Energy for Sustainable Development 28 (2015) 60–67

Contents lists available at ScienceDirect

Energy for Sustainable Development

Jatropha mahafalensis for rural energy supply in south-western Madagascar?

Albrecht Ehrensperger [a,*], Josoa R. Randriamalala [b,c], Léa I.B. Raoliarivelo [b], Janet M. Husi [a]

[a] Centre for Development and Environment (CDE), University of Bern, Hallerstrasse 10, 3012 Bern, Switzerland
[b] Diagnostic Environnemental et Recherche Appliquée pour le Développement en Milieu Rural (DERAD), Lot AKT II A 105, Ambohitsaratelo, Vontovorona-Antananarivo 102, BP 60115, Madagascar
[c] Département des Eaux et Forêts, École Supérieure des Sciences Agronomiques, BP 175, Ankatso, Antananarivo 101, Madagascar

ARTICLE INFO

Article history:
Received 26 September 2014
Revised 31 July 2015
Accepted 31 July 2015
Available online xxxx

Keywords:
Bioenergy
Jatropha mahafalensis
Rural development
Energy
Madagascar

ABSTRACT

In many parts of the eastern African region wood-based fuels will remain dominant sources of energy in coming decades. Pressure on forests, especially in semi-arid areas will therefore continue increasing. In this context, the role of liquid biofuels as substitutes for firewood and charcoal, to help reducing pressure on woody biomass and contributing to a better energy security of rural communities, has remained controversial among researchers and practitioners. At household level, the economic and technical feasibility of straight vegetable oil (SVO) was assessed mainly on *Jatropha curcas*, with unpersuasive results. So far nothing is known about the suitability as an energy carrier of *Jatropha mahafalensis Jum. & H. Perrier*, the only endemic representative of the *Jatropha* genus in Madagascar. This paper explores the potential of this plant as a biofuel feedstock in the agro-pastoral area of Soalara, in the semi-arid south-western part of Madagascar. Only hedge-based production was considered to rule out competition over land with food crops. Yield data, the length of currently existing hedges and energy consumption patterns of households were used to assess the quantitative potential and economic viability of *J. mahafalensis* SVO for lighting and cooking. Tests were conducted with cooking and lighting devices to assess their technical suitability at household level. The paper concludes that *J. mahafalensis* hedges have some potential to replace paraffin for lighting (though without much economic benefit for the concerned households), but not to replace charcoal or firewood for cooking. The paper recommends that rural energy strategies in similar contexts do not focus only on substituting current fuels with SVO, but should also take into consideration other alternatives. In the case of cooking, there seems to be substantially more potential in increasing the efficiency of current fuel production and consumption technologies (kilns and stoves); and in the case of lighting, solutions based on SVO need to be compared against other options such as portable solar devices.

Introduction

Background

Access to affordable, reliable and renewable energy sources has grown into a major global challenge of the early 21st century. It is increasingly recognised as a key ingredient of poverty reduction and rural development (van Eijck et al., 2010; SGEA, 2012). In developing countries, a vast majority of people depend on traditional biomass such as firewood, charcoal or animal dung as a prime energy source. In sub-Saharan Africa, around 75% of the population is relying on traditional biomass fuels for cooking (IEA, 2011). In Madagascar this share reaches 84%, placing the country among the top 20 traditional biomass users (NationMaster). In the semi-arid south-western part of the country, high dependency on charcoal for domestic use is exerting increasing pressure on dry deciduous forests, and therefore contributes to vegetation and water resources degradation, biodiversity and soil loss, and siltation of productive areas (Andrianarisoa et al., 2014). Improved forest management, higher efficiency of energy use, and alternative energy sources are therefore required to satisfy energy needs in a sustainable manner. Potential alternative energy sources need to be inexpensive, readily available, not necessitating elaborate infrastructure and usable for cooking and lighting, which are the two major energy requirements of households.

Second generation liquid biofuels were identified a few years ago as a possible alternative for rural households in developing countries. They are seen as a possibility to alleviate land degradation, while contributing to the reduction of greenhouse gas emissions (Messemaker, 2008; Zah et al., 2011). In this context, *Jatropha curcas* L., an oil producing shrub, has received a lot of attention on the African continent in the early 2000s, mainly due to its ability to grow in arid areas and on poor soils

* Corresponding author. Tel.: +41 31 631 54 58.
E-mail addresses: albrecht.ehrensperger@cde.unibe.ch (A. Ehrensperger), rramarolalonana@yahoo.fr, derad@moov.mg (J.R. Randriamalala), raoliarivelo@yahoo.fr, derad@moov.mg (L.I.B. Raoliarivelo), mjanet_m@yahoo.com (J.M. Husi).

http://dx.doi.org/10.1016/j.esd.2015.07.006
0973-0826/

(Ehrensperger et al., 2012a,b). However, more recent research in East Africa has cast serious doubt concerning the suitability of *J. curcas* as a sustainable source of energy. Some authors have shown that commercial plot based *J. curcas* production, is not economically viable due to low yields, especially in marginal lands, and to unreliable markets (Findlater and Kandlikar, 2011; GTZ, 2009; ODI, 2011). Others have raised concerns pertaining to possible negative impacts of J. curcas cultivation on access to land and food security (Cotula et al. 2011, FAO, 2010). Some nevertheless identified potential for *J. curcas* hedges or live fences (which do not compete for land with food crops), especially for local energy supply to substitute traditional biomass energy and paraffin for lighting and cooking (Feto, 2011; GTZ, 2009; Mogaka et al., forthcoming).

