Energy for Sustainable Development 31 (2016) 163–169

Contents lists available at ScienceDirect

Energy for Sustainable Development

Potentialities and limits of *Jatropha curcas* L. as alternative energy source to traditional energy sources in Northern Ghana

N. Contran [a], L. Chessa [a,b,*], M. Lubino [a], D. Bellavite [a], R. Lobina [a], O. Sahanoon [c], S. Fuseini [c], T.S. Imoro [c], P.P. Roggero [a,b], G. Enne [a]

[a] *Desertification Research Centre (NRD-UNISS), Università degli Studi di Sassari, Viale Italia 39, 07100 Sassari, Italy*
[b] *Dipartimento di Agraria, Università degli Studi di Sassari, Via Enrico de Nicola 1, 07100 Sassari, Italy*
[c] *NewEnergy, Kilometer 7, Yapei Road, Tamale, Ghana*

A R T I C L E I N F O

Article history:
Received 3 December 2015
Revised 2 February 2016
Accepted 2 February 2016
Available online xxxx

Keywords:
J. curcas
Energy sources
Rural development
Participatory Rural Appraisal
Northern Ghana

A B S T R A C T

This article aims to analyze not only the limits but also the potentialities of Jatropha curcas as an alternative energy source to the most common energy sources, such as firewood and charcoal, utilized in Northern Ghana. In 2010, a Participatory Rural Appraisal was conducted in seven rural communities in the West Mamprusi District (Northern region, Ghana). In this context, *J. curcas* plantations were promoted at smallholder scale and 480 ha of decentralized *J. curcas* plantations has been established, involving 1,200 farmers (0.4 ha of land per farmer). *J. curcas* was cultivated only on marginal soil, defined as lands unused for at least 2 years. The proposed *J. curcas* system could potentially replace, in terms of energy content, 21% of firewood or 21.8% of charcoal monthly used by households, with comparable costs and time , respect to the traditional energy sources.

Introduction

Jatropha curcas potential for rural development has been recognized by many people (Eckart and Henshaw, 2012). *J. curcas* is a drought-avoidant perennial large shrub or small tree, with a life expectancy of up 50 years (Heller, 1996). It grows in tropical and subtropical regions, with annual precipitation between 600 and 1500 mm (Trabucco et al., 2010). Its high ecological adaptability allows its growth in an ample range of conditions from semiarid to humid (annual rainfall varying from 300 to 3,000 mm) (Maes et al., 2009) and in wide varieties of soil types, including poor quality soils (Ye et al., 2009). *J. curcas* seeds contain about 30–35% of oil per seed dry weight, which can be expelled or extracted (Jongschaap et al., 2007). The production of oil from *J. curcas* seeds requires two steps: i) de-husking process (with a decorticator), to separate seeds from fruit husk, and ii) oil extraction process, to produce oil and seed cake by-product (Fig. 1). *J. curcas* oil can be used as cooking and lighting fuel, adopting special design equipment, replacing the traditional biomass sources, such as firewood, charcoal, kerosene or petrol. In addition, the oil can be utilized for soap making. The extraction of oil from *J. curcas* seed generates also important by-products: fruit husks are the by-products of de-husking process, while about 50–70% of the original seed weight remains as de-oiled seed cake (Fig. 1) (Brittaine and Lutaladio, 2010; Devappa et al., 2010). Fruits husk and seed cake, having high nutrient content and calorific values, have a wide variety of applications as fuel or organic fertilizer (Ye et al., 2009).

However, *J. curcas* is still a (semi-)wild undomesticated plant and its basic agronomic properties are not thoroughly understood, the growing and management practices are poorly documented, and the environmental effects have not been investigated yet (Contran et al., 2013). *J. curcas* yield is still unknown, and a wide yield range is reported in literature: annual dry seed production can range from about 0.4 t to 12 t per ha (Achten et al., 2008; Parawira, 2010). The current knowledge gaps about the impacts and potentials of *J. curcas* plantation makes large-scale *J. curcas* cultivation for oil and biodiesel production an hazardous business, with predictable negative repercussions on local populations and environment, such as the plantation of *J. curcas* on productive agricultural lands rather than on marginal lands (Kant and Wu, 2011; Dyer et al., 2012).

Contrary to these large scale industrial *J. curcas* programs, community-based *J. curcas* initiatives for local use, such as extensive *J. curcas* plantations on poor quality soils, agro-forestry systems in which *J. curcas* is intercropped, and agro-silvo-pastoral practices, can be seen as efficient opportunities to promote rural development in developing countries. The diversification of smallholder plantations and the introduction of new sources of income for local populations could lead to greater economic and ecological resilience and strength sustainability actions (Settle and Garba, 2011). In contexts where the main energy sources are firewood and charcoal, whose environmental

---

[*] Corresponding author at: Desertification Research Centre (NRD-UNISS), Università degli Studi di Sassari, Viale Italia 39, 07100 Sassari, Italy. Tel.: +39 079229238.

http://dx.doi.org/10.1016/j.esd.2016.02.004
0973-0826/

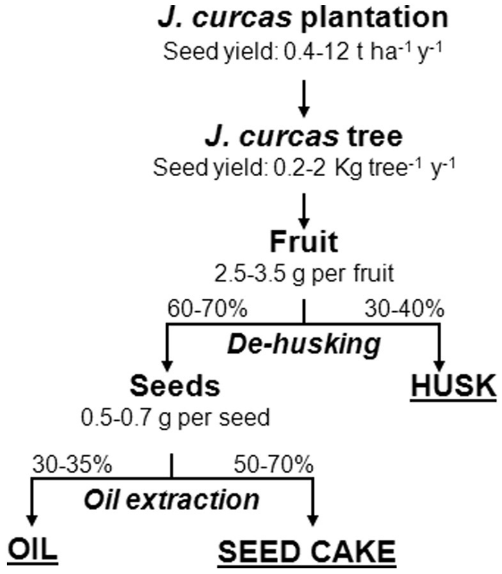

Fig. 1. *J. curcas* system.

sustainability represents a great concern (Menéndez and Curt, 2013), *J. curcas* could be considered a possible alternative energy source.

