 kg diesel, or 2.2 kg Jatropha oil per hour (TaTEDO, 2008), and efficiency is calculated to be $\eta = 0.3$ by balancing specific fuel consumption against brake power. Mechanical power from the engine is transferred to the oil expeller and generator by a system of pulleys.

Expelling and filtering oil

The Sundhara oil expeller, also known as Sayari in Tanzania, is designed for processing a range of oil seeds, including Jatropha. The machine is designed for small scale oil processing enterprises and is adapted to rural operations. The processing capacity of the Sundhara is approximately 70 kg of Jatropha seeds per hour (TaTEDO, 2008). 5 kg of Jatropha seeds gives approximately 1 kg of oil. Jatropha oil needs time for settling before decantation and filtering. About a week is needed for about ¼ of the impurities to have settled. Filtering is done by gravitation through a large textile. The textile needs to be cleaned and washed frequently. Filtering is time consuming, depending on the amount of impurities. The resulting seed cake was not utilized.

Generator and electrical grid

An STC Series three-phase AC synchronous generator is connected to the Lister engine. The generator has a nominal capacity of 7.5 kW and an efficiency of $\eta = 0.9$. About 50 households and shops are connected to the grid. According to TaTEDO (2008), 20% ($\eta = 0.8$) of the energy is lost in the grid.

Boundaries of the study

Since an objective in this article is to show energy flows in the processing of Jatropha fruits to electricity, energy required to produce and maintain the MFP and mini-grid is not included, as would have been done for example in a Life Cycle Assessment (LCA). Since the Jatropha hedges in Engaruka Juu are cultivated and maintained as fences, and not as a crop, energy required for planting, weeding, pruning and replanting are excluded from the energy analysis. Thus human energy requirements are only calculated for the harvesting and de-hulling steps in the process.

The energy output:input ratio of the production of straight Jatropha oil is calculated using the energy (MJ) estimated for each parameter in the following equation:

$$\text{Energy output : input} = \text{Jatropha oil}/(\text{Harvesting} + \text{De-hulling} + \text{Expelling}). \quad (1)$$

To calculate how much electricity could be generated from Jatropha oil, energy efficiency of the engine ($\eta = 0.3$), the generator ($\eta = 0.9$) and the electrical grid ($\eta = 0.8$) is accounted for.

Model: human energy expenditure

A model has been used for quantifying human energy expenditure in processing Jatropha. In the FAO/WHO/UNU (2004) nutritional model energy expenditure is calculated for a given type of physical activity over a given period of time. Basal metabolic rate (BMR) is the minimal rate of energy expenditure compatible with life. Depending on its use, the rate is usually expressed per minute, per hour or per 24 h. The physical activity ratio (PAR) is the energy cost of an activity per unit of time (usually a minute or an hour) expressed as a multiple of BMR. A BMR of 5.4 for a woman of 55 kg, between 30 and 50 years was used, since women were used as test persons in the study. A PAR of 3.4 was used for harvesting of Jatropha fruits, and 1.7 was used for de-hulling (FAO/WHO/UNU, 1985). It is calculated as based on FAO/WHO/UNU (2004):

$$\text{Energy expenditure} = \text{time allocation(h)} * \text{PAR} * (\text{BMR}/24\text{h}). \quad (2)$$

In our study we have chosen to calculate human energy expenditure in agricultural production based on activity levels in specific activities rather than using generalized values for human activity. Although not perfect, the method may be a viable way of estimating human energy input in energy balance analyses since it visualizes the variation in burden of various types of human work in a production process.

Results

Energy flow in rural electrification with Jatropha

Energy flow in production and processing of Jatropha fruits from hedges to electricity is presented in Fig. 1. The functional unit (FU) in the energy flow is 1 kg of Jatropha oil: upstream it is shown how much energy is required to produce 1 kg of Jatropha oil. By applying