While the discussion on *J. curcas* is on-going, very little is known about *Jatropha mahafalensis Jum et Perr* (Fig. 1), the only endemic representative of the *Jatropha* genus in Madagascar. Literature on this plant is rare (Radcliffe-Smith, 1997) or outdated (Heim et al., 1919). A few recent articles focus on the alleged ability of *J. mahafalensis* to inhibit the malaria pathogen Plasmodium falciparum (Baraguey et al., 2001; Nayak and Patel, 2009). But none investigates the potential of this plant as an energy feedstock, apart from Sonnleitner et al. (2012), who have analysed the composition of *J. mahafalensis* oil and assessed its suitability as a fuel for rural households. They conclude that it can contribute to households' energy supply as it is suitable for biodiesel production or for use as straight vegetable oil (SVO) in oil lamps and combustion engines. However, they also noted that further processing of the oil is needed to reduce its viscosity and element content (bleaching or filtering). These conclusions are comparable to the ones made elsewhere on *J. curcas* oil (Rathbauer et al, 2012). Therefore, we assume a similar physical and chemical suitability of *J. mahafalensis* oil as is the case for *J. curcas* oil. What remains to be determined is the technical feasibility and economic viability of village-based production and utilisation of *J. mahafalensis* oil to satisfy households' energy needs.

Objectives of the study

Thus, the overall goal of this study is to assess the potential of *J. mahafalensis* hedges to substitute primary fuels for cooking (firewood and charcoal) and lighting (kerosene/paraffin) in rural households of semi-arid south-western Madagascar. We pursue this goal in order to provide field based evidence to policy makers and practitioners, helping them to take informed decisions when designing energy policies and energy development interventions. Considering the still open debate on the significance of liquid biofuels for household energy supply, we consider this contribution to have high development relevance. We selected a hedge-based production scenario, because of the need to avoid opportunity costs of agricultural land and to not further increase the pressure on this resource. The following specific objectives were selected to address the overall goal: (a) to assess *J. mahafalensis* yield potentials in the region; (b) to estimate the economic viability of *J. mahafalensis* oil as a fuel for local households in the region; and (c) to test the suitability of *J. mahafalensis* oil for cooking and lighting.

Material and methods

Study area

Field work was conducted in the village of Soalara, in Toliara II district of south-western Madagascar (Fig. 2). This area is semi-arid, with an annual rainfall of around 400 mm received mainly from December to February (Raoliarivelo et al., 2010). The landscape is characterised by a sandy coastal area in the west and a calcareous plateau in the east; both areas, are separated by a steep escarpment running in north–south direction. Natural vegetation is dominated by spiny *Didieraceae* and *Euphorbiaceae* bush (Cornet and Guillaumet, 1976). The main livelihood strategies of local communities are fishing, small ruminant and very little zebu herding, some farming, and charcoal production and trade. Hedges and live fences are commonly used by livestock herders to corral animals or to keep them off the crop fields. Replacing part of these traditional hedges with *J. mahafalensis* hedges was therefore identified as an option to produce liquid biofuel for local consumption without increasing pressure on existing land resources.

Mapping of existing hedges

To determine oil production potential, a mapping of existing hedges was done using GIS. The total length of hedges was calculated for the entire village territory and for an area within 3 km distance from the

Fig. 1. *Jatropha mahafalensis* shrub in Soalara (south-west Madagascar).

