

---

## Energy analysis and potentials of biodiesel production from *Jatropha Curcas* in Tunisia

---

Soukaina Fersi\*

Research Unit in Development Economics,  
Faculty of Economics and Management of Sfax,  
University of Sfax,  
Route de l'Aéroport Km 4, 3018 Sfax, Tunisia  
and  
A3i INNOVATION, INEED ROVALTAIN TGV,  
26958 Valence, Cedex 9, France  
E-mail: soukainafersi@gmail.com  
\*Corresponding author

Nouri Chtourou

Research Unit in Development Economics,  
Faculty of Economics and Management of Sfax,  
University of Sfax,  
Route de l'Aéroport Km 4, 3018 Sfax, Tunisia  
E-mail: Nouri.Chtourou@fsegs.rnu.tn

Damien Bazin

GREDEG (Research Group on Law Economics and Management),  
Higher Institute of Economics and Management (ISEM),  
Department of Human Science (MSH),  
University of Nice Sophia-Antipolis (UNS),  
UMR CNRS 6227, 250, rue Albert Einstein, 06560 Valbonne, France  
E-mail: damien.bazin@unice.fr

**Abstract:** Oleaginous plants such as *Jatropha Curcas Linnaeus* (JCL), not intended for human consumption but used for biodiesel production, could contribute to beneficial outcomes. This plant grows on poor land (arid and marginal land) and is drought resistant. *Jatropha Curcas* is native to South America and widely grown in South and Central America, Africa, and Asia (Achten et al., 2007; Kumar et al., 2011). Some areas in Tunisia may be suitable for JCL, although not for food production. The purpose of this paper is to evaluate the energy performance and potential of *Jatropha Curcas* for biodiesel production in Tunisia. The evaluation will be completed through the elaboration of an energy balance using life cycle assessment (LCA), which will facilitate the decision making process. Therefore, the cultivation of JCL production in Tunisia will be an experiment with uncertain results. The energy assessment reveals a negative energy return ( $EE = 0.42$ ). Because of high investment costs and low yield per hectare, *Jatropha* is not a sound economic choice.

**Keywords:** energy balance; life cycle assessment; *Jatropha Curcas*; biodiesel; Tunisia.

**Reference** to this paper should be made as follows: Fersi, S., Chtourou, N. and Bazin, D. (2012) 'Energy analysis and potentials of biodiesel production from *Jatropha Curcas* in Tunisia', *Int. J. Global Energy Issues*, Vol. 35, No. 6, pp.441–455.

**Biographical notes:** Soukaina Fersi holds a degree in Economics and a Master's degree in Advanced Studies in Economic and Financial Dynamics from the Faculty of Economics and Management of Sfax. She is currently preparing for her doctoral thesis in Economics. Her current research focuses on renewable energy, bioenergy, ecological economic, and sustainability development.

Nouri Chtourou holds a degree from the University of Nice Sophia-Antipolis; his doctoral thesis in Economics focused on 'Economic analysis of the state in development issues'. He is a Professor at the Faculty of Economics and Management of Sfax and a Visiting Professor at the University of Nice Sophia-Antipolis. He has served as a Consultant to the World Bank and the African Union. He developed CFAR-m with Professor Rochdi Feki; 'CFAR-m' is an algorithm used a global leader in the field of competitive intelligence (CI). He collaborates with Probus Sigma on CFAR-m with Professor Rochdi Feki. His research focuses on new institutional economics and governance, public economics and the normative and positive models using artificial neural networks on issues such as construction of composite indicators, classification/clustering and ranking/rating.

Damien Bazin received his PhD in Economics and Assistant Professor (Accreditation to Supervise Research) in Economics at the University of Nice Sophia Antipolis, France. After his Postdoctoral studies in Canada and missions in China (programme of the European Union), he joined Research Group on Lawn Economics and Management (GREDEG). He conducts research on macroeconomics and sustainable development. His fields of specialisation are many and varied, including ecology, ethical and environmental economy, macroeconomics, corporate ethics, and topics related to socially sustainable development. He develops projects in the Higher Institute of Economics and Management (ISEM) whose direct applications are found within ecological economics and game theory. He provides lectures on company ethics in prestigious Parisian business schools. His latest works are related to the protection of nature and to economic ethics. He regularly collaborates with national daily papers with the aim of popularising fundamental research.

## 1 Introduction

Today, bioenergy is receiving more attention as it is considered an alternative to fossil fuel. Moreover, the use of this kind of energy essentially revolves around two goals (Dorin and Gitz, 2007; Escobar et al., 2009). The first goal is to ensure energy security in order to reduce dependency on foreign oil. The second goal relates to the sustainable development approach and obligations to reduce greenhouse gas emissions (GHG) in industrialised countries under the Kyoto Protocol. It should be noted that the use of

bioenergy is encouraged by high authorities and countries to ensure the aforementioned objectives (Collantes, 2010).

When bioenergy is used within a sustainable perspective, it can be a source of renewable energy. It stores chemical energy to be used to produce electricity and heat as well as liquid and gaseous biofuels (Escobar et al., 2009). Today, there is a great interest in liquid biofuels used in the transport system. They are produced by foodstuffs known as first generation biofuels.

However, the energy and ecological balance of those biofuels is debatable (USDA, 2002). In fact, the first generation biofuels could be a threat to food security, since the increase in the demand for biofuels in energy markets creates a demand for foodstuffs, destined to the production of biofuels, hence contributing to a rising of prices in the agricultural market.

