Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 95 (2016) 124 – 131
Energy Procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2015, 14-16 October 2015, Riga, Latvia

Environmental life cycle assessment for Jatropha biodiesel in Egypt

Mohamed Marwan Fawzy*, Francesco Romagnoli

Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia

Abstract

The main goal of this paper is to evaluate the environmental performance for the system of Jatropha biodiesel production from cradle to wheel according to the unique Egyptian Jatropha biodiesel model because it depends on waste water which is sewage water and waste land which is desert. This evaluation is performed through a life cycle analysis study which is implemented according to the international standard organization guidelines ISO 14040 and the environmental impacts assessment is executed through SimaPro LCA. The main motivation behind this life cycle analysis is the absence of any environmental life cycle analysis studies for Jatropha biodiesel production in Egypt so such study would be helpful in future Jatropha biodiesel projects in Egypt. Results show that Jatropha biodiesel production in Egypt has many environmental benefits such as combating desertification and fewer impacts compared to fossil diesel which makes Jatropha more than an energy crop. However, there is a need for further social and economic life cycle analysis for Jatropha biodiesel production in Egypt on both small farmers and commercial projects levels. The targeted audiences concerning the results are scientists and stakeholders interested in Jatropha biodiesel production

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.
Keywords: Jatropha biodiesel; rapeseed biodiesel; environmental impact assessment; life cycle analysis; Egypt; Latvia

* Corresponding author: Tel.: 00371022183399
E-mail address: marwanfawzi@hotmail.com

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.
doi:10.1016/j.egypro.2016.09.033

1. Introduction

Jatropha is a promising plant in the field of renewable energy sources that gained a lot of interest recently within the scientific arena due to its ability to mitigate climate change - substituting fossil fuel consumption [1, 2], to tackle desertification – as it increases soil fertility due to its ability to inject nutrients into the soil and to foster employment – as it would present a driver for local employment in the agricultural sector. Jatropha represents a unique icon in biodiesel production due to its ability to strengthen socio-economic development in poor areas, to fight desertification and to produce biodiesel at the same time which resulted in high interest from biodiesel production projects' stakeholders [3]. Life cycle analysis is supposed to be the most appropriate methodology to realize the positive environmental impacts of Jatropha biodiesel use and production such as Life cycle assessment of biodiesel production from Jatropha by Kaewcharoensombat [4] and Generic life cycle assessment of the Jatropha biodiesel system [5]. The main motivation behind this life cycle analysis is the absence of any environmental life cycle analysis studies for Jatropha biodiesel production in Egypt so such study would be helpful in future Jatropha biodiesel projects in Egypt. The Jatropha plant has the ability to adapt to infertile agricultural and desert lands under tough climate conditions which stood for it as a great environmental opportunity to be implemented in developing countries. Moreover, Jatropha does not make any threats concerning competition with food crops for developing or poor countries due to its ability to develop in arid soils and hard climate conditions, it also minimizes pest problems and prevent mass invasion.

2. Jatropha description

Jatropha is a moderate-sized bramble tree that grows up to a height of five or six meters with oil bearing qualities The hardy Jatropha is resistant to drought and pests, and produces seeds containing up to 40 % oil [6]. Jatropha toxicity is due to the existence of phorbol esters [7], the reason that Jatropha is not used as a food crop is because it contains phorbol esters, curcains, trypsin inhibitors and other components that make it toxic [8]. However, *Jatropha Platyphylla* has been distinguished as a non-poisonous genotype of Jatropha which is discovered only in Mexico [5]. The nature of the Jatropha plant is mostly like weed as it does not require insecticides or complicated agricultural methods. However, Jatropha needs to be cultivated in large land areas in order to produce biodiesel viable at the commercial level. Recently, some studies on Jatropha showed that its leaves can be used for carbon dioxide absorption so it helps in decreasing carbon content into the air [9].

3. Life cycle analysis methodology

In this paper we present Jatropha biodiesel life cycle analysis which is based on inventories from different Egyptian sources for the production system in Egypt including several production steps starting from cultivation , harvesting and oil extraction to transesterification and the end use process in order to provide a general view of the environmental performance of Jatropha biodiesel production system through assessing environmental impacts and the influence of different uses of by products on the Jatropha production system. A comprehensive Life cycle analysis approach is a good tool for evaluation of the overall environmental impact in a holistic manner and thus explores the impacts and environmental benefits of the Jatropha-based biodiesel including the evaluation of: plant cultivation impacts, processing impacts and biodiesel consumption impacts, re-use and eventual recycling or disposal of cultivation and processing by-products and waste. LCA is a vital decision-making instrument for developing Jatropha biodiesel production process; such LCA should include environmental, economic and social aspects to maximize benefits and profits.