The aim of this paper is to explore not only the limits but also the potentialities of *J. curcas* as alternative energy source to substitute the traditional energy sources (especially wood and charcoal) normally used in Northern Ghana. This study has been performed in the context of the project "*Use of Jatropha plant to improve sustainable renewable energy development and create income-generating activities*: *an integrated approach to ensure sustainable livelihood conditions and mitigate land degradation effects in rural areas of Ghana* (*Ghaja*)", implemented for five years (2009–2014), within the "Environment and sustainable management of natural resources, including energy" program (EuropeAid). Fourteen rural communities of the West Mamprusi District, in the Northern Region of Ghana, were involved in the project: 7 communities in 2010 (i.e. Bimbini, Loagri, Nasia, Yama, Wungu, Kparigu, Janga) and 7 communities in 2011 (i.e. Bulbia, Zua, Nabulgu, Moatani, Boamasa, Guakudow, Zagsilari). Besides the financial resources for the realization of smallholder *J. curcas* plantations on abandoned farmland and for the provision of the equipment required for *J. curcas* oilseed and by-products production, this project provided: i) scientific input practices combined with appropriate agro-ecological and agronomic management, ii) improvement of farmer knowledge and capacity, iii) development of farmers' capacity to add value through their own business development, and iv) a focus on women's educational and agricultural technology needs. These points are considered the key requirements for sustainable development of African agriculture, as proposed by Pretty et al. (2011).

Materials and methods

Study area

Ghana is one of the most developed countries of the sub-Saharan area. The economic growth of the country has been estimated to 13.5% in 2011 (IMF, 2011) and poverty reduction rates are the best in the Region, as reported by the United Nations (UN, 2011). In 2006, Ghana achieved target A of the first Millennium Development Goal, halving the number of people living below the poverty threshold by 2015, and target B, halving the number of people suffering from hunger (UN, 2011). Despite these successes, Ghana still faces several challenges: Ghana ranks 135 out of 187 countries on the Human Development Index (UNDP, 2011) and 53.6% of its population lives under the poverty threshold, estimated in 2 USD/day (IFAD, 2011). Due to the exponential economic growth during the last decade, the energy demand is high and one of the most difficult challenges which Ghana has to face is the energy supply. About 64% of the total energy supply in Ghana comes from wood-fuel (firewood and charcoal), 9% from electricity, and 27% from petroleum (Duku et al., 2011). The Ghana government is conducting several efforts to modernize the energy supply sector, but assessments indicate that about 50% of the Ghanaian population has no access to grid-electricity and about 90% has not access to liquefied petroleum gas, confirming biomass as the dominant source of energy supply (Kemausuor et al., 2011). Wood-fuel consumption in Ghana is double than other energy sources.

The study area was located in the West Mamprusi District (5,013 km^2), in the Northern Region of Ghana, within longitudes 0°35′ W and 1°45′W and latitudes 9°55′N and 10°35′N and with Walewale as capital (http://westmamprusi.ghanadistricts.gov.gh). The district is classified as a tropical savannah climate zone, characterized by a pronounced dry season (from October to March), in which precipitation is less than 60 mm per month (Peel et al., 2007). In the area of study the average annual precipitation is 1100 mm, and the average annual temperature is 27.8 °C (min 22.3 °C–max 33.4 °C) (www.climatedata.eu).

District total population amounts at 131,650 inhabitants, whose 47.5% is less than 14 years old, 47% is among 15 and 64 years old and 5.5% is over 65 years old. District has 7 markets, the main one is in Walewale. As regards the communities involved in the project, only Bulbia has its own market (District Planning Coordinating Unit-West Mamprusi District Assembly, 2010).

Participatory Rural Appraisal method

A Participatory Rural Appraisal (PRA) was conducted in all the seven communities involved in the Ghaja project in 2010, (Bimbini, Loagri, Nasia, Yama, Wungu, Kparigu, Janga). Within these communities, 402 farmers, hereinafter referred to as interviewees, have been selected (about 55–65 people per community). Each interviewee was representative of a household. The interviewees were 1.8% of the communities' population. Data were collected at the beginning of 2010, before the start of *J. curcas* cultivation. PRA was carried out on small group (max 15 interviewees per group). Groups were selected within the same community. Participatory methods (e.g. individual interviews, focus group discussions, questionnaire, resource mapping, and rankings) were used to elicit data on socio-demographic and socio-economic characteristics, energy services, local land uses and cropping patterns, indigenous knowledge and skills on *J. curcas* cultivation and transformation processes. With reference to energy sources, interviewees have been asked to indicate their main uses, the place of collection, the time spent to access the energy sources, and the main problems in accessing them. Descriptive statistics, percentage data, and weighted averages of categorical data ($\pm$S.D.) have been used to present the results. The percentages of missing data or not answered questions are not reported.

Agricultural practices and oil extraction activities

Between 2010 and 2013, 480 ha of extensive *J. curcas* plantations have been established, involving 1200 farmers, who decided to cultivate *J. curcas* plants in 0.4 ha (1 acres) on marginal soils. Each farmer is representative of a household. Marginal soils were considered lands unused for at least 2 years, due to the unproductive food production. Plant density was 3 m × 2 m (1,667 plants per ha). Direct seed propagation method was used, consisting in sowing 2 seeds at 4–6 cm deep at the beginning of August. Plants were not irrigated and their cultivation was under rainy conditions.