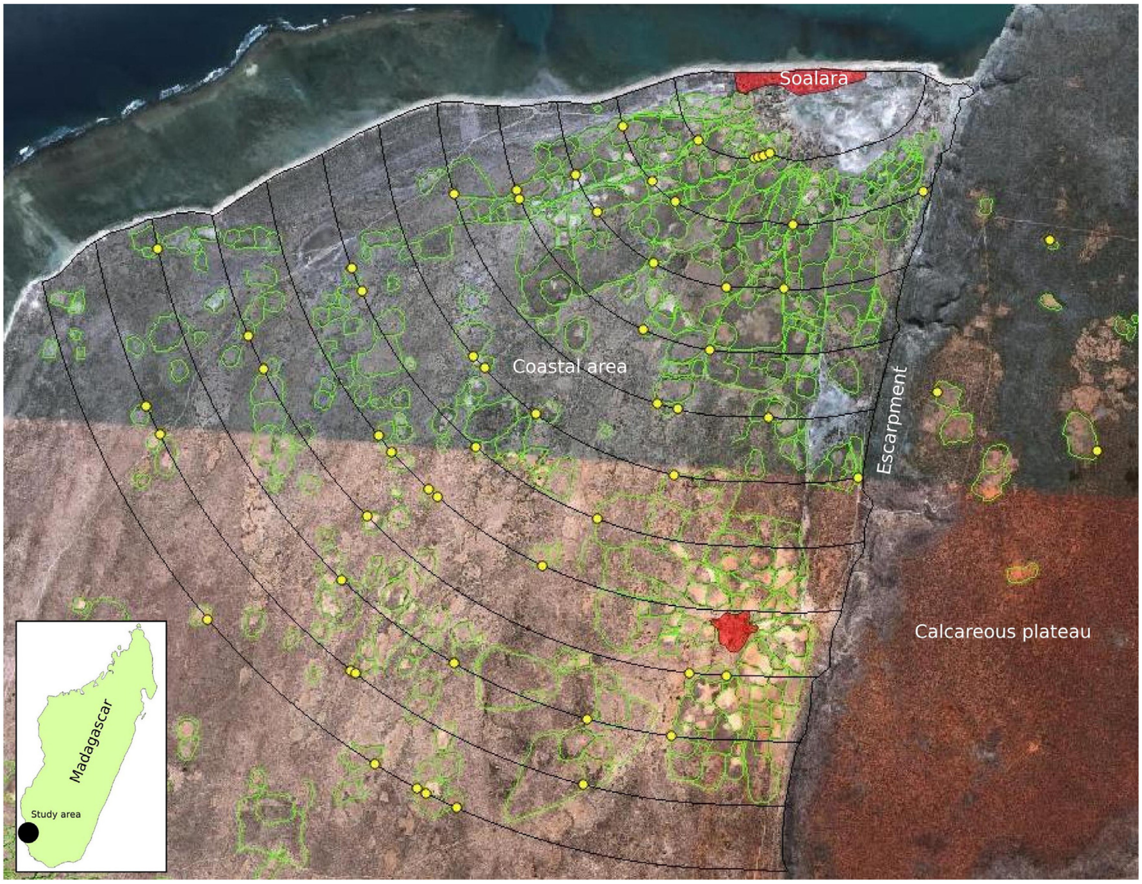

Fig. 2. Soalara area. The village is located on the shore. Existing hedges (green lines) were digitised from a high resolution satellite image. Hedge composition was assessed at 60 locations (yellow dots) selected by intersecting hedge lines with buffer lines calculated at every 500 m starting from the settlement area (black lines). (Features: own mapping; background: © 2012 Google, Image © 2012 GeoEye).

settlement area as a basis for a "low transportation cost" scenario. Oil production potential was calculated using yield data (see below) and 3 scenarios: substitution of 10%, 50% or 80% of existing hedges. Composition of existing hedges was analysed to assess possible loss of biodiversity and of alternative utilisations (food, medicinal use, etc.). Sixty sample sites were selected taking into account possible changes of hedge composition with increasing distance from the village area (Fig. 2): intersections of hedges with 12 virtual buffer lines, calculated at every 500 m starting from the settlement area, were identified. Five intersections were randomly selected on each buffer line. Species composition of hedges was assessed at these locations along a 12 m stretch using the following parameters: type, abundance and height of all species, maximal width and condition of hedge (maintained or not). Relative abundance of species was calculated using:

$$RAi = Ai \cdot 100/A.$$

where RAi is the relative abundance of species i; Ai is the abundance of species i and A is the total abundance of species. A value close to 0 indicates low relative abundance of the considered species; a value close to 100 indicates a dominance of that species. Non-parametric test of Kruskal–Wallis, followed by multiple tests of Mann–Whitney was used to analyse variations of species richness of fences ($p < 0.05$; Xlstat 2008; Addinsoft). Finally, Chi-square test was used to assess relation between distance from settlement and distribution of main species ($p < 0.05$; Xlstat 2008; Addinsoft 1995–2008).

J. mahafalensis yields

All seeds were harvested from 61 plants in February 2011 and from 30 plants in September 2011, as these two months were reported to coincide with *J. mahafalensis* fructification. Samples were weighted, packaged and stored one month in a dry and well aerated room. The same samples were used by Sonnleitner et al. (2012) to determine the physical and chemical suitability of the oil for energy production (see above). GPS coordinates and dendrometric parameters (girth at 30 cm, height of first ramification, total height) of each harvested plant were recorded. Yield analysis was conducted separately for 4 sample groups depending on the age of the plant (<10 years or ≥10 years) and its location (coastal area or calcareous plateau). Non parametric test of Kruskal–Wallis followed by multiple tests of Mann–Whitney were used to examine effects of plant location and ages on yields (Xlstat 2008). Correlation coefficients of Pearson between plant yields and dendrometric parameters were also calculated.

Household survey

Sixty-two households were interviewed in February 2011 about their energy consumption habits and the costs of their fuel procurement in terms of money and labour. A structured questionnaire was used for the survey and special attention was given to the procurement and utilisation of firewood and charcoal. Survey results were analysed in MS Excel using descriptive statistics. One way Analysis of Variance (ANOVA) followed by multiple tests of Tukey (Xlstat 2008) was run to

Table 1
J. mahafalensis seed production. CA = coastal area; CP = calcareous plateau; letters a, b and ab indicate results from multiple comparisons between factors, which are a combination of area and age. Values with different letters are significantly different ($p < 0.05$).