Over time, the economy is constrained by the environment and the system is complex and evolving, which creates fundamental uncertainty about the future consequences of our ongoing actions (Perrings, 2006). In fact, many natural public goods (such as ozone, air, etc.) have been regarded as free goods, and have been over-consumed (Kaul, 2000). Corrective measures should be applied, which is one of the reasons underlying the production of renewable energy such as biofuels. This new alternative should be subject to certain conditions. Furthermore, Hill et al. (2006) adopted a cautious approach to biofuels and argued “to be viable and alternative, biofuel should provide a net energy gain (NEG), and environmental benefits, be economically competitive, and be producible in large quantities without reducing food supplies”. The lack of a mechanism of collective action may cause biofuels to be produced unsustainably. It should also be noted that biofuels should not be produced at the expense of the well being of future generations.

## **2 Literature review**

The energy balance of conventional diesel fuel is 0.8 to 0.9. If the energy balance of biodiesel is higher than these values, it helps reducing dependence to fossil fuels (FAO, 2008). A study conducted by Hill et al. (2006) on soybean biodiesel obtained a positive energy balance of 1.93. However, Pimentel and Patzek (2005) showed that the US production of soybean biodiesel required 27% more fossil energy than the energy produced by the biodiesel. This study showed a negative energy balance. The energy analysis of palm oil biodiesel production in Thailand performed by Papong et al. (2010) obtained a net energy ratio (NER) of 2.42. Prueksakorn and Gheewala (2008), and Prueksakorn et al (2010) studied the life cycle energy balance of *Jatropha* biodiesel production in Thailand; it showed a NEG and NER of 4720 GJ/ha and 6.03, respectively. Even if biodiesel only is considered without co-products, the NER is 1.42. Furthermore, Wang et al. (2011) studied a life cycle assessment (LCA) of the economic, environmental and energy performances of JCL biodiesel in China. Results show EE for both JCL oil and JME at 1.57 and 1.47, respectively. Fredriksson et al. (2006) studied the energy balance and environmental load for systems based on rape methyl ester (RME), ethanol and biogas. NER is 7.6 for RME, 2.8 for ethanol and 4.6 for biogas. The RME scenario showed a favourable energy balance.

The discrepancy in results found in these studies relates to various assumptions, including variation on seed yields, conversion technology for biofuel, efficiency of fertilisers performances, the assessment of energy co-products and the number inputs included in calculations. The LCA of the system using intensive cultivation and applying fertiliser and irrigation resulted in a less positive energy balance compared to the study on the system using low input cultivation (Achten et al., 2007).

### **3 Global warming potential**

The GHG tend to elevate global warming. The 4th IPCC report acknowledges that global warming is undoubtedly caused by human activities. Thus, “Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations” [IPCC, (2007), p.39]. Fighting against climate changes requires that all countries control their contribution as suppliers or consumers of energy. Policy makers are responsible for determining financing mechanisms that will enable us:

- 1 to overcome the dangers caused by climate change in the short and medium terms
- 2 to define a trajectory for an energy system more sustainable in the longer term (Eyton, 2009).

The decline of natural capital is considered to be unsustainable not because it can lead to intergenerational inefficiency but because we fear it may cause irreversible disasters (Kojima, 2006). *Jatropha* biodiesel could be used as an alternative to diesel in engines and could reduce GHG emissions, as compared to diesel (Wang et al., 2011). However, the use of fertilisers and irrigation generates significant GHG emissions (Achten et al., 2007). Modifying the land us to cultivate *Jatropha Curcas* contributes to high GHG emissions. This source of GHG emissions is not addressed in previously cited LCA case studies (Achten et al., 2007; Escobar et al., 2009; FAO, 2008).

### **4 Methodology**

Biofuels used to be seen by many as a source of clean energy. According to Puppan (2002), their environmental benefits are presented during the combustion engines since their emissions of CO<sub>2</sub> are taken into account from the stage of plant growth and hence resulting in a closed carbon cycle. They are biodegradable and conduce to sustainability. It is true that the use of biofuels has benefits, but it also has serious environmental impacts, such as the use of large quantities of water, destruction of forests, increase in soil degradation, the reduction of food production, etc.... (Escobar et al., 2009).

LCA is a useful tool to determine the impact of biofuels on the environment (Achten et al., 2007; Escobar et al., 2009; Fredriksson et al., 2006; Miettinen and Hämäläinen, 1997; Rebitzer et al., 2004). The life cycle energy analysis of biodiesel production was conducted by assessing direct energy input (such as electricity, diesel, gasoline, fuel oil, etc.) and indirect energy input (energy accumulated in fertilisers, agrochemicals, and chemical production, excluding equipment and machinery used in the processes) (Papong et al., 2010). In 2006, ISO published a second edition of LCA standards. ISO standard

14040 of environmental management, based on the concept of sustainable development, describes the principles and framework for LCA (Elcock, 2007).

Various indicators are used to assess the advantages of a type of raw material compared to others. Among these indicators we find energy efficiency:

$$EE = \frac{\text{Output}}{\text{input}} = \frac{\sum \text{EOJ}}{\sum [\text{PFf} \times \text{Cff}] + \sum [\text{Em} \times \text{Cfm}]} \quad (1)$$

Equation (1) is a ratio of energy output divided by the mobilised energy for the life cycle of the product (ADME/DIREM Ecobilan-Pricewaterhouse Coopers, 2002; Escobar et al., 2009; Yu and Tao, 2009). The result should be higher than 1 for this indicator to be considered positive. The energy efficiency is considered more important as long as the result is significantly higher than 1. On the other hand, a score under 1 indicates that a large amount of energy is used to produce biofuel (EHLG, 2007). This indicator serves to recognise the nature of the fuel. In other words, it tells us whether the fuel is considered renewable or not. For instance, if the indicator equal to 1, the fuel is always regarded as non-renewable (Escobar et al., 2009).

