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Assessment of Energy Sustainability and Carbon Footprint of a *Jatropha* Biofuel Chain in Rural Area of Brazil

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ABSTRACT

Because of the world population growth and increasing energy demands, renewable energy sources are seen as valid fossil fuel alternatives that could guarantee environmental benefits. In this context *Jatropha curcas* L. has been identified as a promising feedstock for biofuel production and promoted as a sustainable biofuel crop. This paper analyzes the creation of a *Jatropha*-oil chain in a rural area in north-eastern Brazil (Ceará State) utilizing the Life Cycle Assessment (LCA) method. The aim of this study is to evaluate the energy sustainability expressed as cumulative energy demand (CED) and carbon footprint expressed as global warming potential (GWP) of a *Jatropha*-oil chain in comparison with fossil fuel (diesel). The component with most impact on the *Jatropha*-oil chain was electricity consumption, which accounted for 42% and 63% of CED and GWP, respectively. The analyzed *Jatropha* biofuel-chain presented a more favourable energy balance (94% of CED saved) and a lower effect on global warming (77% of greenhouse gas emission, GHG, avoided) in comparison with diesel fossil fuel. If the biofuel produced, instead of being used locally, was exported over a long distance (i.e. to the European Union), the energy and environmental benefits obtained were completely nullified. Crop management practices based essentially on manual labour of family farming system, as in the present study, determined a positive influence on the energy balance and carbon footprint in the *Jatropha*-oil chain. On the contrary, a crop management practices making high use of inputs (fertilizers, pesticides, irrigation ...) on large areas of monoculture, could negatively affect the socio-economic sustainability of the whole *Jatropha*-biofuel chain.

Key Words: *Jatropha curcas* L.; Environmental Sustainability, Life Cycle Assessment, Family Farming System

INTRODUCTION

Because of the world population growth, energy demand is estimated to increase by 1.6% per year from 2005 to 2030 (UNCTAD 2006). Fossil fuels play a predominant role in the energy sector but they also account for 56.6% of overall anthropogenic greenhouse gas (GHG) emissions (IPCC 2011). The relationship between fossil fuel consumption and GHG production is also underlined by the Kyoto Protocol, which identifies international goals for the reduction of emissions. In this context renewable energy sources are seen as valid fossil fuel alternatives that could guarantee environmental benefits (Cherubini et al. 2009).

Fossil fuels provide about 98% of the fuel necessary for the transport sector in the world (IEA 2011), and there is a growing interest in the use of biofuels as substitutes in this sector. At national and global level, a lot of targets promoting biofuels are being set, such as by the European Union that approved a Directive on the promotion and use of energy from renewable sources in which a 10% share of biofuels in transport consumption by 2020 has been established (EU 2009).

Another important example is that of Brazil, which could be considered as a leader in biofuel policy given that its first biofuel programme, focused on bio-ethanol, was approved in 1975 (National Alcohol Program, 'Proálcool'). The National Program of Production and Use of Biodiesel ('PNPB') was developed in 2004. One of its objectives is a target of 5% of biodiesel in the blend after 2013. The Federal Government has chosen to develop a programme that supports family farming, by tax reductions, diversified depending on feedstock origin, constraining biodiesel companies to conform to three criteria: to purchase a minimum percentage of primary material from family farmers, establish consensual contracts with family farmers and guarantee them technical support. In addition to biodiesel, pure vegetable oil can also make a substantial contribution to bioenergy: it may be used crude or refined in co-generation power plants or adapted tractor engines, and in this way assume a primary role in a short biofuel production chain (Esteban et al. 2011).

Brazil is a clear example that the tropics present great possibilities for biofuel production because of considerable arable lands, fertile soils and favourable climate for growing energy crops (Amigun et al. 2011). Despite the recent expansion of the global bioenergy market, questions on the sustainability of biofuel life cycles have still to be answered. The main issues that remain can be summarized in food security, land use change, impact on GHG emissions of biofuel life cycles, real economic and social benefits of biofuel production. To solve these issues, in particular in the tropics, it is necessary to identify non-food crops with low production inputs, which can be cultivated by local farmers and that can exploit marginal lands. In this context *Jatropha curcas* L. has been identified as a promising feedstock for biofuel production (Achten et al 2010a) and promoted as a sustainable biofuel crop (Carels 2009). In recent years many public and private investors developed projects on *Jatropha*-biofuel production chain, but in contrast to all expectations, these investments often pointed out the economic risk of *Jatropha* cultivation on a large scale. Most problems arose due to the lack of knowledge about the ecological needs and proper crop production system of a still wild species (Maes et al. 2009, Trabucco et al. 2010). In Brazil, *Jatropha* is considered a potential raw material for fuel production but it is not currently promoted by PNPB because researches on the sustainability of its crop cycle are still on-going (EMBRAPA 2009).