Area	Age of plant (years)	Nr. of plants	Average weight per plant (g)		p value inter-seasons	Total seed production 2011
			February 11	Sep-11		
CA	<10	16	358.0 a	273.6 a	>0.05	631.7
	≥10	14	687.0 b	222.8 ab	<0.001	909.9
CP	<10	20	349.8 a	4.1 b	<0.001	354
	≥10	11	634.6 ab	73.0 ab	<0.001	707.7
p-Value			<0.01	<0.001		

analyse relations between total time spent on procurement of firewood and charcoal and energy costs. Total time spent on procurement of firewood and charcoal was coded like this: short duration (3–8 h/month; N = 18), medium duration (10–30 h/month; N = 26) and long duration (40–100 h/month; N = 18).

J. mahafalensis oil combustion tests

J. mahafalensis oil was tested in simple oil lamps and cookers that are available locally. Combustion of *J. mahafalensis* seeds instead of oil was also tested in combination with charcoal in traditional cookers. These simple tests did not involve technical adaptation or improvement of lamps or cookers. Therefore, they have preliminary character; more advanced tests have to be done on adapted devices to achieve reliable conclusions on the suitability of *J. mahafalensis* oil for local energy supply.

Results

J. mahafalensis production potential

Seed production

The February 2011 samples (Table 1) indicate that average seed production of *J. mahafalensis* plants is increasing with age, even though the difference between both age groups is not significant for plants on the calcareous plateau. There is no significant seed production difference, for both age groups, between plants located in the coastal area and those found on the plateau, even though there seems to be a tendency for higher production in the coastal area. The weight of seeds per plant is not influenced by dendrometric parameters (total height of plant, height of first ramification, number of ramifications at base). Table 1 also shows that seed production decreased significantly in September 2011, with the exception of younger plants in the coastal area. This is due to the drought that took place in September, a frequent occurrence in the region, and that lead to a general productivity decrease. The totals of the February and September averages indicate annual productions per plant ranging from 600 to 900 g in the coastal area and from 350 to 700 g on the calcareous plateau.

Length, composition and utilisation of existing hedges

The total length of existing hedges in the entire Solara communal territory is 236 km. The hedges located within a radius of 3 km form Soalara village have a total length of 93 km.

A total of 110 species was recorded in the 60 sample locations. The most frequent species (Fig. 3) and also the only ones that are purposefully planted as hedge plants are *Opuntia stricta* (*Cactaceae*; *raketa mena*) and *Agave* sp. (*Asparagaceae*; *laloasy*). *O. stricta* is classified as an invasive species, but this does not seem to be a problem in Soalara, as the arid climate limits the plant's progression and enables the community to burn it when expanding too much. Additionally, it is a good fencing material and is used as fodder for zebus during dry spells. *Agave* sp. is used for its fibre instead of sisal, but its use is marginal. The other species recorded are usually found in abandoned hedges and are also common in the surrounding natural spiny bush vegetation. They grow spontaneously, when hedge maintenance is discontinued. Specific diversity of hedges varies from 2 to 26 species. Average species diversity per buffer line varies from 7 to 12 species. These variations are not significant ($p > 0.05$; N = 59), which means that species diversity does not change with distance from the settlement area. The distribution of *O. stricta* and *Agave* sp. are slightly dependant on distance from the settlement ($p \sim 0.05$; Chi square = 19.35; degree of freedom = 11): the first is dominating at almost all distances, whereas the second is slightly dominant closer to the settlement area.

Household survey

Energy carriers used by households

Charcoal and firewood are, by far, the most important energy carriers for the local population. They are mostly used on traditional open fire places (Table 2). Paraffin, for lighting, as well as batteries for powering radios and torches rank second and are similarly important energy carriers, used by around half of the households. All other sources of energy, like biogas, *J. mahafalensis* oil, or electricity from generators are marginal.

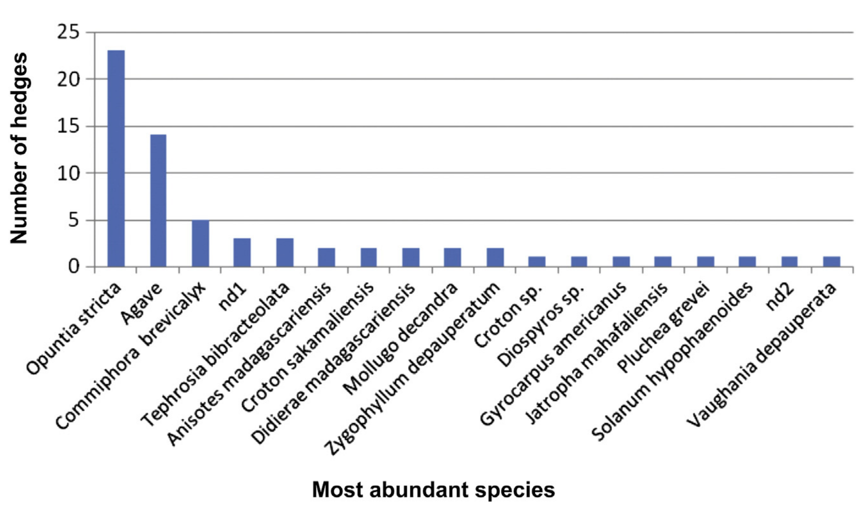

Fig. 3. Distribution of dominant species at 60 sample locations in the hedges of the study area. Mean relative abundance of *O. stricta* is 61 ± 18% (±standard deviation; SD) and mean relative abundance of *Agave* sp. is 80 ± 18% (±SD). nd1 and nd2: species not identified.