3.1. Goal and scope

The goal of the performed life cycle analysis in this paper is evaluating the environmental performance for the system of Jatropha biodiesel production from cradle to wheel according to the unique Egyptian Jatropha biodiesel model because it depends on waste water which is sewage water and waste land which is desert for Jatropha trees irrigation and cultivation. The scope of the life cycle analysis approach is implemented according to the

International Standard Organization guidelines ISO 14040 [10] and the environmental impacts assessment is executed through SimaPro LCA software. Cradle to wheel life cycle analysis method is applied on Jatropha production system in Egypt including cultivation, harvesting, oil extraction, transesterification and end use process. Infrastructure and transportation are included.

3.2. Functional unit

The functional unit is the production and use of one tonne of Jatropha biodiesel by average pickup car on normal road including production steps, necessary infrastructure and transportation. The choice of one tonne of Jatropha biodiesel as functional unit make it more useful and easier to use in benchmarking and comparing with fossil diesel and other biodiesel types whether at the commercial or the environmental level.

3.3. Life cycle inventory and system boundaries

In Fig. 1, we can see three main boundaries which are the natural resource extraction, the system boundary and the expanded boundary. The system boundary includes the main steps of the life cycle analysis process which are seeds production for plantation, Jatropha seeds for the production process, oil extraction, transesterification and finally the end use process, also the system boundary shows main inputs and outputs for these processes. The expanded boundary shows co-product use such as biogas and fertilizers, it also shows the avoided products such as natural gas, artificial fertilizers, fossil glycerin and fossil diesel.

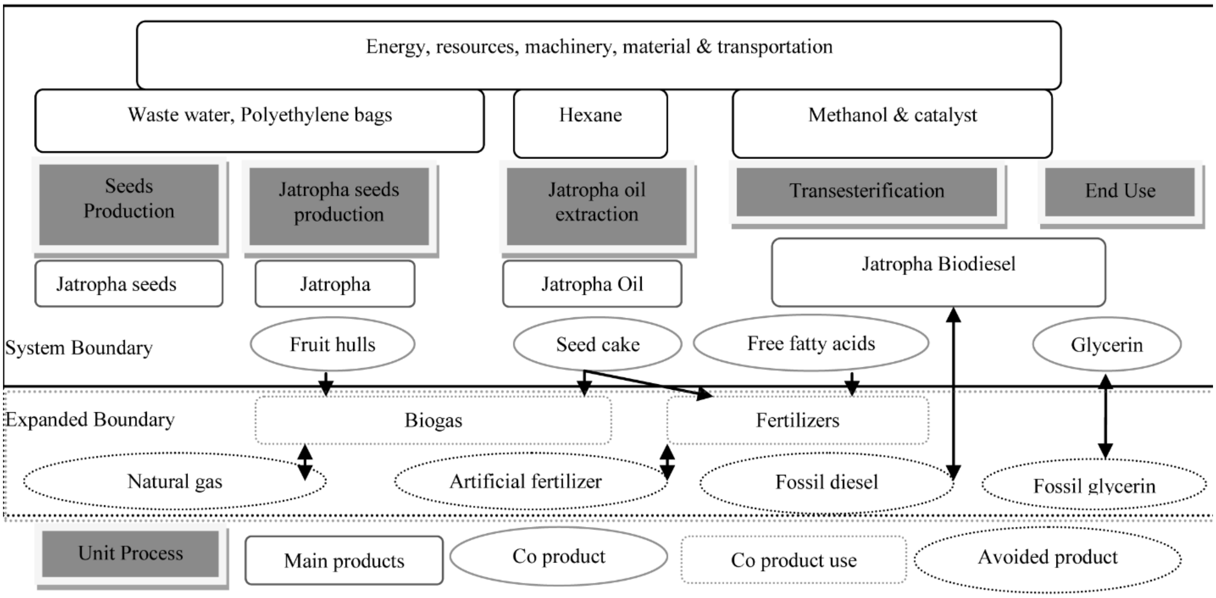


Fig. 1. Life cycle analysis system and expanded boundaries scheme implemented in SimaPro.