This paper analyses the creation of a *Jatropha*-oil chain in a rural area of the Ceará State and its impact on climate change and energy resource depletion adopting the "Life Cycle Assessment" method. This is a carbon footprint and primary energy consumption study with the aim to evaluate the real benefits of *Jatropha* –chain oil compared to fossil fuel production.

"Life Cycle Assessment" (LCA) is based on a standard method (ISO 14040 and ISO 14044) and, in the past 20 years, it has become an essential method for describing resource consumption and environmental impact of a product during every phase of its life cycle. LCA is considered a useful method for the evaluation of the potential risks and benefits associated with biofuels production (Cherubini et al. 2009). In the last years this method has increasingly been adopted in studies focused on energy and GHG balances of *Jatropha* oil and biodiesel production systems (Ndong et al. 2009, Achten et al. 2010b, Wang et al. 2011).

MATERIALS AND METHODS

Goal, Scope and System Boundaries

The objectives of this study are to evaluate the energy source depletion (cumulative energy demand, CED) and climate change (global warming potential, GWP) of *Jatropha* oil production in comparison with fossil fuel production in Brasil. The study is justified by the recent interest in *Jatropha* crop for energy purposes in Brazil (Folegatti Matsuura et al. 2011). Input and output data adopted for LCI (Life Cycle Inventory) preparation consist of information collected from a *Jatropha* plantation located in the northern part of Ceará State. These data are integrated with the NGO field database, suitable bibliography and the EconInvent 2.2 database.

The system boundary analyzed covers the *Jatropha* cultivation phase (including the nursery), in order to obtain seeds production, and then the oil extraction phase, in which seeds are processed for energy purposes (Figure 1). The system is analyzed considering a perennial plantation for 20 years as crop model.

The functional units (FU) of the cradle-to-grave energy and environmental impacts are compared on a land-basis [ha] for the crop production phase, and on product- [kg of oil] and energy- [MJ] experimental units for the oil production phase. The fuel comparison considers their energy content [MJ], taking into account different lower heating values (LHV) of *Jatropha* oil (37 MJ kg^{-1}) and diesel (43 MJ kg^{-1}) (EU 2009).

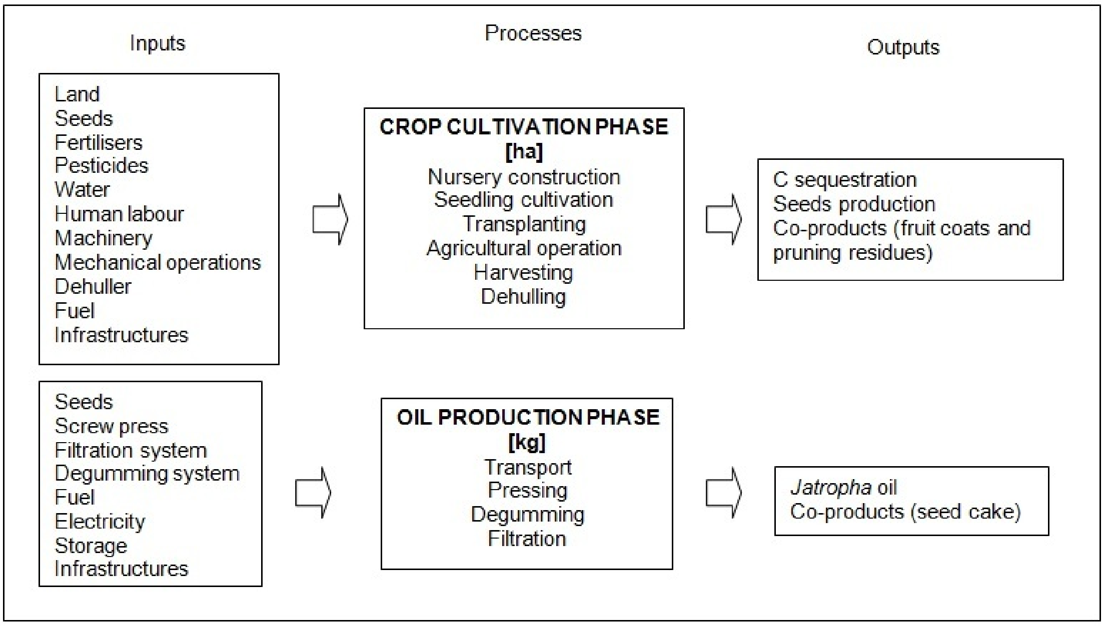

Figure 1. System boundaries of the analyzed LCA study.