The economics of firewood and charcoal

The quantity of firewood used (10 to 450 kg/month) and the money spent for this fuel (1.8 to 8.4 Euro/month) are highly variable (Table 3). Most households collect firewood themselves, therefore incurring no, or only little cash expenses, but spending between 20 and 100 h per month collecting (average ≈ 50 h). 24 households indicated purchasing firewood from the local market. Households, who can afford to purchase wood or charcoal, only spend between 3 and 20 h per month on fuel procurement (average ≈ 8 h). Only 11 households rely on charcoal. Monthly costs for charcoal are slightly lower than for firewood, probably because charcoal is used less frequently than firewood, which is the default cooking fuel. Sourcing of firewood and charcoal is commonly done by the household head or his/her spouse.

Table 3
Economics of firewood and charcoal.

	Firewood	Charcoal
Use	55 HH (89%), only for cooking	11 HH (18%), only for cooking
Quantities	10 to 450 kg/month (average 206 kg)[a]	40 to 150 kg/month (average 81 kg)
Price	0.01–0.06 Euro/kg (average 0.03 Euro/kg)[b]	around 0.035 Euro/kg
Costs	1.8–8.4 Euro/month (average 4.5 Euro/month)	1.4–6.3 Euro/month (average 2.7 Euro/month)
Sourcing	38 HH (61%) collect themselves spending 20 to 100 h/month (av. 50 h/month). 24 HH purchase from local market	Local market and individuals. None of the households indicated producing charcoal for its own consumption
Who sources	In 40 HH (65%) the household head or his/her spouse take care of firewood collecting; in 10 HH (16%) the entire family; in 3 HH (4%) only the children; and in 1 HH (2%) another person	Mostly the HH head or the spouse (8 HH), the entire family (1 HH), or other persons (1 HH)
Distance	2.1 km–6.5 km (average 5 km)	Not applicable

HH = households.
[a] Households using charcoal use either no firewood (6 HH), or maximum 150 kg/month (5 HH).
[b] Information provided by 22 households.

Paraffin and other energy sources

Fifty seven households out of 62 (92%) rely on paraffin for lighting. Quantities of fuel consumed per month are 2.75 l in average. This is equivalent to average monthly costs of 1.86 Euros (Table 4). Four households indicated using a private generator for lighting, leisure (2 of the 4 own a TV), charging batteries and other (not revealed) uses. Among these four households, one uses 20 l of fuel per month, which is equivalent to 21 Euro, and two use 4.5 and 5 l respectively (3.5 to 6 Euro/month). None of the interviewed households uses solar panels, and grid electricity is not available in the village. Only 2 households are using *J. mahafalensis* for lighting. Mostly this plant is used for fencing (44), medicinal (32) or veterinary (2) purposes, or other (unspecified) uses (10).

Overall energy costs (time and cash)

The overall energy costs per household (including biomass, paraffin and batteries) range from 0 to 12 Euro per month. The total time spent on procurement of fuels ranges from 3 to 100 h per month. Energy costs tend to decrease when time spent on procurement of firewood increases (Table 5; $F = 12.863$; $df = 2$; $p < 0.001$). Households spending less than 10 h/month on procurement of firewood and charcoal are incurring the highest energy costs.

Combustion of J. mahafalensis seeds and oil

Cooking

Seeds. In the case of *J. mahafalensis* seeds, two methods were tested using a widely available cooking stove (Fig. 4): direct combustion using only seeds and indirect combustion using charcoal for preheating. Direct combustion proved to be unsuitable as seeds did not produce flames, but underwent slow calcination instead. Indirect combustion yielded some flames, but of insufficient duration for cooking.

Table 2
Household energy assets (N = 62).

Cooking	Majority (54) of households uses simple 3 stones fireplace for cooking. The remaining households are using improved (7) or simple (2) earthenware stoves. None has a gas, biofuel, or electric stove.
Lighting	About half of the households (33) own an electric torch, but mostly rely on paraffin for lighting. Two households indicated using *Jatropha* and one is using firewood for lighting.
Transport	The only frequent vehicles are oxen carts (20 households) and sailing boats (15). Only 1 household indicated owning a bicycle and only 2 have an engine powered boat. None has a motorbike.
Energy production	There are 4 privately owned generators among the interviewed households. Mostly, generators are used to produce electricity, which is used for lighting in the evenings, powering radios and TVs, as well as recharging mobile phone batteries. Hence, generators are mainly used in the evenings.

Oil. A simple wick stove was used to test cooking with *J. mahafalensis* oil (Fig. 4). This stove was constructed from a small container, a round metal plate with holes for the wicks and a reinforcing rod to hold the pan (Fig. 4). Tests were conducted individually with portions of 200 g of sweet potatoes, beans, rice and dried manioc. In all cases, cooking with *J. mahafalensis* oil lasted longer than with charcoal and required significantly more maintenance of the combustion process. This is due to the fact that this process produces a lot of sooth and therefore tends to clog the wicks.