In Table 1, the production for 1 ha of *J. curcas* standard plantation is presented.

All the required activities necessary to cultivate 0.4 ha of *J. curcas* plantation are listed in Table 2. For each activity, both the year of implementation and the working days per year are indicated.

Data of Tables 1 and 2 refer to literature and have been verified on the basis of information derived from informal and formal meetings organized in the framework of the Ghaja project with the farmers involved in *J. curcas* cultivation and processing. A source of validation has been also represented by internal project reports produced by scientific and technical staff that assisted *J. curcas* farmers and monitored project activities.

Parameters of comparison

J. curcas energy products (oil, husk and seedcake) as alternative energy sources for cooking and lighting are compared to energy sources daily used by the interviewees, i.e. firewood, charcoal, kerosene. In fact, oil, husk and seedcake can be namely used in specifically designed stoves for cooking, while the sole oil can be used in lamps for lighting.

The potentialities and limits of *J. curcas* as substitute for traditional energy sources have been analyzed according to three parameters: calorific values, costs and time spent in accessing the source.

The total energy (quantity per calorific value) of oil, husk, and seed cake produced by the described standard *J. curcas* plantation was compared to the total energy of firewood, charcoal, and kerosene respectively consumed for cooking and lighting. Calorific values of the energy sources are reported in Table 3.

The total cost of oil, husk, and seed cake production from the standard *J. curcas* plantation was compared to the total cost of the proportionate quantity of firewood or charcoal used in 10 years. The data related to the costs had been collected during the PRA conducted in 2010. Prices and costs were expressed in Ghanaian New Cedi (GHS), and are converted in this paper according to the official 2010 exchange rate GHS/USD, i.e. 0.67 (http://usd.fxexchangerate.com). The data on unit cost per person has been collected during informal meetings with stakeholders, and it was equal to 0.41 USD per hour. With reference to firewood and charcoal, the total cost was calculated considering both the cost of the combustible (replaced by *J. curcas* energy products) and the cost of one person in charge of the energy source collection, estimated according to the PRA results. The costs of the initial investments for the *J. curcas* establishment (machinery provision for *J. curcas* processing and use) are not taken into consideration in this analysis. Furthermore, this study does not take into consideration opportunity costs of marginal lands, assuming that *J. curcas* plantations do not impede other activities which can be implemented on these areas, such as hunting and grown of medicinal plants, thus apparently not entailing significant changes in the economic value of marginal lands.

The time spent in both *J. curcas* plantation management practices and oil, husk, and seed cake production (Table 2) was compared with the time required to harvest or purchase the proportionate quantity of firewood or charcoal. The quantity (kg) of energy sources used by the interviewees and the time spent in collecting the traditional energy sources used by the interviewees were estimated according to the PRA results.

Table 1
Estimated production for 1 ha of *J. curcas* standard plantation.

J. curcas products	kg ha^{-1} year^{-1}	kg ha^{-1} 10 years^{-1}
Dry seeds[a]	1000	8000
Fruits[b]	1539	12,312
Husk	538	4304
Oil[c]	210	1680
Seed cake	494	3952

[a] Characteristics are defined considering a normal water supply (rainfall 700–1220 mm y^{-1}) and low-medium fertility (Achten et al., 2008; FACT, 2010).

[b] The total production over a period of 10 years was estimated multiplying 1 year data by factor 8, since *J. curcas* trees are productive starting from the third year of the plantation.

[c] Oil density 920 kg m^{-3}.

Table 2
J. curcas agronomic practices and oil extraction activities. For each activity, the years of implementation and the working days per year are reported, considering a plantation of 0.4 ha over a period of 10 year.

Activities	Plantation year	Working days per year[a]
Land cleaning	1°year	1
Plowing	1°year	1
Sowing	1°year	1
Refilling	1°year	1
Thinning	1°year	1
Weeding	1–10°years	4
Pruning	1–10°years	1
Harvesting	3–10°years	6
Fertilizing	3–10°years	2
Fruit transport	3–10°years	2
Decorticator	3–10°years	1
Seeds dried	3–10°years	1
Expeller	3–10°years	1
Oil and seed cake transport	3–10°years	2
TOT (10 years)		175

[a] Estimated for 0.4 ha plantation and an average distance of 6 km for transport.

The considered *J. curcas* scenario includes some other social and environmental potentialities deriving from the production of soap by women, utilizing 5 kg of *J. curcas* oil per year, and from the fertilization of *J. curcas* plantations with 247 kg of seed cake per ha per year. The amount of 5 kg of *J. curcas* oil per year is calculated assuming the production of around 5 kg of soap per year, using approximately 150 g of sodium hydroxide with 0.750 l of water for 1 l of oil (Contran et al., 2013). The amount of 247 kg of seed cake per ha per year is calculated assuming the net compensation of fruit harvesting: since the seed cake composition is nitrogen (N) 3.82–6.40% per dry matter weight, phosphorus (P) 0.9–2.8% per dry matter weight, and potassium (K) 0.95–1.75% per dry matter weight, and the nutrient net removal, estimated from the fruit nutrient composition, is equals to 14.3–34.3 kg N, 0.7–7.0 kg P and 14.3–31.6 kg K per ha, considering a seed yield of 1000 kg per ha (Jongschaap et al., 2007).