Life Cycle Inventory

Research Area

The study is being conducted in the Uruoca Municipality (Lat. S 3° 18’ 50’’, Long. W 40° 33’ 24’’), Ceará State, Brazil. The area has a semi-arid climate, with a rainy season between January and June, and a dry season during the rest of the year. Average annual rainfall of the last ten years is 957 mm and average annual temperature is 26-28 °C (IPECE 2012). The soil has a loamy-sandy texture, with poor organic content but without pH and salinity problems. The area is now characterized by a degraded vegetation cover. Indeed in order to prepare the soil for annual seeding crops, the original xeric shrub-land biome covering the area and known as *caatinga*, had been burned down by local farmers. The ecological succession, restarting from sparse shrubs replacing the *caatinga,* is formed today by a much poorer vegetation cover than the native one.

Jatropha cultivation is also promoted in the studied area by two NGOs involved in environmental topics. In 2011, they developed a programme which involved small farmers of the semi-arid northern part of Ceará in order to create a sort of network of *Jatropha* seed producers. The vegetable oil extracted from the seeds will be used to power a local diesel engine which provides mechanical power to run a generator in order to produce accessible energy services useful for the rural community. The aim of the project is the development of a multi-functional based agriculture, improving rural family living conditions and protecting the area from environmental degradation. These two NGOs have supplied a lot of information regarding social and environmental aspects of the studied site.

Cultivation Phase

All materials and energy necessary for this phase, including the nursery, are summarized in Tables 1, 2 and 3. The seeds used presented a germination capacity of 84%. Polybags were prepared manually: sandy and clay soils characteristic of the area were used as substrate, with organic and mineral fertilizers added. Seedlings were grown in the nursery for 50 days during which time they were irrigated and pesticide treated. The seedlings were transplanted in the field in the first months of 2011 on 50 ha . The crop surface was prepared by manual and mechanical labour, with the aid of a Caterpillar. 30 cm deep furrows were prepared manually and by a tractor with furrower. All the operations necessary to transport and plant the seedlings out in the field are considered: the distance between the nursery and the field is 9 km. Crop density is 1660 plants ha^{-1}, with a distance of 2 m on rows and 3 m between rows. Pruning was carried out manually during the second year after transplanting with a 50% reduction of the aboveground biomass. Weeding operations, done manually and by a tractor with crop cultivator, were limited to the first three years of the crop because it is considered that after the third year plants are able to cover spaces between the rows, preventing weed emergence (FACT 2010).

Table 1. Main factors utilized during the crop cultivation phase of the *Jatropha*-oil chain

Factors	Units	Quantity	Data sources
Fertilisers application (NPK 10-10-10)	kg ha^{-1}	9.5	*Jatropha* farmer (fieldwork)
Seed	kg ha^{-1}	1.5	*Jatropha* farmer (fieldwork)
Polybags	kg ha^{-1}	5	*Jatropha* farmer (fieldwork)
Irrigation	m^3 ha^{-1}	12	*Jatropha* farmer (fieldwork)
Pesticide application (dimethoate)	kg ha^{-1}	0.005	*Jatropha* farmer (fieldwork)

Table 2. Manual labor utilized during crop cultivation phase of *Jatropha*-oil chain. Data on Energy are based on FAO/WHO/UNU (2001) and the time was estimated from the farmers during field work.

Operation	Labour utilised	
Nursery preparation	energy	4.1 MJ h^{-1}
	time	0.32 h yr^{-1}
Polybags preparation	energy	4.1 MJ h^{-1}
	time	1.3 h yr^{-1}
Irrigation	energy	3.6 MJ h^{-1}
	time	0.02 h yr^{-1}
Pesticide distribution	energy	4.0 MJ h^{-1}
	time	0.17 h yr^{-1}
Driving tractor	energy	2.1 MJ h^{-1}
	time	0.68 h yr^{-1}
Field preparation	energy	6.6 MJ h^{-1}
	time	40 h yr^{-1}
Transplanting	energy	4.1 MJ h^{-1}
	time	35 h yr^{-1}
Pruning	energy	3.6 MJ h^{-1}
	time	138 h yr^{-1}
Weeding	energy	4 MJ h^{-1}
	time	0.6 h yr^{-1}
Harvesting	energy	3.4 MJ h^{-1}
	time	457.1 h yr^{-1}

Table 3. Transport and machinery utilized during the life cycle of *Jatropha*-oil chain. Data obtained from the farmers during field work, except for the values for Dehuller from FACT (2010)

Agricultural machinery	Units	Quantity
Caterpillar	fuel consumption [L h^{-1}]	24
	time [h yr^{-1}]	0.43
Tractor 90 kW (crop cultivator and furrower included)	fuel consumption [L h^{-1}]	5
	time [h yr^{-1}]	0.35
Pick up	fuel consumption [km L^{-1}]	9
	distance [km yr^{-1}]	608
Dehuller	energy consumption [kWh]	0.75
	time [h yr^{-1}]	5.5