Lighting

Lighting (Fig. 4) was tested using a simple floating wick lamp made from locally available and inexpensive components: a 250 cm^3 jar, a cotton wick and a floater (slice of maize cob wrapped in aluminium foil). Combustion was slow and economical: after 2 h of burning, only 30 cm^3 were consumed. However, the lamp requires frequent adjustment of the wick, which gets easily crusted by sooth deposits.

Discussion of results

Considering that currently available cooking devices using *J. mahafalensis* oil or seeds are not working properly and are therefore unlikely to replace the commonly used charcoal stoves, or the traditional three-stone-stoves for firewood (see 3.3.1 above), the calculations made below are focusing on the quantitative potential and the affordability of *J. mahafalensis* oil as a substitute of paraffin for lighting.

Quantitative potential of J. mahafalensis hedges for energy supply in Soalara

Using *J. mahafalensis* oil for lighting is not common and would require changes in the land use system (replacement of existing hedges) and in household habits (use of modified lamps). Therefore,

Table 4
Paraffin consumption and costs.

	Consumption (l/month)			Costs (Euro/month)		
	Min.	Max.	Average	Min.	Max.	Average
Paraffin	0.5	8	2.75	0.35	5.2	1.86

Note: averages are rounded figures.

Table 5
Relation between time spent on procurement of firewood and energy costs per household per month.

Time spent on procurement of firewood and charcoal (h/month)	Average energy costs (€/month)
3-Aug	5.6a
Oct-30	2.9b
40–100	2.4b
p	<0.001

a and b indicate results from multiple comparisons by time spent on procurement of firewood and charcoal. Values with different letters are significantly different ($p < 0.05$).

we are proposing a conservative assessment of the quantitative potential of *J. mahafalensis* hedges for energy supply in Soalara. We are basing this assessment on the following system boundaries and estimates:

1. Suitable production area and length of existing hedges: We only take into consideration the coastal stretch of the study area within a linear distance of 3 km from the main village of Soalara (see Fig. 2). We consider that beyond these limits, collection of *J. mahafalensis* seeds is not worth doing because of increasing transportation effort. Within this area, the length of existing hedges is 93 km.
2. Composition of productive *J. mahafalensis* hedges: Considering the semi-arid climate of the study site, the need for extra zebu fodder during dry spells, and the crown size of adult bushes, we suggest a spacing of 3 to 4 m between *J. mahafalensis* plants (300 plants per km of hedge) and the use of either *agave* sp. (as shown in Fig. 1) or *O. stricta* to fill the gaps.
3. Production per plant: The sample data shows seed production values ranging from 600 g to 900 g per plant and year in the coastal stretch. We think it is safe to use the upper value (900 g per plant per year), considering that better tending of the plants would help increasing these yields considerably, and also because 2011 was a drought year with comparatively low yields.
4. Oil content of seeds: Using solvents, 35% to 50% oil content can be extracted from *J. mahafalensis* seeds gathered in the coastal stretch (Sonnleitner et al., 2012). Less efficient mechanical extraction is expected to achieve extraction ratios of around 30% of seed weight, which is comparable to values obtained through mechanical extraction of *J. curcas* oil.
5. Number of households: Soalara village has a population of around 4700 and an average household size of 6, which is equivalent to around 780 households. We are rounding up this figure to 800 to take into consideration possible population increase in recent years.
6. Combustion rate of devices: Based on the few tests conducted for this study, we assume a combustion rate of 15 cm^3 of oil/h for floating wick oil lamps, which translates to approximately 67 h lighting per litre of oil.

In Table 6 we are calculating the number of days during which all households of Soalara could light a floating wick lamp during two hours, for example in the evening. We used the above estimates and 3 hedge replacement scenarios (10%, 50% and 80% of existing hedges in the considered area). The table shows that the highest replacement scenario (80%) would allow producing 6026 l of oil, which would last roughly 250 days, i.e., slightly more than two thirds of a year, if all households use a floating wick lamp during 2 h per day. Probably

Fig. 4. Combustion of *J. mahafalensis* seeds in combination with charcoal in a conventional charcoal stove (top-left), oil using a wick stove for cooking (bottom) and a floating wick lamp for lighting (top-right). Photographs by authors.

Table 6
Seed, oil and seedcake production potential for 3 hedge replacement scenarios.

Number of JM plants @ 300 plants/km of hedge		Production values @ 0.9 kg of seeds per plant			Energy potential for lighting 800 households @ 2 h per household per day	
Hedge replacement scenario	JM plants (Nr)	Seeds (kg)	Oil (l)	Seedcake (kg)	Available combustion time (h)	Available combustion time per household (2 h/days/year)
10% = 9.3 km	2790	2511	753	1758	50,451	32
50% = 46.5 km	13,950	12,555	3767	8788	252,389	158
80% = 74.4 km	22,320	20,088	6026	14,062	403,742	252

optimising the production (more *J. mahafalensis* trees per km and higher yields through active plant tending) would allow to achieve full replacement of paraffin for lighting under the given utilisation scenario.