The NEV is a measure of the energy gain or loss from the biodiesel used, defined as the energy content of the biodiesel minus the non-renewable energy used in the life cycle of the biodiesel production (Papong et al., 2010).

#### 4.1 Energy balance

##### 4.1.1 Input data

Most of the irrigated perimeter of JCL that covers 13,000 hectares are located southern Tunisia. Wastewater is used to restore degraded lands while increasing the welfare of the inhabitants and reducing GHG emissions as part of a project initiated by the Ministry of Agriculture and Water Resources in 2008. The area of agricultural lands in the nine provinces taken into consideration amounts to 4.2 million ha (in reference to the first forest and pastoral inventory edited in 1995 and to the second inventory edited in 2007) according to Géomatix (2008) and SERAH (2008).

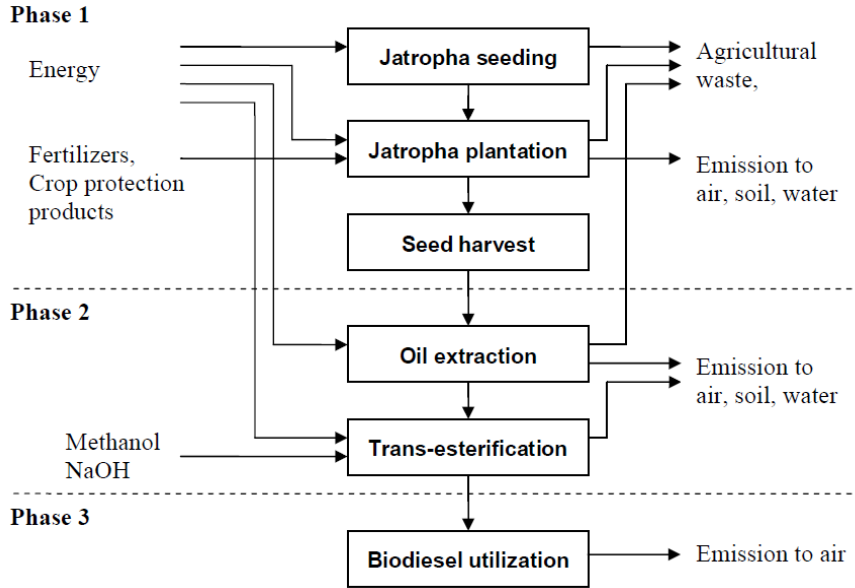
An area amounting 686,600 ha is likely to be planted with *Jatropha Curcas* (pluvial option) (i.e., 16% of the agricultural lands in the provinces of Zaghuan, Sousse, Kairouan, Monastir, Mahdia, Sfax, Sidi Bouzid, Medenine and Gabes).

The selection criteria are based on the condition of the lands (Semiarid, Arid and Sahara) with precipitation  $\leq 250$  mm per year (Aini, 2008). Data on mechanisation (diesel for tractor) were taken from Prueksakorn and Gheewala (2006). Data on fertilisers were taken from Reinhardt et al. (2008), and Prueksakorn and Gheewala (2008). Data on seed harvest were taken from Rapier (2010) (40 kg/day/worker) in an eight-hour day and the yield is 1.7 tons per ha/yr (Pimentel, 2012) with reference to Rapier (2010) concerning the oil extraction. Seeds ripen at different times. This has made mechanisation of harvesting *Jatropha* impossible to date (Rapier, 2010).

The LCA system consists of three phases as schematically shown in Figure 1. Phase one relates to the stage of plantation. *Jatropha* has the advantage of growing in semiarid and arid areas that can be irrigated with treated wastewater (Makkar and Becker, 2009). After one year, *Jatropha* plants appear, although maximum productivity only takes place after 4 or 5 years (Prueksakorn and Gheewala, 2006). The yield widely varies from one

country to another depending on climate, water supply, fertilisation, etc.... It is noteworthy to mention that these factors should be carefully studied and controlled. The planting stage is demanding in terms of non-renewable energy associated with nitrogen fertilisers and mechanisation (tractor fuel consumption). In a second stage, the harvest fruits are separated from their shells using a decorticator.

**Figure 1** Three phases of *Jatropha Curcas* biodiesel production life cycle



Source: Sampattagul et al. (2007)

The second phase is concerns oil extraction. After this process, oil can be used as crude vegetable oil for specific energy use or converted into biodiesel that meets the standards of usage through the transesterification, a demanding process in terms of energy consumption essentially related to methanol.

The third phase revolves around the final use of biodiesel which is related to GHG. This study is limited to analysing the energy balance of *Jatropha* biodiesel. The calculations in the study were performed using the Microsoft Excel 2007.

#### 4.2 Energy balance without co-products

The energy model is based on the same structure as the Yu and Tao (2009) model.

$$EE = \frac{\sum EOJ}{\sum [PFf \times Cff] + \sum [Ek \times Cfk]} \quad (2)$$

where

- EOJ (MJ) is the energy presented in biodiesel of JCL during its life cycle stage
- PFf (kg, m<sup>3</sup>, KWh, ...) is the consumption of fossil energy (fuel 'f' gasoline, diesel)

- Cff (MJ/kg, MJ/m<sup>3</sup>, MJ/KWh, ...) is the energy coefficient of fuel ‘f’
- Ek is the consumption of energy feedstock ‘k’ (*Jatropha*)
- Cfk (MJ/kg, MJ/m<sup>3</sup>, MJ/KWh, ...) is the energy coefficient of feedstock.