The harvest, carried out in 2012 at the end of the rainy season, provided a seed yield of about 1000 kg seeds ha^{-1}. Taking into account that rainfall during 2012 was more than 50% lower with respect to the average of the previous ten years (FUNCEME 2012) and in order to obtain data on the maturity yield of the crop, reached with plants at least three years old (Carels 2009), three different future productions were hypothesized in relation to different climatic and growing conditions:

1. Standard scenario that the study is based on, 4000 kg seed ha^{-1}, a yield similar to other Brazilian studies on *Jatropha* (Folegatti Matsuura et al. 2011);
2. Maturity yield decreased by 50% compared to the standard scenario (2000 kg ha^{-1}) considering adverse growing conditions;
3. Maturity yield increased by 50% compared to the standard scenario (6000 kg ha^{-1}) considering high production rates.

The annual fruit harvest is done manually by local labour: it is taken into account that a man is able to gather 70 kg seeds day^{-1} (FACT 2010). Fruits are dehulled mechanically using a dehuller with a working capacity of 1000 kg fruits h^{-1}. Drying operations are not necessary because of the favourable climatic conditions during the harvesting period.

Oil Extraction Phase

The oil production phase considered mechanical oil extraction from seeds and consecutive oil filtering and degumming (refining) processes. The oil content of the studied *Jatropha* seeds was 31% and the distance between the plantation and extraction system 17 km. The screw press used, suitable for extracting vegetable oil from different oil seeds, was an "MPS 60 MT" mechanical screw press (Mailca, Italy). In the case of *Jatropha* seeds, the processing capacity was 26 kg seeds hour^{-1}, with an oil extraction efficiency of about 75% and a production of 6.5 kg oil hour^{-1} (personal communication). The refining processes considered in this study are filtration and water degumming (Esteban et al. 2011). The main parameters regarding oil production phase are reported in Table 4.

Table 4. Main characteristics of the studied oil production system. Data from University of Udine except for deguming from Esteban et al. (2011)

System	Value
Press working capacity	26 kg seeds h^{-1}
Extraction efficiency	75 %
Degumming water	0.02 kg kg^{-1} oil
Total energy consumption	15 kWh

Allocation Methods

The European Union recommends utilizing the energy allocation for co-products of biofuel production processes, with the exception of agricultural crop residues which are not taken into account (EU 2009). Following these indications, pruning residues and fruit coats were considered as crop residues, therefore their impacts are not calculated in the study. On the contrary, the same EU directive suggests to allocate the GHG emission according to the energy content of co-products. Hence, the energy allocation method is adopted in this study to evaluate the seed cake as co-product of the oil production phase, considering, for its calculation, the LHVs of different *Jatropha* products (Reinhardt et al. 2008) (Table 5).

Impact Assessment

This LCA study aims to assess energy and environment impacts of the *Jatropha*-fuel chain in two categories: climate change and energy resource depletion.

Table 5. Basis for energy allocation of *Jatropha* products and co-products

Characteristic	Oil	Seed cake
LHV [MJ kg^{-1}]	37 [1]	19.5 [2]
mass fraction [%]	23.2	76.7
energy fraction [%]	36.9	63.1

[1] EU 2009, [2] Reinhardt et al. 2008

The energy resource depletion is calculated by the 'Cumulative Energy Demand' (CED) method which considers renewable and non-renewable energy consumptions and expresses the energy cost of each process in MJ.

The 'Human Energy Requirement' method is applied to the study for the evaluation of manual labour, which is not present in SimaPro databases. This method quantifies the energy cost of human activities in relation to sex, age and body size (FAO/WHO/UNU 2001).

In order to evaluate the energy efficiency of the system, the ratio between energy obtained and energy consumed ("Energy Return On Investment", EROI) is calculated. EROI is used as a synthesizing concept for biofuel analyses and is a very useful concept for evaluating the production efficiency of the fuel-obtaining process (Esteban et al. 2011).

The climate change is quantified by the global warming potential (GWP) calculated by the "IPCC 2001" method, which calculates GHG emissions during a time horizon of 20 years. All the GHGs are considered in relation to their effects on global warming, in order to express GWP in kg CO_2 (IPCC 2006). In particular, N_2O emissions are quantified by the IPCC method (IPCC 2006), whereas CH_4 emissions are considered as 1% of the N fertilizer inputs to the soil (Cherubini et al. 2009). Considering the cultivation phase, this study is also focused on the evaluation of the effects of land use change (LUC) on global warming, which concerns the modification in carbon stocks linked to soil and vegetation cover transformation (IPCC 2006). In the studied case, the vegetation cover prior to the plantation is classified by the IPCC standard as grassland because of its degraded vegetation depletion caused by previous burning.