Results and discussion

Participatory Rural Appraisal

The majority of interviewees involved in the study were men and illiterate and more than half of them were under 50 years old (Fig. 2). Households were mainly composed by 6–15 people and about half of interviewees were land owners (Fig. 2). Their main activity was farming, from which derived the majority of income. Farm equipment, food, energy, education, and clothing were the main expenses. Details of the socio-economic profile are showed in the Fig. 2.

In this District, the community chief is the custodian of the lands, but each household could retain the usufruct of lands for personal agricultural practices. More than half of the interviewees own between 4 and 12 ha of lands and about 26% of total lands are considered poor quality

Table 3
Calorific values of energy sources used by the interviewees and *J. curcas* energy products. In order to avoid overestimated evaluation, the calorific values of *J. curcas* energy products were the lowest values reported in literature, while the calorific values of the energy sources were the highest values reported in literature.

	Calorific value (MJ kg^{-1})	Reference
Firewood	20	Lamers et al. (1994)
Charcoal	32	Rosillo-Calle et al. (2007)
Kerosene	46	Kalyan and Ishwar (2007)
J. curcas husk	11	Jongschaap et al. (2007), Achten et al. (2008)
J. curcas oil	37	
J. curcas seed cake	18	

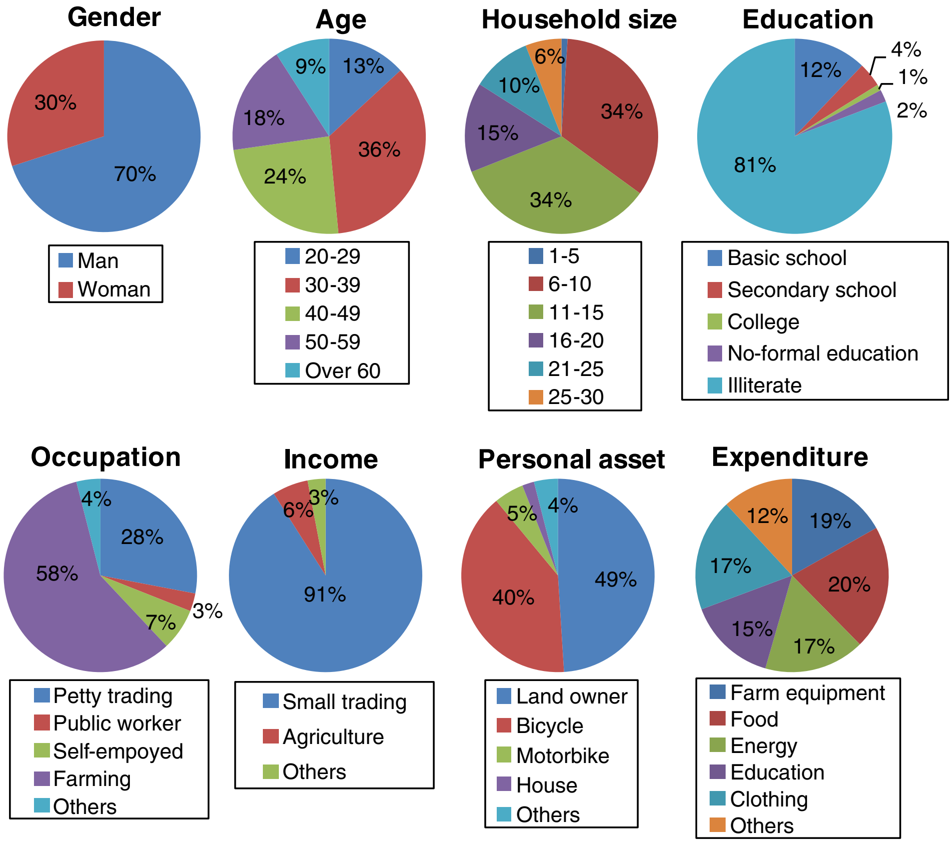

Fig. 2. Socio-economic profile of the interviewees involved in the study (N = 402). Data are expressed as percentage.

soils or agriculture unproductive soils (Fig. 3). The interviewees categorized the soil following a standard soil categorization proposed by the NGO NewEnergy, on the basis of an exploratory analysis on the field.

The main cultivated crops were cereal crops and leguminous crops. The yield was quite variable due to the dependence on agronomic inputs, management practices, and climatic annual conditions. According to the PRA study, the total yield for cereal and leguminous crops was around 326 kg (±210) per ha per year. The household consumption was about 65% (±30) of the own production.

Firewood, charcoal, fuel and electricity were the energy sources commonly used in the communities. Most of the interviewees would choose firewood as first energy source, because it is accessible, appreciably cheap, and it is one of the best energy source for cooking purpose (Fig. 4a). Each household used about 104 kg (±55) of firewood per month, with an average price around 10.4–17.4 USD per household per month. Firewood is generally purchased or harvested by women through the pruning of their own trees (Figs. 4b and 5). The main problems in accessing firewood were the lack of transport and the accidents.

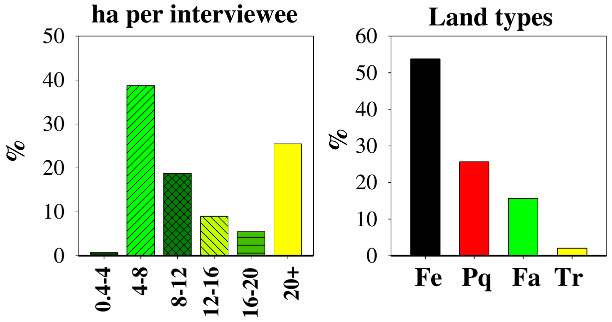

Fig. 3. Percentages of ha per each interviewee (left) and percentages of land types (right) in the study area (Fe = fertile soils, Pq = poor quality soils, Fa = fallow soils, Tr = tree planted areas).