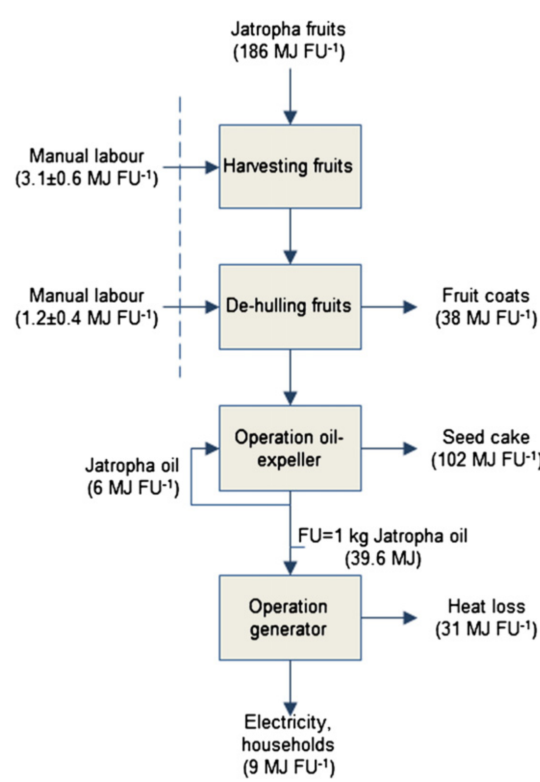

Fig. 1. Flow diagram showing amount of energy in each processing step in generation of electricity from Jatropha. The functional unit (FU) is 1 kg Jatropha oil.

Eq. (1) to the data in Fig. 1, the energy output:input ratio of production of Jatropha oil where human energy input is included is calculated to be: 39.6 MJ/(3.1 MJ + 1.2 MJ + 6.2 MJ) = 3.8. Fig. 1 shows that 55% of the energy harvested as fruits is in the form of seed cake, and 21% of the energy is found in the fruit coats. 24% of the energy contained in the Jatropha fruits is recovered in the resulting Jatropha oil, of which care returned to the process of expelling oil. The by-products had not been utilized in Engaruka.

Downstream, the amount of electricity from 1 kg of Jatropha oil delivered to the households through the grid is given as 9 MJ∗0.2778 = 2.5 kWh. For every 186 MJ worth of fruits collected, 9 MJ is delivered as electricity to the households through the mini-grid.

Harvesting and de-hulling time

As shown in Table 1, 36 l of fruit gave about 5 kg dried Jatropha seeds. 5 kg of dried seeds gives 1 kg of oil. At the site of the experiment, about 220 m of hedge was required to collect 36 l of fruit.

According to the participants in the study these yields are moderate, compared with what is sometimes collected. The calculated average time to harvest 36 liter Jatropha fruit was 4.1 ± 0.8 h. Time required to de-hull Jatropha fruits to equal to 5 kg of Jatropha seeds was found to be 3.4 ± 1.0 h. These findings were confirmed by asking people who collect and sell seeds in Engaruka Juu.

The economy in rural electrification with Jatropha

Jatropha seeds have been collected and sold from Engaruka since 2006. Companies buy seeds for production of biofuel, and price per kilo of Jatropha seeds has increased steadily from 100 TZS/kg in 2006 to 250 TZS/kg in 2010. The cost for Jatropha oil, excluding capital costs, operating costs, lubrication and maintenance is 1250 TZS/kg. Thus if the fuel cost for running the MFP on Jatropha oil was set by market prices for Jatropha seeds, the minimum cost would be 1250 TZS/ 2.5 kWh = 507 TZS/kWh.

Retailers buy seeds from collectors and sell them to companies. People in Engaruka involved in collecting and de-hulling Jatropha fruit are not employed, but pick for free from farmers' fences since the value of the Jatropha fruit is too low for the farmers to be interested in the crop. Harvesters say that during peak season they typically collect fruits and de-hull a couple of hours in the morning and a couple of hours in the afternoon. When there are less fruits on the Jatropha hedges, collection is more sporadic. To calculate potential daily income for the collectors, time allocated to collection and de-hulling is set to 7.5 h: 3.4 h to collect fruits and 4.1 h to de-hull 5 kg of Jatropha seeds. At a price of 250 TZS/kg, collectors can earn an income of 1250 TZS per day, or 0.9 USD/day (December 2010).