According to the national project for safe utilization of treated sewage water for afforestation, planting Jatropha has been accomplished in Upper Egypt in Luxor governorate by Grade C treated municipal sewage water which is preliminary treated waste water according to the Egyptian code of waste water use is utilized as a part of the watering system of industrial oil yields as Jatropha [3]. Seedlings were generated by planting Jatropha seeds in polyethylene dark sacks in nurseries and that were uprooted before planting in gaps 30x30x30 cm in sandy desert soil [7]. Separating in Jatropha trees plantations was 3x3 m which implies 1260 seedling/ha [3].

The Jatropha biodiesel model life cycle analysis is done for two main scenarios. The first is the economic-based or business as usual scenario hereafter called base scenario which refers to a typical industrialized scenario for the biodiesel production using Jatropha with the priority to maximize the economic benefits of production over environmental and social benefits through applying high efficient agricultural and extraction technologies to increase production rates, reducing expenses and working hours. The second scenario is a human labour social based scenario hereafter called scenario A at which the primary priorities are given to the environmental and social benefits over economic feasibility. An amount of 1.025 tonne of Jatropha crude oil is needed to produce 1 ton Jatropha biodiesel. Due to the lower extraction efficiency of the ram press and avoiding hexane use we will need more Jatropha seeds. The needed quantity of seeds is considered to be 5.1 tonnes. Consequently inventory values such as polyethylene bags, seedlings fertilizers and land area would be changed slightly in the Jatropha green model. Data inventories for the 2 Jatropha biodiesel scenarios are presented in Table 1.

Table1. Jatropha Base Scenario and Scenario A inventory referred to 1 tonne of biodiesel.

Data	Base scenario	Scenario A	Source
Land[ha]	-0.5	-0.62	[2]
Seeds[Kg]	-0.6	-0.75	[5]
Polyethylene bags[units]	-630	-784	[3]
Seedling organic manure[Kg]	-63	-78.3	[3]
Seedling irrigation[liter /seedling]	5	5	[3]
Irrigation electricity(1 hp pump)[kWh]	-70.124	-86.95	[11]
Wastewater for irrigation & fertilization[m3/year]	-253	-314.70	[3, 12]
Human energy[MJ]	3100	3844	[13]
Polyethylene waste[Kg]	20.6	25.62	[3, 5]
Fruit hulls[tonne]	3	3.73	[6]
Nitrate NO_3 Emissions to water [Kg]	2.5	3.10	[12]
Phosphate PO_4 Emissions to water[Kg]	0.25	0.310	[12]
Ammonia NH_4 Emissions[Kg]	0.1	0.12	[12]
Tractor field preparation[hours]	3	3.73	[3]
Tractor transport from Luxor city	50 Km by 40 tonnes Truck	50 Km by 40 tonnes Truck	[14]
Seeds transport from Sudan	1000 Km by 40 tonnes Truck	100 Km by 40 tonnes Truck	[14]
Jatropha Seeds[tonne]	4.1	5.1	[2]
Data	Oil Extraction	Oil Extraction	Source
Jatropha seeds[tonne] (26)	-4.1	-5.1	[11]
Hexane[ton] (26)	-20.5	_	[11]
Electricity[Kwh] (48)	-614	_	[11]
Jatropha seed cake[ton] 3 (26)	3	3.73	[11]
Hexane transport from Giza 633 Km by 30 tons Truck (59)	633 Km by 30 tonnes Truck	_	[11]
Human energy[MJ]	_	-3000	[11]
Jatropha crude oil[tonne] 1.025 (26)	1.025	1.025	[11]
Data	Transesterification	Transesterification	Source
Jatropha crude oil[tonne]	-1.025	-1.025	[2]
Methanol[Kg]	-113	-113	[2]
NaOH catalyst[Kg]	-7.5	-7.5	[2]
H3PO4 for Glycerine purification[Kg]	-3.5	-3.5	[2]
Electricity[Kwh]	-420	-420	[9]
Glycerine[Kg]	122	122	[2]
Free fatty acid[kg]	20	20	[2]
Methanol transport from Damietta	893 Km by 32 tons Truck	893 Km by 32 tons truck	[14]
Jatropha Biodiesel[ton]	1	1	
Flows	End Use	End use	Source