Charcoal is generally the second source of energy, utilized to cook and heat water, because it is smokeless than firewood and it is easily accessible (Fig. 4a). Each household used about 56 kg (±39) of charcoal per month, with an average price around 10.4–13.9 USD per household per month. Charcoal was generally purchased by women from their own village community or from the nearby market (Figs. 4b and 5). The main problems in accessing charcoal were the high price and the lack of transport.

Kerosene was the main oil fuel source, because it is easy to use and it is the best energy source for lighting purpose (Fig. 4a). Each household used about 5.2 l (±2.5) of kerosene per month, equivalent to 4.1(±2) kg per month, with an average price around 10.4–16.7 USD per household per month. Fuel was generally purchased by men from their own village community or from the nearby market (Figs. 4b and 5). The main problems in accessing kerosene were the high price and the lack of transport.

More than one third of the interviewees would choose electricity as third source of energy for its efficiency. Electricity was utilized to provide energy for lighting purpose or to power grinding mills (Fig. 4a). Each household spent around 10.4–17.4 USD per household per month. Interviewees accessed electricity from their own village community and the responsibility to buy electricity or pay the electricity bills was mainly in charge of men (Figs. 4b and 5). At the time of the survey, not every involved community had access to the national grid power to obtain electricity. For this reason, some interviewees used to produce their own electricity through diesel generators while others used to go to the nearby market for charging mobile phone, rechargeable lamps and touch lights (Fig. 4b). The main problem in accessing electricity was its high price.

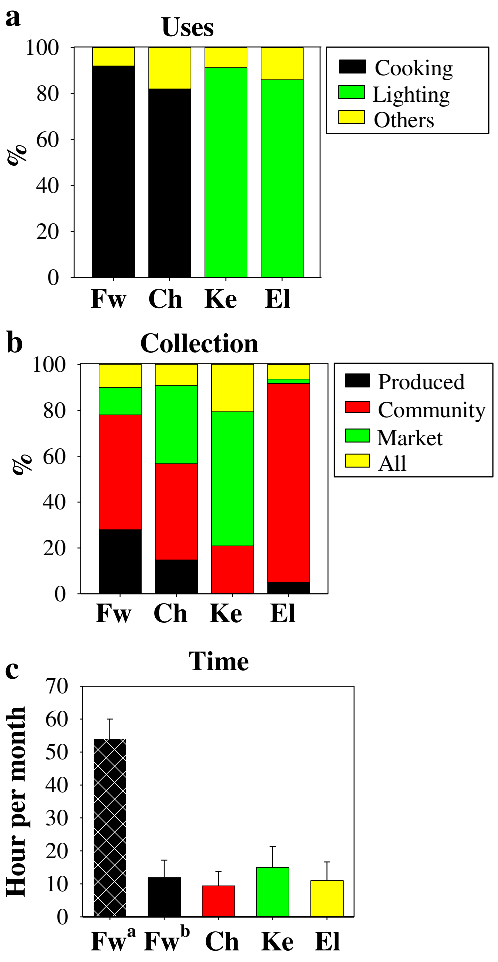

Fig. 4. a) Additive percentages of interviewees per energy source potential uses. b) Additive percentages of interviewees per energy sources collection types. c) Average (±S.D.) monthly time spent to the source per month. (Fw^a = harvested firewood, Fw^b = purchased firewood, Ch = charcoal, Ke = kerosene, El = electricity). See details in the text.

On average, interviewees spent approximately 54 (±6) hours per month to harvest firewood, 12 (±5) hours per month to purchase firewood, 9 (±4) hours to collect or purchase charcoal, 15 (±5) hours to purchase kerosene, and 11 (±6) hours to travel to the District capital to pay electricity bills or to obtain electricity from the nearby market or from the community village (Fig. 4c).

As emerged from the PRA analysis, *J. curcas* was already known among local communities in the West Mamprusi District with the local name "Baanyemaasim", which literally means "shade under which the dog rests". Anyway, since the benefits of *J. curcas* were not well known, before the beginning of the project only 9% of the interviewees cultivated it as a hedge and used *J. curcas* to provide shade for animals (44%), to protect the fowl from hawks (39%), as a live-fencing (13%), for medical proposes and as snake repellent. No interviewees used *J. curcas* with agronomic purposes. With respect to the management practices already applied to *J. curcas* as hedge, around half of the farmers who cultivated *J. curcas* weeded the land before planting and applied fertilizer, 40% carried out regular weeding during the rainy season, 80% carried out regular pruning, and none of the farmers performed activities against pest and diseases. There were no prejudices for its cultivation, and local farmers expressed the willingness to be engaged in *J. curcas* system. Eighty-eight percent of the interviewees knew that it is possible to extract oil from *J. curcas* seeds and 12% knew that it is possible to obtain soap, but none of them used these products. On the contrary, 16% of the interviewees used regular *J. curcas* leaves, roots, and stem, powdered or water boiled, to treat fever, stomach pains, headache, ringworm, or toothache. Additionally, *J. curcas* sap was used by children to mend books.

Potentialities and limits of J. curcas system as alternative energy source

Since each farmer has contributed to the project with 0.4 ha of land (1 acre), *J. curcas* system as alternative energy of source has been calculated on the basis of 0.4 ha *J. curcas* plantation. According to Table 1, excluding soap production (50 kg of *J. curcas* oil per 10 years) and fertilization (988 kg of seed cake per 0.4 ha per 10 years), considering the purpose of energy production, from 0.4 ha of *J. curcas* plantation over a period of 10 year, it is possible to collect 1,722 kg of *J. curcas* husk, 622 kg of *J. curcas* oil, and 593 kg of *J. curcas* seed cake.