It seems fairly clear that the achievable *J. mahafalensis* production volumes will, by no means, be able to replace both the current lighting and cooking fuels. Therefore, our decision not to envisage *J. mahafalensis* oil or seeds as a substitute for firewood or charcoal out of technical considerations (see above), is strengthened by unambiguous quantitative conclusions.

Affordability of J. mahafalensis oil to substitute paraffin for lighting

If used for lighting, *J. mahafalensis* would need to compete with paraffin. At current utilisation intensity paraffin costs households between 0.35 and 5.2 Euros per month, i.e., between 4.2 and 62.4 Euros annually (22.30 Euros in average). The costs of producing and utilising *J. mahafalensis* oil for lighting have not been assessed directly in Soalara. Therefore, we are relying on previous research conducted by Ehrensperger et al. (2012a) on *J. curcas* in Ethiopia, Kenya and Tanzania.

We do not count labour input for hedge planting and tending, seed harvesting and processing in the cost comparison for the following reasons: hedges fulfil a function of their own and therefore need to be planted and tended even when not used for fuel production; seed harvesting and processing (de-husking and pressing) can mostly be done in off-peak moments and do therefore not infringe on other important economic activities.

We assume that oil extraction is done at household or village level using a simple ram press costing roughly 150 Euros. Such presses are fixed on heavy wood beams, which cost roughly 10 Euro and the oil is collected in buckets or containers costing around 5 Euro. We assume that all of the above components have an approximate lifespan of 10 years. Annual costs of 60 Euro are required for the monthly purchase of gravity filters (approximately 5 Euro per piece), which are needed to filter the oil.

Thus, over an amortisation period of 10 years, the average annual costs for one processing unit, including the above listed components, are totalling around 70 to 80 Euros. This means that using *J. mahafalensis* instead of paraffin for lighting starts to become profitable if at least three households share the costs for one processing device, when considering average values. Profitability increases when more households are investing together. For example, if 10 households share one device, initial investment would be reduced to 16 Euro per household and annual costs would total 7 to 8 Euro per household in average.

Conclusion and outlook

Even in a land use system relying heavily on hedging, such as the one of Soalara, *J. mahafalensis* hedges do not have the quantitative potential to replace traditional cooking fuels (charcoal and firewood). Furthermore, there are currently no satisfactory technical solutions for *J. mahafalensis* oil or seed combustion for cooking. As opposed to this, the substitution of paraffin for lighting using *J. mahafalensis* oil from hedges seems to be a viable option provided that: (1) yields are improved through active selection and tending of *J. mahafalensis* plants; and (2) at least three households cooperate to share costs of seed processing equipment. The advantages of such a substitution are reduced dependency on fossil fuels and reduced exposure to their fluctuating prices, as well as the possibility to use very simple and inexpensive lamps. Disadvantages are initial investment for the processing device, as well as increased unpaid labour input for harvesting, de-husking and pressing the seeds. It is expected that households will only accept this additional workload, if it does not infringe on other livelihood activities and if the financial benefit is tangible, i.e., if a sufficient number of households are ready to collaborate in purchasing a processing device.

Based on these findings, we recommend that rural energy policies and development strategies in similar contexts do not focus only on the substitution of current fuels with oil from *J. mahafalensis* or comparable feedstock. In the case of cooking, there seems to be substantially more potential in increasing the efficiency of current fuel production and consumption technologies (improved charcoal kilns, efficient firewood and charcoal stoves); and in the case of lighting, solutions based on straight vegetable oil need to be compared against other options such as portable solar devices which have a much higher energy efficiency. Additionally, research on the readiness of households to substitute fossil fuels with locally produced *J. mahafalensis* oil remains to be done and will have to take into consideration aspects such as the seasonality of *J. mahafalensis* fructification and of other livelihood activities, as well as the workload of harvesting and processing and how this could compete with potential income generating activities. Finally, it would be worthwhile exploring alternative business models including small-scale production and processing enterprises that would sell locally produced *J. mahafalensis* oil to households for a small fee.

Acknowledgments

This study was conducted in the frame of the ERA-ARD funded (www.era-ard.org) Bioenergy in Africa (BIA) project (www.bioenergyinafrica.net), which was implemented between 2009 and 2012 in East Africa and Central America. The BIA project focusses on identifying potentials and risks of biofuels for the rural poor. Additional support was provided by the Eastern and Southern Africa Partnership Programme (www.cde.unibe.ch/) funded by the Swiss Agency for Development Cooperation (SDC; www.sdc.admin.ch).