**Table 1** Energy inputs and costs in the first phase

Inputs	Quantity	Energy coefficient	Costs TND/ha	Energy MJ/ha	%
Electricity (irrigation)	1.08 <sup>a</sup> kWh/ha	1 kWh = 3.6 MJ	0.103 <sup>b</sup>	3.9	0
Water (irrigation)	11,000 <sup>a</sup> m <sup>3</sup> /ha/yr		1,100 <sup>a</sup>		
Total cost of irrigation			7,812 <sup>a</sup>		
Mechanisation (tractor)	222,812 <sup>c</sup> L/ha	38.6 <sup>d</sup> MJ/L	225 <sup>b</sup>	8,600.54	62
Fertiliser (N:P:K)	N <sup>e</sup> : 48 kg/ha/yr	N <sup>f</sup> : 87.9 MJ/kg	309.7 <sup>g</sup>	4,219.2	30
	P <sup>e</sup> : 19 kg/ha/yr	P <sup>f</sup> : 26.4 MJ/kg	122.6 <sup>g</sup>	501.6	4
	K <sup>e</sup> : 53 kg/ha/yr	K <sup>f</sup> : 10.5 MJ/kg	341.9 <sup>g</sup>	556.5	4
Subtotal			(774.2)		(38)
Decorticator (electricity)	6 <sup>e</sup> kWh/ton of fruit/ha/yr	3.6 MJ/kWh	1,173 <sup>b</sup>	79.3	1
Total			8,812.3	13,961	100

Notes: <sup>a</sup>SERAH (2008)

<sup>b</sup>Portrait of Tunisian Industry

<sup>c</sup>Prueksakorn and Gheewala (2006)

<sup>d</sup>Elert (2012) (calorific value of diesel = 38,6 MJ/L).

<sup>e</sup>Reinhardt et al. (2008)

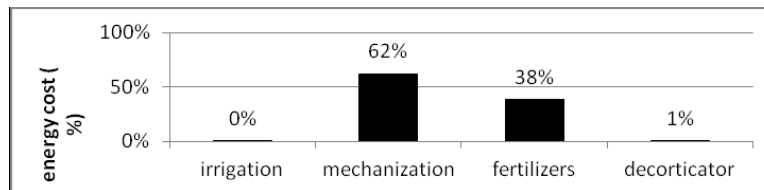
<sup>f</sup>Prueksakorn and Gheewala (2008)

<sup>g</sup>Department of Chemistry, Faculty of Sciences of Sfax (the cost of 1 litre of NPK is 8 TD), Kuentz Establishments (1 litre of NPK = 1.240 kg).

<sup>h</sup>Pimentel (2012) (1.7 t/ha/yr).

Source: The authors

**Figure 2** Energy mobilised in the first phase of biodiesel JCL production



Source: The authors

The mobilisation of energy, in the first phase (Figure 2), is linked to mechanisation and nitrogenous fertilisers at 62% and 38% respectively.

In the transesterification step (Figure 3), 83% of the non-renewable energy consumption is contributed using Methanol. Thus, the latter is associated with an

excessive monetary cost (385 TND/ha). In other words, for 13,000 hectares, we need a total of 5 millions of TND for methanol only.

The production of biodiesel from JCL requires energy mobilisation amounting to 32,919.486 MJ/ha of non-renewable energy. 47% of this mobilisation relates to planting and husking while 53% relate to transesterification.

**Table 2** Energy input of the second phase

<i>Inputs</i>	<i>Quantity</i>	<i>Energy coefficient</i>	<i>Costs TND/ha</i>	<i>Energy MJ/ha</i>	<i>%</i>
Oil extraction electricity	0.014 <sup>c</sup> kWh/kg oil <sup>e</sup>	3.6 MJ/kWh	0.54 <sup>a</sup>	17.13	0
NaOH	2,228.10 <sup>-3</sup> kg <sup>b</sup> /kg of oil/ha	19.87 <sup>d</sup> MJ/kg	4.54 <sup>f</sup>	15.05	0
Methanol	0.1 <sup>g</sup> kg/kg <sup>h</sup> of oil/ha	38.08 <sup>f</sup> MJ/kg	385 <sup>i</sup>	13,328	84
Electricity	0.42 <sup>c</sup> kWh/kg of oil <sup>e</sup>	3.6 MJ/kWh	16.42 <sup>a</sup>	2,570.4	16
Subtotal		405.96	15,913.45	100	
Total		406.5	15,930.58	100	

Notes: <sup>a</sup>Portrait of Tunisian Industry.

<sup>b</sup>Prueksakorn and Gheewala (2006).

<sup>c</sup>Reinhardt et al. (2008)

<sup>d</sup>Prueksakorn and Gheewala (2008).

<sup>e</sup>Pimentel (2012) (1.7 t/ha/yr); Rapier (2010) « Jatropha Reality Check » 7 March 2008, 20% of oil is recoverable by mechanical expression (the experience in Madagascar) in this case (0.34 t of oil of Jatropha).

<sup>f</sup>Department Chemistry, Faculty of Sciences of Sfax (the cost of 1 kg of NaOH is 6 TND).

<sup>g</sup>ADEME/DIRM (2002).

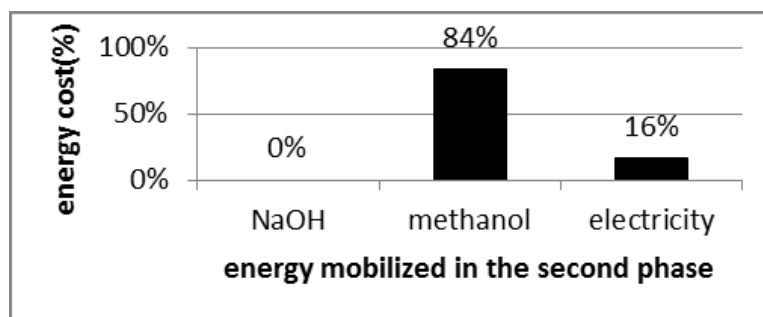
<sup>h</sup>1 litre of Methanol = 0.791 kg, temperature 20°C)

(<http://www.scribd.com/doc/105854544/Methanol-Energy-Balance>; accessed 30/09/2012).