Taking into consideration the calorific values (Table 3), when used as combustible fuel for cooking or lighting, *J. curcas* oil, seed cake and husk could replace 21.0% of firewood,21.8% of the charcoals, or 100% kerosene used by each household (Fig. 6), over a period of 10 years.

Over a period of 10 years, considering a *J. curcas* plantation of 0.4 ha, the replacement of 21.0% of firewood avoids the use of 2621 kg of firewood (of a total of 12,480 kg) per household. The replacement of 21.8% of charcoal avoids the use of 1465 kg of charcoal (of a total of 6,720 kg) per household. The 492 kg of kerosene used by interviewees in 10 year can be easily replaced with the *J. curcas* products. For the replacement of the total consumption of all traditional fuels consumed (firewood, charcoal and kerosene), a household, mostly composed by 6–15 people, should cultivate about 3.9 ha. Generally, the harvesting of firewood takes place through an intensive tree pruning (20–33 kg per tree). Unfortunately it has not been possible to find in literature the value of annual productivity of the most common tree species present in the Ghanaian savannah. In order to calculate the potential reduction of deforestation due to the *J. curcas* cultivation, further investigations are necessary.

With reference to the costs parameter, the cost of one person employed in the *J. curcas* plantation and production of its energy products, calculated in 574 USD per 10 years, is in line with the range of expenditures made by each household for firewood harvested (496–620 USD), purchased (334–614 USD) or charcoal supply (326–492 USD). It is worth mentioning that the real cost of purchased firewood and charcoal includes both material and labor costs, while the real cost of *J. curcas* energy products includes only the labor costs, since all the

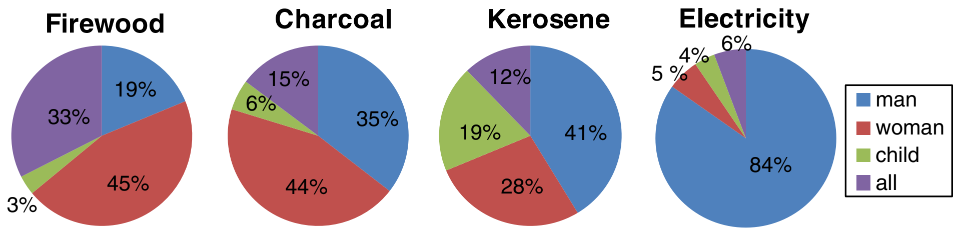

Fig. 5. Percentages of responsibility to collect or buy the different energy sources.

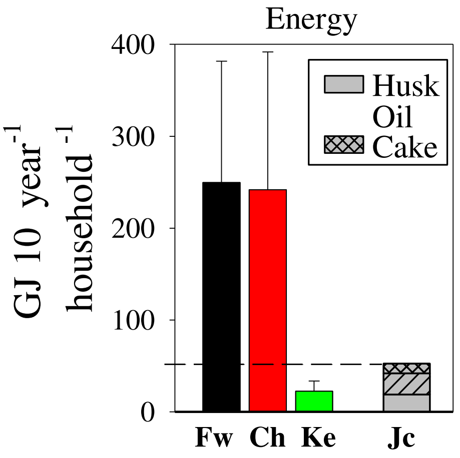

Fig. 6. Average (±S.D.) of the total energy of firewood (Fw, black), charcoal (Ch, red), and kerosene (Ke, green) consumed for cooking and lighting over a period of 10 years per household and estimated average of the total energy of *J. curcas* energy products per household (Jc, gray - oil, husk, and seed cake) produced from 0.4 ha plantation over a period of 10 years.

costs related to *J. curcas* productive chain are not considered in this analysis. The cost of one person employed in the *J. curcas* plantation and production of its energy products is in the range of expenditures made by each household for the firewood supply and slightly higher for the charcoal supply (Table 4).

Taking into consideration the time, for the third of interviewees who directly harvested firewood, the time spent in the production of *J. curcas* energy products is comparable to the time spent in the firewood harvesting. Whereas the production of *J. curcas* energy products implies an additional work, if compared with firewood or charcoal purchasing. The time requested for carrying out both all the agricultural practices on the standard *J. curcas* plantation and the oil extraction activities has been calculated and amounts to 1400 h over a period of 10 years (175 days/8 h per day, as shown in Table 2). In order to properly compare the time spent in the production of *J. curcas* energy products and the time in firewood collection, it is important to analyze independently the interviewees (31%) who harvested firewood and those (67%) who purchased it. The time spent to harvest 2621 kg of firewood is around 1361 h (±151) over a period of 10 years, which is comparable, in term of time, with the production of *J. curcas* energy products. On the other case, the time spent, over a period of 10 years, to purchase 2621 kg of firewood amounts at 302 h (±126) while the time to purchase 1465 kg of charcoal is around 235 h (±92) (Fig. 4b). Hence the production of *J. curcas* energy products implies an additional work of 13–15 days per year. However, this result does not consider the following: i) in the first and second years, when *J. curcas* plants are not productive yet, the total time spent for the plantation management is equals to 10 and 5 days per year respectively (Table 1), ii) the more efficient work organization, mostly concentrated at the end of the rainy season or during the drought season, and iii) the time saved by the farmers, when *J. curcas* trees are intercropped with food crops, for the carrying out of the common agricultural practices, such as weeding or fertilizing (6 days per year).