References

Andrianarisoa JH, Rabeniala R, Raoliarivelo LIB, Randriamalala JR. Identification et analyse d'activités alternatives à la fabrication de charbon de bois dans le District de Toliara II: Développement de l'élevage de petits ruminants. Rapport de projet. Eastern and Southern Africa Partnership Programme; 2014.
Baraguey C, Blond A, Cavelier F, Pousset JL, Bodo B, Auvin-Guette C. Isolation, structure and synthesis of mahafacyclin B, a cyclic heptapeptide from the latex of *Jatropha mahafalensis*. J Chem Soc Perkin Trans 2001;1:2098–103.
Cornet A, Guillaumet JL. Divisions floristiques et étages de végétation à Madagascar. Cahiers ORSTOM n°55; 1976.
Cotula L, Finnegan L, Macqueen D. Biomass energy: another driver of land acquisitions? The global land rush. iied briefing. London: International Institute for Development and Environment; 2011.
Ehrensperger A, Portner B, Kiteme B. Potentials and limitations of *Jatropha curcas* for rural energy supply in East Africa: a case study based comparative assessment in Ethiopia,

Kenya and Tanzania. Paper presented by Brigitte Portner at the 2012 Tech4Dev International Conference on May 30th 2012 at EPFL in Lausanne, Switzerland; 2012a. [http://cooperation.epfl.ch/2012Tech4Dev].

Ehrensperger A, Grimm O, Kiteme B. Food insecurity drivers in Kenya; consequences for current and future biofuel investments. Paper presented on July 4th 2012 at the IFSA 2012 Conference in Aarhus; 2012b. [www.ifsa2012.dk].

FAO. Bioenergy and food security. The BEFS analysis for Tanzania. In: Maltsoglou I, Khwaja Y, editors. Environment and natural resources management working paper 35. Rome: FAO; 2010. p. 240.

Feto A. Energy, greenhouse gas and economic assessment of biodiesel production from *Jatropha*: the case of Eastern and North Eastern Ethiopia. MSc Thesis Haramaya: Haramaya University; 2011.

Findlater KM, Kandlikar M. Land use and second-generation biofuel feedstocks: the unconsidered impacts of *Jatropha* biodiesel in Rajasthan, India. Energy Policy 2011; 39(6):3404–13.

GTZ. *Jatropha* reality-check. A field assessment of the agronomic and economic viability of *Jatropha* and other oilseed crops in Kenya. Endelevu Energy, World Agroforestry Centre, Kenya Forestry Research Institute; 2009.

Heim F, Garrigue E, Husson M. Un nouvel oléagineux de Madagascar: 'le Betratra' Jatropha mahafalensis Jum. (Euphorb.). Bulletin de l'Agence Générale des Colonies, 12; 1919. p. 679–91.

IEA. Energy for all. Financing access for the poor. Special early excerpt of the World Energy Outlook 2011. Paris: International Energy Agency; 2011 [http://www.iea.org/papers/2011/weo2011_energy_for_all.pdf].

Messemaker. Assessment of the *Jatropha* value chain and its potential for pro poor biofuel development in Northern Tanzania. MSc thesis International development studies at the Faculty of Geosciences. The Netherlands: Utrecht University; 2008.

Mogaka V, Iiyama M, Ehrensperger A, Birtel M, Gmünder S. Understanding adoption of *Jatropha curcas* L. by smallholders in Kenya. The examples of Bondo, Kibwezi and Kwale districts; 2012g [forthcoming].

NationMaster. Data on biomass energy compiled from World Development Indicators database and CIA World Factbooks. http://www.nationmaster.com/encyclopedia/Biomass-energy.

Nayak BS, Patel KN. A marvel plant — *Jatropha*: an appraisal. Int J Pharm Res 2009;1(3): 35–9.

ODI. Biofuels in Eastern Africa: dangers yes, but much potential as well. Project briefing No 66. September 2011. Written as part of the Bioenergy in Africa (BIA) project; 2011 [www.bioenergyinafrica.net].

Radcliffe-Smith A. Notes on Madagascan *Euphorbiaceae* V: *Jatropha*. Kew Bull 1997;52(1): 177–81.

Raoliarivelo LIB, Rabeniala R, Masezamana HN, Andrianarisoa JH, Randriamalala RJ. Impact de la fabrication de charbon de bois sur la production et la disponibilité fourragère de pâturage en zone subaride, cas de la commune de Soalara-Sud, Toliara II. Rapport de projet. Eastern and Southern Africa Partnership Programme; 2010.

Rathbauer J, Sonnleitner A, Pirot R, Zeller R, BAcovsky D. Characterisation of *Jatropha curcas* seeds and oil from Mali. Biomass Bioenergy 2012;47:201–10. http://dx.doi.org/10.1016/j.biombioe.2012.09.040.

SGEA (Secretary-General's High-Level Group on Sustainable Energy for All). Sustainable energy for all: a global action agenda. www.sustainableenergyforall.org, 2012. [Last accessed on January 30th 2013].

Sonnleitner A, Rathbauer J, Randriamalala RJ, Raoliarivelo LI, Andrianarisoa JH, Radobarimanjaka R, et al. *Jatropha mahafalensis* oil properties and suitability for rural energy supply in Madagascar. Paper submitted to Energy for Sustainable Development in December 2012; 2012.

van Eijck J, Smeets E, Romijn H, Balkema A, Jongschaap R. *Jatropha* assessment. Study carried out in the framework of the Netherlands Programme Sustainable Biomass by the Copernicus Institute, Utrecht University, Technical University, Eindhoven and Plant Research International, Wageningen UR; 2010.

Zah R, Gmuender S, Ehrensperger A. Biotreibstoffe aus Entwicklungsländern. Biol Unserer Zeit 2011;41(5). [Available on www.wileyonlinelibrary.com].