RESULTS AND DISCUSSION

The results of the LCA analysis consist of:

- analysis of CED and GWP related to the *Jatropha* oil production chain, focusing in particular on cultivation and oil production phases;
- sensibility analysis of the *Jatropha*-oil chain, considering three different seed yields of the crop; and
- comparison between the studied system and diesel production.

All the results are presented as average value per year during a 20-year lifetime of the production system.

Jatropha- Oil Production Chain

Crop Cultivation Phase

Figure 2a presents the energy consumption of the cultivation phase, in which the harvesting is the most energy expensive operation because it represents about 70% of the total cultivation CED.

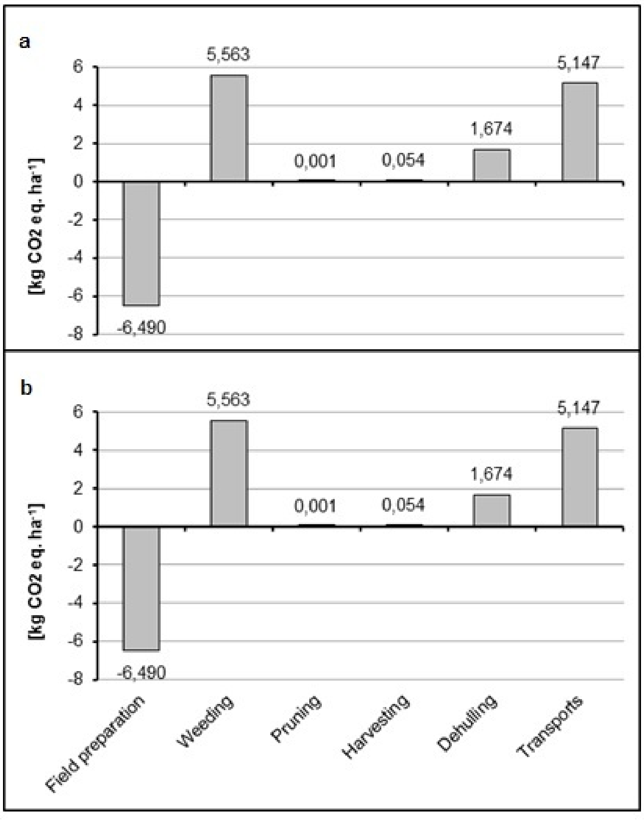

Figure 2. CED (a) and GWP (b) of the crop cultivation phase.

Looking at GHG emissions (Figure 2b), field preparation results in negative values; this means a positive impact of LUC on global warming because of spared emissions, due to higher carbon content of *Jatropha* plantation in comparison with the previous land cover. On the other hand, weeding and de-hulling operations evidence the higher impact on GWP. The crop management technique adopted in the studied *Jatropha* crop was characterized by low inputs of energy and materials. The main annual agronomic operation consists of seed harvesting, whereas pruning and weeding are done during the first three years of the cultivation. Because of this low input technique, the impacts on energy balance and GHG emissions in the field are significantly lower than other studies in which higher use is made of inputs (Prueksakorn et al. 2010, Ndong et al. 2009, Wang et al. 2011). Indeed it has been demonstrated, for example, that chemical fertilizers application contributes 30.3% to the GHG emissions of whole *Jatropha*-biodiesel chain (Prueksakorn and Gheewala 2006).

The land use change (LUC) contributes to an increase of GHG emissions in several biofuel-crop chains (Achten et al. 2012), but in this environment, the *Jatropha* crop evidenced a significantly higher carbon content if compared with the previous degraded vegetation, resulting in an annual carbon stock increase. Moreover, the low input crop management techniques adopted, like minimum tillage and crop residues left on the field, without any chemical fertilization or irrigation, determined an increase in soil carbon stocks (IPCC 2006).

Oil Production Phase

The oil extraction and electricity consumption had the most impact on the CED, corresponding to 25.8% and 63.5% respectively (Figure 3a). Likewise GHG emissions were mainly caused by the electricity use (Figure 3b) in the oil production plant. This power consumption appears difficult to curtail because it is directly related to the plant dimensions and characteristics; a solution would be to replace the electricity coming from the national grid with a low-impact renewable energy, produced locally.

Seed Cake Allocation Method

In this study vegetable oil is the principal product of the *Jatropha* chain. However seed cake amounted to 63.1% of the oil production phase and, quantitatively, represented the most important output of the whole process;

consequently an inaccurate choice of allocation method could result in completely misleading conclusions and different outcomes (Bailis and Baka, 2010).