Therefore, in an economy of scale, the spent time is taken up by the standard agronomical food crops practices. The cultivation of 3.9 ha per household, necessary for the replacement of the total consumption of traditional fuels, will imply an additional time of more than 4 months per year per household. For this reason, as long as *J. curcas* market is not well developed and established yet, an increase in the number of hectares cultivated by a household does not seem economically viable.

The usage of the traditional energy sources concerns old and sedimented attitudes, whose change is arduous and does not depend only on the economic or social convenience. In this regard, it could be interesting to compare the cultivation of *J. curcas* on marginal lands with the reforestation of these areas with dry-deciduous forest, in order to make traditional fuels (firewood and charcoal) more sustainable.

Social and environmental implications

The introduction of community-based *J. curcas* plantations could be able to modify the tasks and activities within the household, changing the responsibilities and labor divisions between men and women. Abandoned farmlands are, in fact, frequently owned by women, and it often represents the sole land that women can have access to (Rossi and Lambrou, 2008). Furthermore, the responsibility to collect or buy firewood and charcoal is mostly in charge of women (Fig. 5), while the agricultural works are mainly performed by men. As a consequence, *J. curcas* plantations and energy products could increase the value of woman land properties and reduce their labor activities, generating socio-economic impacts not predictable, and analyzable only in the long-term.

Furthermore, the utilization of *J. curcas* oil in order to produce soap can represent a high value income-generating activity for women (Eckart and Henshaw, 2012).

From the environmental point of view, the cultivation of *J. curcas* can lead environmental benefits, including the reduction of deforestation and soil degradation. *J. curcas* ability to grow on poor quality soils, combined with its capacity to improve soil physical conditions and reduce soil erosion, makes this tree an excellent biological system for the reclamation of degraded soils, such as abandoned farmland (Openshaw, 2000). The development of a deep taproot, functioning as an efficient nutrient circulation pump, permits to extracts mineral and nutrients leached down and releases them to the surface through the leaf or fruit shed, forming mulch nearby the base of the tree (Kumar and Sharma, 2008). In this context, the fertilization of *J. curcas* plantations with the by-products of oil extraction, such as seed cake, should be an essential action in order to allow effective soil reclamation. Practically, the nutrient net removal from the soil due to the fruit production and harvesting should be compensated by fertilizing *J. curcas* plantations with 100 kg of seed cake per year. Over a long period, intercropping or agro-forestry systems can be considered additional benefits for the local populations.

Table 4

Range of cost (in USD) for firewood (harvested or purchased), charcoal, and *J. curcas* energy products. For firewood and charcoal, both the cost of the combustible (replaced by *J. curcas* energy products) and the labor cost of one person in charge of the energy source collection over a period of 10 years are considered. For *J. curcas* energy products, the cost of one person employed in the *J. curcas* plantation management and in the oil, husk, and seed cake production over a 10 year period is considered.

	Amount	Unit	Material cost per 10 year	Person cost per 10 year[a]	TOT USD
Harvested Firewood[b]	104	kg month^{-1} household^{-1}	–	496–620	496–620
Purchased Firewood[b]	104	kg month^{-1} household^{-1}	262–438	72–176	334–614
Charcoal[c]	56	kg month^{-1} household^{-1}	272–364	54–129	326–492
J. curcas	0.4	ha household^{-1}	–	574	574

[a] 0.41 USD per hour.

[b] Considering the cost of the 21.0% of used firewood.

[c] Considering the cost of the 21.8% of used charcoal.

It is worth reaffirming that the above mentioned possible positive social and environmental aspects can be revealed only in case really marginal lands are used for *J. curcas* cultivation, thus avoiding trade-offs with food production. However, the cultivation of *J. curcas* on marginal lands can result into two opposite risks: on one hand the hope of obtaining higher yields could push farmers to extend their cultivation also on fertile areas, thus replacing food crops and threatening their food security; on the other side, the low yields obtained on poor soils, and consequently the poor gains, could lead to the abandonment of *J. curcas* cultivation (Soto et al., 2013). Moreover in our experience we noticed a high awareness and wisdom in farmers' attitudes in not wasting their fertile lands and energies on risky and uncertain investments, as can be still considered *J. curcas* plantation.

Conclusions

This paper analyzed the potentialities and limits of *J. curcas* as alternative energy source. Its main derived products, i.e. crude oil, husk and seedcake, have been compared with the most common energy sources daily used in the West Mamprusi District, namely wood, charcoal, kerosene and electricity. Taking into consideration three parameters, i.e. calorific values, costs and time to access to the source, this analysis revealed that the cultivation of 0.4 ha of *J. curcas*, associated with the extraction activities, could replace, in terms of energy contents, 21% of firewood, 21.8% of charcoals, or 100% kerosene used by the interviewees over a period of 10 years, with comparable costs and time. It is also worth mentioning that *J. curcas* oil can be used only in specifically designed stoves for cooking which are frequently difficult to operate and maintain, while households are used to firewood and charcoal, which are contrarily easy to use. Furthermore, the replacement of charcoal and firewood by husk and seed cake and the replacement of kerosene by *J. curcas* oil may imply possible drawbacks on the grounds of low energy density, smoke, and others (Contran et al., 2013). However, results confirm that community-based *J. curcas* initiatives for local use, such as smallholder and decentralized *J. curcas* plantations on poor quality soils, can be seen as an opportunity for positively contributing to rural livelihoods in Ghana.

Acknowledgments

This program is funded by the European Union (DCI/ENV/2008/151-872). The contents of this publication are the sole responsibility of the authors and can in no way be taken to reflect the views of the European Union. The authors wish to thank Francesco Fava, Laura Altea, Luciano Gutierrez and their partners of the Ghaja project: George Yaw Obeng, Micheal Adjaloo, Stephen Kwasi Nutsugah, James Mantent Kombiok, Joseph Yeng Faalong, and Christopher Akai.