<sup>i</sup>Department Chemistry, Faculty of Sciences of Sfax (over one year, the cost of 1 litre of methanol has soared from 9.440 TD in 2008 to 15.340 TND in 2009).

Source: The authors

**Figure 3** Energy mobilised in the second phase of biodiesel JCL production



Source: The authors

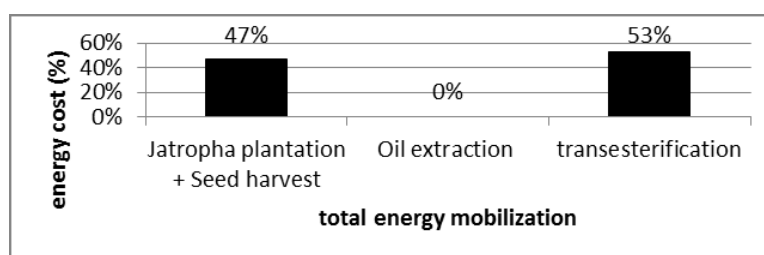


**Table 3** Total energy input

	Costs TD/ha	Energy MJ/ha	Total energy GJ	%
Jatropha planting + seed harvest	8,812.3	13,961	181.493	47
Extraction	0.54	15.05	195.65	0
Transesterification	405.96	15,913.45	206,874.85	53
Total	9,218.8	29,889.5	388,563.5	100

Source: The authors

**Figure 4** Total energy mobilisation in the biodiesel JCL production



Source: The authors

**Table 4** Energy coefficient of biodiesel JCL

Land potential	Production ton/ha/year	LHV MJ/kg	LHV MJ/L	LHV toe/ton
686,598 <sup>a</sup> ha	0.34 <sup>b</sup>	37 <sup>c</sup>	33 <sup>c</sup>	0.86 <sup>c</sup>
13,000 <sup>d</sup> ha irrigated	0.34 <sup>b</sup>	37 <sup>c</sup>	33 <sup>c</sup>	0.86 <sup>c</sup>

Notes: <sup>a</sup>Géomatix (2008). Forest and pastoral inventory edited in 1995 and 2007.

<sup>b</sup>Rapier (2010).

<sup>c</sup>EurObserv'ER (2009)

<sup>d</sup>SERAH (2008) Forest and pastoral inventory edited in 1995 and 2007.

Source: The authors

**Table 5** Energy output from biodiesel JCL

Land potential	Production ton/ha/year	Output MJ/ha	Output GJ	Output Ktoe/year
686,598 <sup>a</sup> ha	0.34 <sup>b</sup>	12,580	8,637,402.84	218.475
13,000 <sup>c</sup> ha irrigated	0.34 <sup>b</sup>	12,580	163,540	4.13
Total			8,800,942.84	222.6

Notes: <sup>a</sup>Géomatix (2008). Forest and pastoral inventory edited in 1995 and 2007.

<sup>b</sup>Rapier (2010)

<sup>c</sup>SERAH (2008). Forest and pastoral inventory edited in 1995 and 2007.

Source: The authors

It should be noted that the transportation of seeds to the processing factory and the transportation of *Jatropha* oil after extraction are not included in the energy balance because of a shortage in data. Furthermore, the project is still in the planting phase, as

Jatropha will begin producing seeds with maximum productivity only after 4 or 5 years (Prueksakorn and Gheewala, 2006). The transport factor in the balance sheet is weak, 1% throughout the production process. This value is confirmed by ADME/DIREM Ecobilan-Pricewaterhouse Coopers (2002) in the energy balance of rapeseed biodiesel.

The energy produced by JCL biodiesel presents 222.6 Ktoe/yr (Table 5). JCL biodiesel may cover 11% of the national consumption of diesel (Audinet Tunisie, 2009).

**Table 6** Energy indicators of JCL biodiesel

<i>JCL biodiesel</i>	<i>MJ/ha</i>
Energy mobilised	29,889.5
Energy output	12,580
Energy output/energy mobilised	0.42
Net energy value (NEV)	-17,309.5

*Source:* The authors

### 4.3 Results and discussion

According to equation (2):

$$\text{Energy mobilised} = \sum [\text{PFf} \times \text{Cff}] + \sum [\text{Ek} \times \text{Cfk}] = 29,889.5 \text{ MJ / ha}$$

(calculated according to Tables 1, 2 and 3).

$$\text{Energy output} = \sum \text{EOJ} = 12,580 \text{ MJ / ha (calculated according to Table 5).}$$

$$\text{EE} = \frac{12580}{29889.5} = 0.42$$

The total energy efficiency, calculated as the energy in the fuel produced divided by the total allocated energy use, was 0.42 for JCL biodiesel. The energy balance of JCL biodiesel is negative without taking into consideration co-products. The result is found to be much less than 1. A recent study conducted by Prueksakorn and Gheewala (2008) on the energy analysis of JCL biodiesel production in Thailand obtained an EE of 1.42. Makkar and Becker (2009) (EE = 1.7) in Germany, came to the same conclusion.

However, it is necessary to be careful concerning the nature of land. According to Prueksakorn and Gheewala (2008), JCL grown in marginal and semi-arid lands consumes twice as much energy as in fertile lands to obtain a similar yield. Jatropha is not a good economics choice because of the low yield per hectare (0.34 t/ha) (Rapier, 2010). It should be noted that the seeds are harvested every day because they do not all ripen at the same time. This causes very high labour costs; they can exceed \$4/day (Pimentel, 2012). The cost of a litre of Jatropha oil for worker effort ranges from \$19 to \$96 per litre (Rapier, 2010). This affects the economic feasibility of a Jatropha biodiesel project.