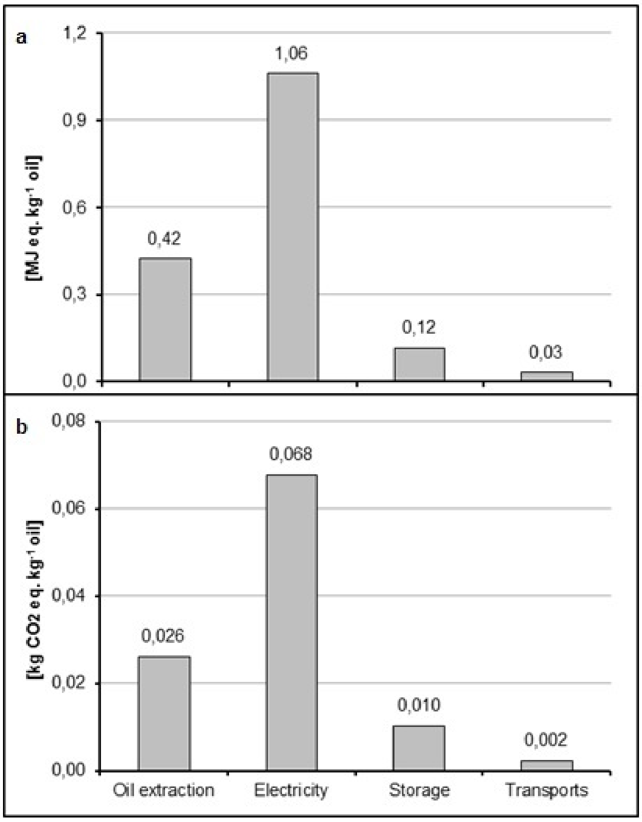

Figure 3. CED (a) and GWP (b) of the oil production phase.

Although *Jatropha* seed cake possesses excellent nutritive characteristics its use as animal feed is prevented because of its toxicity (Makkar and Becker 2009). The available detoxification processes (Kumar et al. 2010, Wang et al. 2011) are expensive from both energy and economic points of view (Openshaw 2000) and are impractical in the studied area, where the most suitable use of the seed cake can be as organic fertilizer or as biomass. For this reason, the energy allocation for the seed cake seemed the correct choice.

The use of edible seed cake as animal feed could improve the economic sustainability of the *Jatropha* oil chain and the cultivation of non-toxic *Jatropha* varieties, on which agronomic studies are now focused, including in Brazil (EMBRAPA 2009), seems the most viable solution.

Total Jatropha Oil Chain

Results referred to the entire chain are split into cultivation, oil production, electricity consumption and transport.

The total CED and GHG emissions were 2.6 MJ eq. kg^{-1} oil (Figure 4a) and 0.11 kg CO_2 kg^{-1} oil (Figure 4b), respectively.

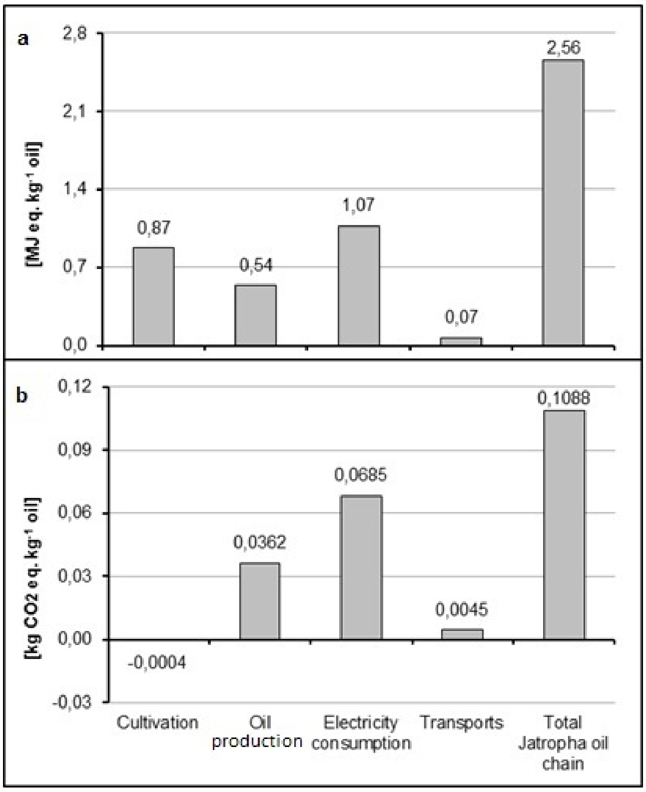

Figure 4. CED (a) and GWP (b) of the total *Jatropha*-oil chain.

The component with most impact was the electricity consumption necessary for several operations (de-hulling, mechanical oil extraction, oil filtering and degumming operations), which account for 42% and 63% on CED and GWP, respectively. In order to reduce this impact, the electricity needed for the main operations like fruit cracking, de-hulling and the oil extraction process, could be obtained utilizing the *Jatropha* oil to power a small power plant (a simple diesel engine) able to operate as an electric power generator.