Nitrogen Oxides (Kg)	2.10	210	[6]
Particulates Matter(Kg)	0.13	0.13	[6]
Biodiesel transport to Cairo	624 Km by 28 tons lorry	624 Km by 28 tons lorry	[11]
Flows	Avoided products	Avoided products	
Fossil Glycerine[tons]	0.12	0.12	[11]
Natural gas[m3]	1143	11421	[11]
NPK fertilizers[tons]	0.11	0.13	[11]

4. Environmental impact assessment

Impact classes can depict ecological effects on diverse levels. One option is to utilize impact on the environment like eutrophication, acidification, ozone depletion or global warming which are classified as midpoint impacts. An alternate option is to utilize the outcomes these impacts will have, in the same way as diminish biodiversity or shorter length of life of people which are identified as endpoint impacts. The method IMPACT2002+ which is included in Simapro is used to carry out the Jatropha biodiesel environmental impact assessment in this paper. Three impact categories are chosen to be presented in this paper which are characterization a midpoint impact category as in Fig. 2, weighting and single score as end point impact categories as in Fig. 3. They are presented in terms of mPt which represents the impact on one person per year. We should take into account that a negative value means environmental benefit.

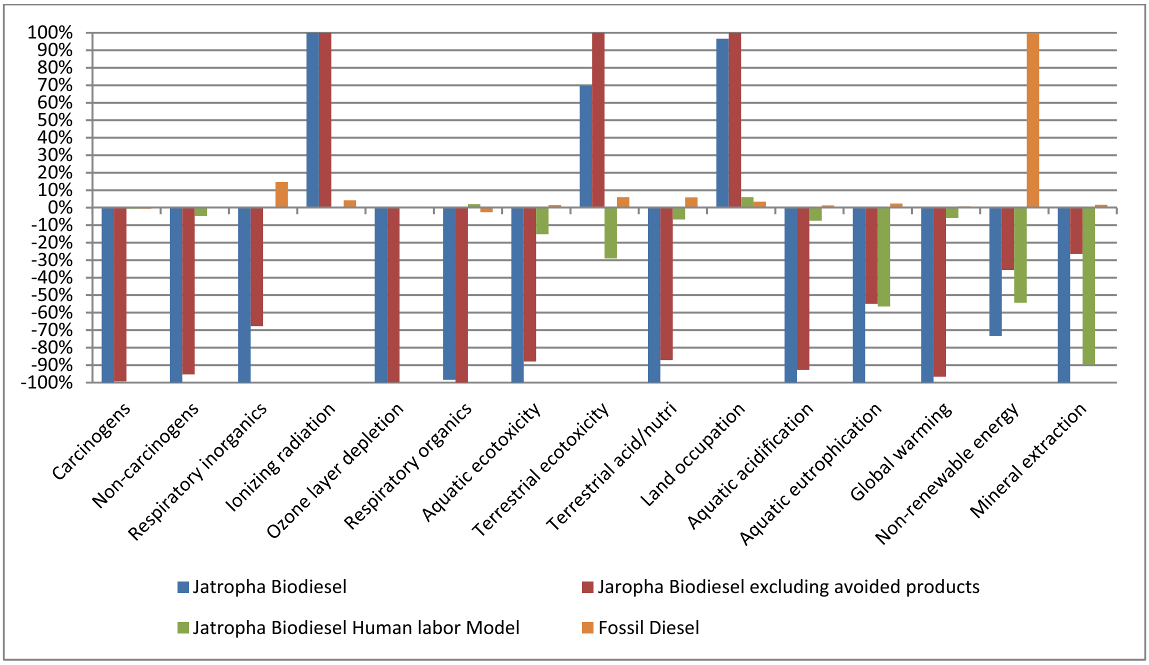
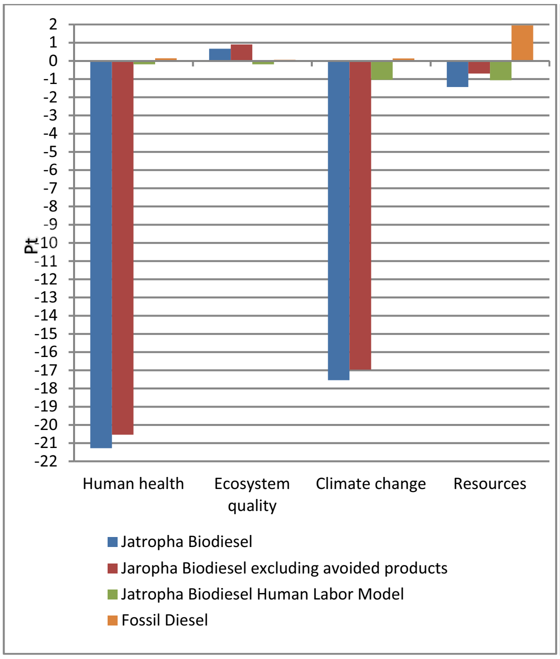