The energy output from co-products can be estimated at 6.03 Mtoe. It covers 74% of the national demand for energy in 2009 and 70% in 2011 (ANME, 2009).

It presents a very interesting multidimensional development approach, which positively affects the agricultural and energy sectors in a sustainable development perspective. Investing in the valorisation of co-products is indispensable. In fact, it contributes to a national energy balance surplus and generates creative income-generating

activities (creation of skilled and unskilled rural employment). In this case, it creates 1 job/ha (Missaoui, 2008) with a total of 13,000 jobs. Indeed, several studies show the existence of an interdependent relationship between renewable energy consumption and economic growth (Apergis and Payne, 2010).

However, it is essential to keep in mind that the *Jatropha* biodiesel project requires a very high investment, which negatively affects product competitiveness.

**Table 7** Energy produced by seed cake

<i>Land potential</i>	<i>Production ton/ha/year</i>	<i>Calorific value toe/ton</i>	<i>Calorific value GJ/year</i>	<i>Calorific value Ktoe/year</i>
686,598 <sup>a</sup> ha	1.3 <sup>d</sup>	0.476 <sup>d</sup>	17,851,548 <sup>c</sup>	424.866
13,000 <sup>b</sup> ha irrigated	6.5 <sup>d</sup>	0.476 <sup>d</sup>	1,690,000 <sup>c</sup>	40.222
Total			19,541,548	465.088

Notes: <sup>a</sup>Géomatix (2008). Forest and pastoral inventory edited in 1995 and 2007.

<sup>b</sup>SERAH (2008). Forest and pastoral inventory edited in 1995 and 2007.

<sup>c</sup>Lottmann (2008) (20 MJ/kg).

<sup>d</sup>Missaoui (2008).

Source: The authors

**Table 8** Energy produced by biomass

<i>Land potential</i>	<i>Production ton/ha/year</i>	<i>Calorific value toe/ton</i>	<i>Calorific value GJ/year</i>	<i>Calorific value Ktoe/year</i>
686,598 <sup>a</sup> ha	22 <sup>c</sup>	0.353 <sup>c</sup>	223,245,200.16	5,332.120
13,000 <sup>b</sup> ha irrigated	50 <sup>c</sup>	0.353 <sup>c</sup>	9,606,612.6	229.450
Total			232,851,812.76	5,561.57

Notes: <sup>a</sup>Géomatix (2008). Forest and pastoral inventory edited in 1995 and 2007.

<sup>b</sup>SERAH (2008). Forest and pastoral inventory edited in 1995 and 2007.

<sup>c</sup>Missaoui (2008).

Source: The authors

**Table 9** The total energy produced by all co-products

<i>Co-products</i>	<i>Potential energy Ktoe/year</i>
Seed cake	465.088
Biomass	5,561.57
Total	6,027.45

Source: The authors

## 5 Conclusions

This study shows the results of the life cycle energy analysis for *Jatropha* biodiesel production. The main factors of energy consumption, in the process of biodiesel production from JCL, are mechanisation and nitrogen fertilisers during the planting phase, 62% and 38% respectively. In the transesterification phase, methanol clearly is the strongest factor of energy consumption. It is considered the main contributor to energy consumption in the second phase.

Clearly, most energy consumption occurs at the transesterification stage, which accounts for 53% of the total energy use. This step is expensive and increases the cost of biodiesel production. Technical advancement and R&D progress could reduce the high cost of this stage. Additionally, they could increase the competitiveness of JCL biodiesel vis-à-vis the alternative fuels.

To conclude, the total energy mobilised by JCL biodiesel has reached 29,889.5 MJ/ha, whereas the energy output is about 12580 MJ/ha. Therefore, -17,309.5 MJ/ha is the net energy deficit (NED). The energy balance of JCL biodiesel is negative; JCL biodiesel production required 42% more fossil energy than the biodiesel fuel produced. Therefore, the yield per hectare is very low. The energy balance of JCL biodiesel could be further improved if we take into consideration the energy output of co-products. However, investing in this sector is very expensive and non-competitive.

This study is only a first step toward a possible production of JCL biodiesel in Tunisia. It should later be coupled with a sensitivity analysis, life cycle impact assessment (LCIA) in various aspects, such as greenhouse gases, land use, etc. and life cycle costing (LCC).

### Acknowledgements

We thank Mr. Karim Nefzi from the National Agency for Energy Conservation of Tunisia and Mr. Atef Rahmani for their recommendations, and Mrs. Marguerite Storm for helpful comments and suggestions, as well as those who contributed, directly or indirectly, to the completion of this modest work.