Although the energy demand of the entire biofuel-chain was very low compared to other studies (Prueksakorn and Gheewala 2006, Wang et al. 2011) it should be noted that the cultivation phase alone accounts for 34% of the total energy requirement, mainly due to the manual harvesting. The seed harvesting of 1 ha, in fact, requires about 457 h if done manually (table 2) but only 5-13 h if mechanized, using a prototype mechanical harvesting machine (personal communication). Since the harvesting is manual in the studied area, the requirement for human labour in a large-scale *Jatropha* plantation could determine high economic costs, which are not considered in this study, but are essential to evaluate the socio-economic sustainability of the whole chain.

Sensibility Analysis

Figures 5a and 5b present how different seed yield could influence CED and GWP, respectively. The energy cost and GHG emissions per kg of oil decrease when the crop yield increases, evidencing an increasing efficiency of the system. The same efficiency is shown by the relation between the seed yield and land area necessary to produce 1 MJ of bio-oil; with seed yields of 2000, 4000 and 6000 kg ha^{-1}, the area necessary to produce 1 MJ is 0.40, 0.21 and 0.14 m^2, respectively. High production levels entail greater efficiency, but optimal water supply and good soil nutrient content also have to be maintained (FACT 2010). This means that high yield and the consequent reduction in energy consumption and GHG emissions of the entire *Jatropha* oil chain are difficult to obtain with the low agronomic input techniques adopted in this study.

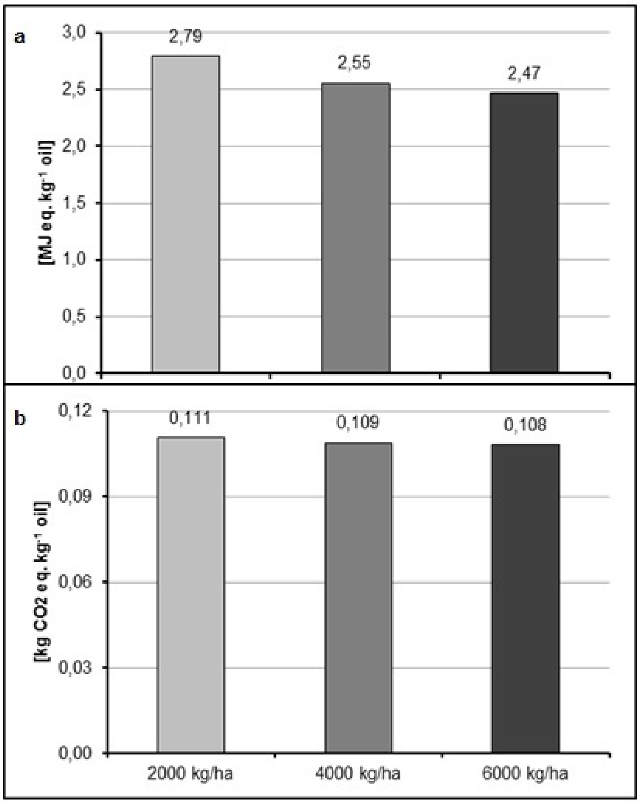

Figure 5. CED (a) and GWP (b) of the total *Jatropha*-oil chain considering three different seed yield scenarios.

Jatropha Oil Vs Diesel

The analyzed *Jatropha* biofuel-chain presented a more favourable energy balance (94% of CED saved) and a lower effect on global warming (77% of GHG avoided) in comparison with diesel, the fossil fuel mainly utilized in the target area (Figures 6a and 6b). These very encouraging results (CED of 0.07 MJ MJ^{-1} of bio-oil and GWP of 0.003 kg CO$_2$ MJ^{-1} of bio-oil) could make the export of *Jatropha* oil from Brazil to European Union, which has set important targets for biofuel (EU 2009), very attractive.