References

Achten WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, et al. Jatropha bio-diesel production and use. Biomass Bioenergy 2008;32:1063–84.

Brittaine R, Lutaladio N. Jatropha: a smallholder bioenergy crop — the potential for pro-poor development. Integrated Crop Management. Rome: FAO; 2010. p. 1–114.

Contran N, Chessa L, Lubino M, Bellavite D, Roggero PP, Enne G. State-of-the-art of the *Jatropha curcas* productive chain: from sowing to biodiesel and by-products. Ind Crop Prod 2013;42:202–15.

Devappa RK, Makkar HPS, Becker K. Biodegradation of *Jatropha curcas* phorbol esters in soil. J Sci Food Agric 2010;90:2090–7.

District Planning Coordinating Unit-West Mamprusi District Assembly. A 4-Year Medium Term Development Plan (2010–2013); 2010A.

Duku MS, Gu S, Hagan EB. A comprehensive review of biomass resources and biofuels potential in Ghana. Renew Sustain Energy Rev 2011;15:404–15.

Dyer JC, Stringer LC, Dougill AJ. *Jatropha curcas*: sowing local seeds of success in Malawi? In response to Achten et al. (2010). J Arid Environ 2012;79:197-110.

Eckart K, Henshaw P. *Jatropha curcas* L. and multifunctional platforms for the development of rural sub-Saharan Africa. Energy Sustain Dev 2012;16:303–11.

FACT. The Jatropha Handbook — From Cultivation to Application; 2010 [www.fact-foundation.com].

Heller J. *Jatropha curcas* L. — Promoting the conservation and use of underutilized and neglected crops. Rome: International Plant Genetic Resources Institute; 1996. p. 1–66.

IFAD. Rural Poverty report 2011; 2011 [http://www.ifad.org/rpr2011/report/e/print_rpr2011.pdf].

IMF. World Economic Outlook: Slowing Growth, Rising Risks; 2011 [http://www.imf.org/external/pubs/ft/weo/2011/02/pdf/text.pdf].

Jongschaap REE, Corré WJ, Bindraban PS, Brandenburg WA. Claims and facts on *Jatropha curcas* L.: global *Jatropha curcas* evaluation, breeding and propagation programme. The Netherlands: Plant Research International BV, Wageningen. The Netherlands and Stichting Het Groene Woud; 2007. p. 1–66. [Report 158].

Kalyan A, Ishwar KP. Combustion Science and Engineering. CRC Press; 2007. p. 851.

Kant P, Wu S. The extraordinary collapse of *Jatropha* as a global biofuel. Environ Sci Technol 2011;45:7114–5.

Kemausuor F, Obeng GY, Brew-Hammond A, Duker A. A review of trends, policies and plans for increasing energy access in Ghana. Renew Sustain Energy Rev 2011;15:5143–54.

Kumar A, Sharma S. An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): a review. Ind Crop Prod 2008;28:1–10.

Lamers JPA, Michels K, Vandenbeldt RJ. Trees and windbreaks in the Sahel: establishment, growth, nutritive, and calorific values. Agrofor Syst 1994;26:171–84.

Maes WH, Trabucco A, Achten WMJ, Muys B. Climatic growing conditions of *Jatropha curcas* L. Biomass Bioenergy 2009;33:1481–5.

Menéndez A, Curt MD. Energy and socio-economic profile of a small rural community in the highlands of central Tanzania: a case study. Energy Sustain Dev 2013;17:201–9.

Openshaw K. A review of *Jatropha curcas*: an oil plant of unfulfilled promise. Biomass Bioenergy 2000;19:1–15.

Parawira W. Biodiesel production from *Jatropha curcas*: a review. Sci Res Essays 2010;5:1796–808.

Peel MC, Finlayson BL, McMahon TA. Updated world map of the Köppen–Geiger climate classification. Hydrol Earth Syst Sci 2007;11:1633–44.

Pretty J, Toulmin C, Williams S. Sustainable intensification in African agriculture. Int J Agric Sustain 2011;9:5–24.

Rosillo-Calle F, de Groot P, Hemstock SL, Woods J. The Biomass Assessment Handbook: Bioenergy for a Sustainable Development. London: Earthscan; 2007.

Rossi A, Lambrou Y. Gender and Equity Issues In Liquid Biofuels Production — Minimizing the Risks to Maximize the Opportunities. Rome: FAO; 2008.

Settle W, Garba MH. Sustainable crop production intensification in the Senegal and Niger River basins of francophone West Africa. Int J Agric Sustain 2011;9:171–85.

Soto I, Feto A, Keane J. Are *Jatropha* and other biofuels profitable in Africa ? Jatropha Facts Ser; 2013.

Trabucco A, Achten WMJ, Bowe C, Aerts R, Van Orshoven J, Norgrove L, et al. Global mapping of *Jatropha curcas* yield based on response of fitness to present and future climate. Glob Change Biol Bioenergy 2010;2:139–51.

UN. The Millennium Development Goals Report; 2011 [http://www.un.org/millenniumgoals/11_MDG%20Report_EN.pdf].

UNDP. Human Development Report 2011. Sustainability and Equity: A Better Future for All; 2011 [http://www.beta.undp.org/content/dam/undp/library/corporate/HDR/2011%20Global%20HDR/English/HDR_2011_EN_Complete.pdf].

Ye M, Li CY, Francis G, Makkar HPS. Current situation and prospects of *Jatropha curcas* as a multipurpose tree in China. Agrofor Syst 2009;76:487–97.