### References

- Achten, W.M.J., Mathijs, E., Verchot, L., Singh, V.P., Aerts, R. and Muys, B. (2007) 'Jatropha biodiesel fueling sustainability', *Biofuels, Bioproducts and Biorefining*, Vol. 1, No. 4, pp.283–291.
- ADME/DIREM Ecobilan-Préciserwaterhouse Coopers (2002) 'Bilan énergétique et gaz à effet de serre des filières de production de biocarburants'.
- Aini, R. (2008) 'Jatropha Curcas, Les biocarburants: Potentiel et perspectives d'une énergie durable en Tunisie', Tunis, 4 November, Ministère de l'Agriculture et des Ressources Hydrauliques.
- ANME (2009) *Programme Quadriennal de Maîtrise de l'Énergie 2008–2011*.
- Apergis, P. and Payne, J.E. (2010) 'Renewable energy consumption and growth in Eurasia', *Energy Economics*, Vol. 32, No. 6, pp.1392–1397.
- Audinet Tunisie (2009) 'Le secteur de l'énergie en Tunisie 2007–2009: Une flambée de production', Samedi, 18 April, 12:10, [online] [http://www.investir-en-tunisie.net/index.php?option=com\\_content&view=article&id=684:le-secteur-de-lenergie-en-tunisie-2007-2009—une-flambee-de-production&catid=71:dossiers&Itemid=316](http://www.investir-en-tunisie.net/index.php?option=com_content&view=article&id=684:le-secteur-de-lenergie-en-tunisie-2007-2009—une-flambee-de-production&catid=71:dossiers&Itemid=316) (accessed 12 March 2010).
- Collantes, G. (2010) 'Do green tech policies need to pass the consumer test? The case of ethanol fuel', *Energy Economics*, Vol. 32, No. 6, pp.1235–1244.
- Dorin, B. and Gitz, V. (2007) 'Life-circle-analyses of biofuels: from controversies to agricultural challenges', *Natures, Sciences, Sociétés*, Vol. 16, No. 4, pp.337–347.
- Elcock, D. (2007) 'Life-cycle thinking for the oil and gas exploration and production industry', ANL/EVS/R-07/5, prepared by the Environmental Science Division, Argonne National Laboratory, September.

- Elert, G. (2012) 'The physics fact book TM', Energy Density of Diesel Fuel, ©1998–2012 Glenn Elert [online] <http://hypertextbook.com/facts/index-topics.shtml> (accessed 30/09/2012).
- Escobar, J.C., Lora, E.S., Venturini, O.J., Yáñez, E.E., Castillo, E.F. and Almazan, O. (2009) 'Biofuels: environment, technology and food security', *Renewable and Sustainable Energy Reviews*, Vol. 13, Nos. 6–7, pp.1275–1287.
- EurObserv'ER (2009) 'Biofuels barometer', *Systèmes Solaires, journal des énergies renouvelables*, July, No. 192, pp.54–77 [online] <http://www.eurobserv-er.org/pdf/baro192.pdf> (accessed 12 March 2010).
- Euskal Herriko Laborantza Ganbara (EHLG) (2007) 'Les agrocarburants, Energie et Agriculture' [online] [http://www.iholdioztibarre.com/fileadmin/documents/economie/agriculture/les\\_agrocarburants.pdf](http://www.iholdioztibarre.com/fileadmin/documents/economie/agriculture/les_agrocarburants.pdf)
- Eyton, D. (2009) 'Expanding wings in the hydrocarbon sector – the era of collaboration', Vice President, Research and Technology Group at British Petroleum [online] [http://www.bp.com/liveassets/bp\\_internet/globalbp/STAGING/global\\_assets/downloads/D/D\\_GPE\\_Petrotech\\_Jan09\\_pdf](http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/D/D_GPE_Petrotech_Jan09_pdf) (accessed 20 March 2010).
- FAO (2008) 'La situation mondiale de l'alimentation et de l'agriculture, Les biocarburants: perspectives, risque et opportunité'.
- Fredriksson, H., Baky, A., Bernesson, S., Nordberg, A., Norén, O. and Hansson, P.-A. (2006) 'Use of on-farm produced biofuels on organic farms – evaluation of energy balances and environmental loads for three possible fuels', *Agricultural Systems*, Vol. 89, No.1, pp.184–203.
- Géomatix (2008) 'Etude sur l'identification des terres disponibles pour la plantation de Jatropha curcas en vue d'une production de biocarburants en Tunisie, Les biocarburants: Potentiel et perspectives d'une énergie durable en Tunisie', Ministère de l'Environnement et du Développement Durable, Coopération Technique Allemande GTZ, Tunis, 4 November.
- Hill, J., Nelson, E., Tilman, D., Polasky, S. and Tiffany, D. (2006) 'Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels', *PNAS*, Vol. 103 No. 30, pp.11206–11210.
- IPCC (2007) *Climate Change 2007: Synthesis Report*, IPCC Plenary XXVII, Valencia, Spain, 12–17 November [online] [http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4\\_syr.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf) (accessed 20 March 2010).
- Kaul, I. (2000) 'Perspectives pour la coopération internationale: Biens publics globaux, un concept révolutionnaire', *le monde diplomatique*, June, pp.22–23 [online] <http://www.monde-diplomatique.fr/2000/06/KAUL/13929.html> (accessed 12 January 2010).
- Kojima, S. (2006) 'Reconsideration of dynamic utility optimisation and intergenerational equity in sustainable development studies', *International Journal of Ecological Economics & Statistics*, Vol. 6, No. F06, pp.26–36.
- Kuentz Establishments [online] [http://www.kuentz.com/bt/index.php?module=produit&prd\\_id=1536&code\\_cat=BB20&page=1](http://www.kuentz.com/bt/index.php?module=produit&prd_id=1536&code_cat=BB20&page=1) (accessed 12 March 2010).
- Kumar, N., Anand, K.G.V. and Reddy, M. P. (2011) 'In vitro regeneration from petiole explants of non-toxic Jatropha curcas', *Industrial Crops and Products*, Vol. 33, No. 1, pp.146–151.
- Lottmann, J.H. (2008) 'Lessons to be learned for Tunisia from the cultivation and utilization of *Jatropha Curcas Linnaeus* (JCL) worldwide', Report for GTZ.
- Makkar, H.P.S. and Becker, K. (2009) 'Jatropha curcas, a promising crop for the generation of biodiesel and value-added coproducts', *Eur. J. Lipid Sci. Technol.*, Vol. 111, pp.773–787.
- Miettinen, P. and Hämäläinen, R.P. (1997) 'How to benefit from decision analysis in environmental life cycle assessment (LCA)', *European Journal of Operational Research*, Vol. 102, No. 2, pp.279–294.
- Missaoui, R. (2008) 'Etude technico-économique de la filière de production de biocarburant à partir du Jatropha', *Conference on Biocarburants: Potentiel et perspectives d'une énergie durable en Tunisie*, Tunis, 4 November.