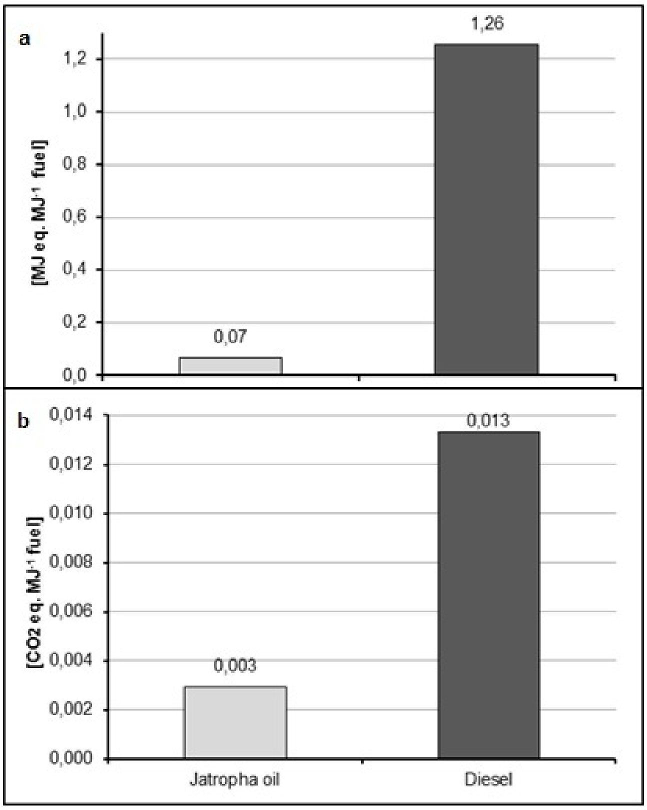

Figure 6. CED (a) and GWP (b) comparision between *Jatropha* oil and fossil fuel (diesel).

In order to evaluate this hypothesis, a calculation of how CED and GWP could be affected by the transportation from Brazil to Europe is reported. Following the

EcoInvent database indications, *Jatropha* oil is carried by about 22 Mg capacity shipping containers that are transported by 16-28 Mg lorries from the extraction plant to the Fortaleza harbour (about 300 km) and loaded on a tanker. Sea transport from Fortaleza to the south coast of Italy (about 8000 km) is considered. With this assumption, CED and GWP values resulted in 0.22 MJ MJ^{-1} of fuel and 0.014 kg CO_2 MJ^{-1} of fuel, with an increase of more than three and four fold respectively, in comparison to the CED and GWP of the local *Jatropha*-oil chain.

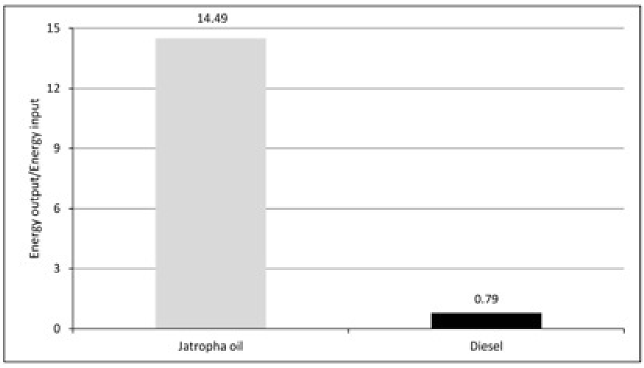

Figure 7. Energy output/Energy inputs (EROI) comparison between *Jatropha* oil and fossil fuel (diesel) production.

The ratio of energy output to energy input of the two systems is calculated with EROI, which results in 14.5 for *Jatropha* oil and 0.8 for diesel (Figure 7). This value is typical of many other perennial biomass crops but significantly higher than other bio-oil annual crops such as rapeseed, which presents EROI values between 2.34 and 4.51 (Esteban et al. 2011).

CONCLUSIONS

The main results of the study, carried out in a rural area of north-eastern Brazil (Cearà State), highlight how *Jatropha* oil obtained with low inputs crop cultivation and a simply mechanical oil extraction process has a significantly better energy sustainability and lower carbon footprint in comparison with conventional diesel fuel. Moreover the cultivation of *Jatropha* on a marginal area, characterized by semi-arid climate and degraded vegetation cover can guarantee an increase of above- and below-ground carbon stock.

Crop management based essentially on manual labour of the family farming, necessary in particular for the annual harvesting, determines the positive influence on energy and environment balance. On the contrary, a crop management practices making use of high inputs level (fertilizers, pesticides, irrigation, etc.), could negatively affect the socio-economic sustainability of the whole *Jatropha*-biofuel chain.

The implemented idea of multinational companies namely of producing biofuel in rural areas of tropical and sub-tropical regions of the world and then export to Europe is a definitely wrong strategy from an environmental and energy point of view. In fact, as obtained in this study, the long-distance transportation of *Jatropha* oil for export to other countries, completely nullifies both the large energy and environmental benefits with respect to the fossil fuel.

For the above reasons, projects driven by local ownership in which small farmers produce *Jatropha* oil as biofuel for their own use or for community applications, appear likely to produce and sustain benefits for a rural community and reported that small-scale, community-focused *Jatropha* projects may actually be much more successful than large scale projects (Commission on Sustainable Development 2007, Acthen et al. 2010a).

Small local initiatives could be developed by the rural community and *Jatropha* could be cultivated as a living fence or as intercropping with food crops, increasing farmers' income without interfering with their agricultural production for food purposes. Moreover the *Jatropha*-biofuel chain by-products as seed cake, fruit shells and wood could be used as biomass for domestic fuel, substituting the traditional local energy sources of wood and coal, often obtained from non-sustainable practices (Governo do Estado do Cearà 2010).

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