Discussion

Human energy input

Our study shows that one person may harvest an amount of Jatropha fruits equal to 10 kg of seeds per day. This is less than indicated in the Jatropha Handbook (FACT, 2010), though it is similar to picking efficiency in a study at Indonesian island, Sumbawa (Gaul, 2012-this issue). The compilation of picking efficiencies from various studies around the world presented in the Jatropha Handbook shows that picking efficiency varies between wild stands (low yielding — harvests of 20–30 kg seeds per person per day) and well managed plantations (high yielding — from 40 to 70 kg seeds per person per day). A study made at Sumbawa found that 30 kg fruits, equaling 2 l of oil, can be harvested in 8 h from Jatropha kept as living fences (Gaul, 2012). There may be various reasons for the discrepancy from the findings in the Jatropha Handbook. In the area where the study was conducted, people sporadically harvest fruits that are ripe from the hedges. So the hedges may not have yields as in a plantation. In our study the collectors were also followed as they were going about their business as usual, and this most likely leads to a lower picking efficiency than if the study was done under controlled conditions. The hedges used in the study – which are common in Engaruka Juu – were on average 3.5 meter tall. Sticks are therefore used to collect the high hanging fruits, and this adds to the time spent harvesting.

Our findings indicate that the human energy input is marginal relative to the energy flow as a whole in the Jatropha rural electrification system (Fig. 1). Part of the reason might be that we have excluded the energy requirements in cultivation of the crop. Exertion of energy is often measured in terms of energy utilized per hour. For comparison mega joule (MJ) can be converted to kilo calories (kcal): harvesting requires 183 ± 30 kcal/h, and de-hulling 91 ± 23 kcal/h. This equals 'light work' and is not considered as exhausting even over a duration of several hours (Åstrand et al., 2003). Excluding human energy input from sustainability analyses of labor intensive Jatropha production could give a misleading picture of the social sustainability. Although the energy balance is positive, the people harvesting spend large amounts of time on the work relative to the output. A whole day's worth of work produces an amount of seeds equal to 1 kg of oil.

By harvesting and selling Jatropha seeds it is possible to make about a dollar a day in Engaruka Juu as seen in this study. FACT fuels (2010) recommends establishment of plantations in areas where the wage rate is less than 4 USD per day. It is clear that there is labor willing to work for less than 4 USD per day in Engaruka since Jatropha is collected and sold despite the low income. Casual labor may be paid as much as 5000 TZS per day during season. Since collection and de-hulling may provide an income of about 1250 TZS per day, it does not pay to use casual labor for this activity. Despite the low income it may generate, Jatropha seeds are collected and sold. People making a living from agriculture in rural areas of developing countries typically diversify their livelihoods to generate income and reduce their vulnerability (Ellis, 2000). Jatropha fruits are harvested mainly during peak seasons and income generated from harvesting is only one of several sources. Jatropha fruits are freely accessible, and harvesting can be a way of diversifying sources of income in times when there are few other income generation opportunities. Talking with people in Engaruka Juu confirmed that those harvesting Jatropha may do it in their spare time because it is relatively light work.

Economic viability

The MFP in Engaruka Juu was not functioning at the time the research was conducted. As suggested in another study of MFPs being run on Jatropha oil, this may be because such projects prone to challenges connected with economic competitiveness (Bouffaron et al., 2012). The minimum fuel cost for generating electricity from Jatropha is 507 TZS/kWh, which is several times greater than what TaNESCO (Tanzania Electric Supply Company Limited) provides through the national grid (Domestic Low Usage tariff 60 TZS/kWh for <50 kWh in 2011). Since there already is a market for Jatropha seeds, the cost of electricity is determined by the price for Jatropha seeds rather than willingness to pay among the consumers. It follows that when

Table 1
Volume and weight of dried Jatropha fruits, fruit coats and seeds corresponding to 1 kg Jatropha oil. Energy content for each fraction is given as MJ kg^{-1}.

	Volume (l)	Weight (kg)	Energy content (MJ kg^{-1})
Dry fruits (coats and seeds)	36	9	21.2[a]
Dried fruit coats	13	4	10.7
Dried seeds (w/oil)	11	5	25.5[a]
Jatropha oil	0.914[b]	1	39.6[b]

[a] Openshawd, 2000.
[b] Achten et al., 2008.