- Papong, S., Chom-In, T., Noksa-nga, S. and Malakul, P. (2010) 'Life cycle energy efficiency and potentials of biodiesel production from palm oil in Thailand', *Energy Policy*, Vol. 38, No. 1, pp.226–233.
- Perrings, C. (2006) 'Ecological economics after the millennium assessment', *International Journal of Ecological Economics & Statistics*, Vol. 6, No. F06, pp.8–22.
- Pimentel, D. (2012) *Global Economic and Environmental Aspects of Biofuels*, published by CRC Press, Taylor & Francis Group, ISBN-13: 978-1439834633, Edition 1, 453p.
- Pimentel, D. and Patzek, T.W. (2005) 'Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower', *Natural Resources Research*, Vol. 14, No. 1, pp.65–76.
- Prueksakorn, K. and Gheewala, S.H. (2006) 'Energy and greenhouse gas implications of biodiesel production from *Jatropha curcas* L.', *The 2nd Joint International Conference on Sustainable Energy and Environment (SEE 2006)*, Bangkok, Thailand, 21–23 November, pp.1–6.
- Prueksakorn, K. and Gheewala, S.H. (2008) *Full Chain Energy Analysis of Biodiesel from *Jatropha curcas* L. in Thailand*, The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand.
- Prueksakorn, K. and Gheewala, S.H., Malakul, P. and Bonnet, S. (2010) 'Energy analysis of *Jatropha* plantation systems for biodiesel production in Thailand', *Energy for Sustainable Development*, Vol. 14, No. 1, pp.1–5.
- Puppan, D. (2002) 'Environmental evaluation of biofuels, Periodica Polytechnica', *Social and Management Sciences*, Vol. 10, No. 1, pp.95–116.
- Rapier, R. (2010) 'Is Camelina the next *Jatropha*?' [online] <http://www.consumerenergyreport.com/2010/05/06/is-camelina-the-next-jatropha/> (accessed 18 September 2010).
- Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W-P., Suh, S., Weidema, B.P. and Pennington, D.W. (2004) 'Review life cycle assessment, part 1: framework, goal and scope definition, inventory analysis, and applications', *Environment International*, Vol. 30, No. 5, pp.701–720.
- Reinhardt, G., Becker, K., Chaudhary, D.R. et al. (2008) 'Basic data for *Jatropha* production and use', Tech. Rep., Ifreu, Heidelberg, Germany.
- Sampattagul, S., Suttibut, C., Yucho, S. and Kiatsiriroat, T. (2007) 'Life cycle management of *Jatropha* bio-diesel production in Thailand' [online] <http://www.lcm2007.org/paper/326.pdf> (accessed 10 January 2010).
- Société d'Etude, de Réalisation, d'Aménagement et d'Hydraulique (SERAH) (2008) 'Etude d'utilisation des eaux usées traitées dans la production de biocarburants en Tunisie à partir de *Jatropha Curcas*, Les biocarburants: Potentiel et perspectives d'une énergie durable en Tunisie', Tunis, 4 November.
- The Portrait of Tunisian industry [online] <http://www.tunisianindustry.nat.tn/fr/doc.asp?mcat=3&mrub=58&msrub=191&dev=true> (accessed 12 Mars 2010).
- USDA (2002) 'The energy balance of corn ethanol', US Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses, Agricultural Economic Report No. 813, pp.1–16 [online] <http://www.transportation.anl.gov/pdfs/AF/265.pdf> (accessed 6 May 2010).
- Wang, Z., Calderon, M.M. and Lu, Y. (2011) 'Life cycle assessment of the economic, environmental and energy performance of *Jatropha curcas* L. biodiesel in China', *Biomass & Bioenergy*, Vol. 35, No. 7, pp.2893–2902.
- Yu, S. and Tao, J. (2009) 'Economic, energy and environmental evaluations of biomass-based fuel ethanol projects based on life cycle assessment and simulation', *Applied Energy*, Vol. 86, Supplement 1, pp.S178–S188.

## **Abbreviations**

---

ADME	French Environment and Energy Management Agency
DIREM	French Department of Energy and Mineral Resources
EE	Energy Efficiency
EHLG	Euskal Herriko Laborantza Ganbara (i.e., Chamber of Agriculture of the Basque Country)
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization of Standardization
JCL	Jatropha Curcas Linnaeus
JME	Jatropha Methyl Ester
K	Potassium
LCA	Life cycle assessment
MTD	Million Tunisian Dinars
N	Nitrogen
NaOH	Sodium hydroxide
NEG	Net energy gain
NER	Net energy ratio
NPK	Nitrogen, phosphorus, potassium
P	Phosphorus
R&D	Research and development
RME	Rape Methyl Ester
US	United States

---

## **Units of measure**

---

<i>Unit</i>	<i>Term</i>
CO <sub>2</sub>	Carbon dioxide
GJ	Gigajoule
ha	Hectare = 10,000 m <sup>2</sup>
kg	Kilogram
ktoe	Kilogram of toe
kWh	Kilo Watt hour
L	Litter
m <sup>2</sup>	Square metre
m <sup>3</sup>	Cubic metre
MJ	Mega Joule
Mteo	One million of toe
TND	Tunisian Dinar
Toe	Tonne of oil equivalent

---