willingness to pay for electricity is lower than the cost of the electricity provided, it is likely that the project will not be economically viable without subsidies. Gaul (2012) studied the Jatropha supply chain through a comprehensive Life Cycle Inventory (LCI) and found that its low efficiency and high labor intensity results in high costs and a low return on labor compared with pathways using alternative renewable energy technologies and a baseline of fuels in use today. In his conclusion, Gaul also suggests the importance of institutional aspects to make such projects viable. Nygaard (2010) suggests that the multiple qualities in terms of development achievements connected with the MFP have in fact proved a central challenge to the viability of this technology, not least on the management side. Interviews with key informants both in Engaruka Juu and in TaTEDO confirmed that difficulties in management of the MFP had been a major constraint, not excluding economic checks and balances. Romijn and Caniels (2011) put forward that 'unless Jatropha is introduced on a commercially sound basis and accompanied by strong local capacity building for project management and maintenance, the (…) concept will not be sustainable after the donors pull out'. Whereas subsidies, or 'Low Usage Tariffs', are provided for households connected to the national grid, a similar support mechanism is not yet in place for rural mini-grid solutions in Tanzania. Rather than relying solely on running the operation on a "commercially sound basis", we propose subsidies as a more sustainable way of ensuring the economic viability of such projects in the long run.

Sustainability

From an energy perspective, production of Jatropha oil in Engaruka Juu can be considered sustainable because it harnesses sunlight to produce energy to the society corresponding to 3.8 times the amount of energy invested through human and mechanical labor in the production. In the system delineated in this study all the energy used can be considered as renewable. Jatropha oil production based on a system of hedges around fields to protect other crops can therefore be an environmentally sustainable solution, compared to intensive production systems depending on fertilizer and other inputs but with less known effects on the environment due to limited knowledge about the agronomy of the Jatropha plant (Achten et al., 2008).

As shown in Fig. 1 a substantial amount of energy is lost in the form of seed cake (102 MJ) and fruit coats (38 MJ) to produce 39.6 MJ Jatropha oil, since the by-products were not utilized in the MFP in Engaruka Juu. According to Giampietro et al. (1992) sustainability implies that human exploitation of natural resources maintain a flow of energy sufficient to maintain the stability of its biophysical capital, original structures and functions. This could be an argument for returning the waste products directly to the Jatropha hedges. Jatropha hedges have a limited impact on biodiversity, but it has been pointed out that the sustainability of the Jatropha energy system depends on the use of the waste materials (Achten et al., 2007). This has lead to experimentation on gasification of Jatropha nut shells (Manurung et al., 2009; Singh et al., 2008; Vyas and Singh, 2007) and anaerobic digestion of seed cake to produce fertilizer and biogas (Staubmann et al., 1997). Jatropha is promoted in relatively arid areas, and anaerobic digestion is therefore not necessarily a suitable solution since it requires much water. Additional energy and income could be generated from utilizing the energy in the waste products.

This study has identified challenges connected with village-scale use of Jatropha for electrification. Despite this it has been suggested that village-scale use of Jatropha oil in motors could become a cost- and energy efficient option through further optimization (Gaul, 2012). Judging from the energy flows quantified in this study (Fig. 1) it seems clear that there is much to gain from utilizing the by-products since this is where most of the energy is found. The ethical aspect of provision of modern and "sustainable" energy services by taking advantage of marginalized people's willingness to work to is another matter. The households connected to the mini-grid in Engaruka Juu were typically relatively well-off. Those persons who harvest Jatropha were unable to pay for the energy services to be provided through the MFP. Although division of "classes" is a classical problem in studies of development, it is still worth mentioning since availability of cheap enough labor may be the most important factor for having a viable, decentralized energy solution. The system may work as long as some in the community are willing to work for low payment per unit of time vested.

Conclusion

The findings show that energy input in terms of human labor in rural electrification with Jatropha allows for a positive energy balance. But the viability of this way of electrifying rural areas depends on the availability of labor willing to work for an income below the poverty line. Our energy flow chart of generation of electricity from Jatropha oil shows that human energy expenditure is marginal relative to the total amount of energy in the system. Harvesting is labor intensive work, and both harvesting and de-hulling is time consuming relative to the amount of Jatropha oil produced. Still, harvesting of Jatropha offers an optional income source particularly for marginalized groups, and the hedges are cultivated and maintained regardless of its profitability. Efficiency and economic viability of rural electrification of Jatropha can be improved by utilizing the waste products, but more research and development is needed in this area. For long-term viability of decentralized electricity generation based on biofuel, subsidies are required.

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