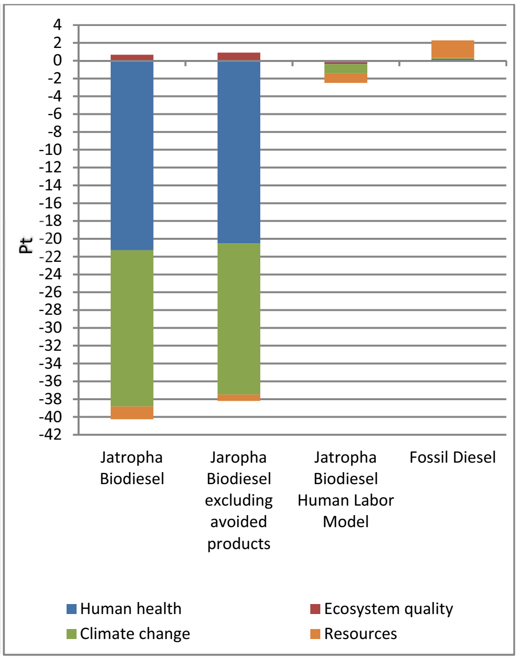
Fig. 2. Jatropha biodiesel and fossil diesel characterization comparison.

The characterization category indicates the impact potential on nature from a certain substance compared to different substances in the same class. The characterization changes over the relegated LCI results to the basic unit of the class pointer. Jatropha biodiesel base scenario shows high environmental benefits. However, it shows significant negative impacts concerning ionizing radiation and land occupation. Jatropha scenario A generally shows not as good environmental performance than the Jatropha base scenario which is mostly due to elimination of hexane from the oil extraction stage. However, the green model shows less negative environmental impacts potential regarding land occupation midpoint category. Another advantage of the human labour model is that it shows environmental benefits regarding terrestrial eco toxicity. The fossil diesel model does not show any environmental benefits. However, it shows less significant negative environmental impacts than Jatropha biodiesel model concerning some midpoint impact categories such as ionizing radiation, terrestrial eco toxicity and land occupation.

It is important to notice that non renewable energy is the most significant negative environmental impact in the fossil diesel model.Weighting is a conversion process at which the environmental impacts of the life cycle analysis are converted to an overall environmental impact. Fig. 3a illustrates the weighting element which is related to endpoint impact categories considering four damage oriented impact categories: human health, ecosystem quality, climate change and resources.



(a)



(b)

Fig. 3. (a) Jatropha biodiesel and fossil diesel weighting comparison; (b) Jatropha biodiesel and fossil diesel single score comparison.

A single score represents the total load of the process on the environment which makes it the best option to compare different processes. Fig. 3b illustrates a clear environmental load comparison between the Jatropha biodiesel models and the fossil diesel model considering single score analysis for four endpoint impact categories. The Jatropha biodiesel model shows the best environmental performance showing significant environmental benefits except for slightly negative environmental impact regarding ecosystem quality. The Jatropha biodiesel human labour model shows less environmental benefits and it does not show any negative environmental impacts. However, the main advantage of the Jatropha biodiesel human labour model is that it shows environmental benefits considering ecosystem quality. The fossil diesel model shows negative environmental impacts mostly considering resources and climate change but it does not show any environmental benefits.

Environmental life cycle analysis and energy balance can be considered as a basic step in benchmarking analysis. E_i is an energy balance indicator which represents the ratio of the energy consumed in fuel production in terms of nonrenewable sources and the biodiesel fuel energy in terms of calorific value [11]. We should understand that as long as the ratio value is lower than one, then the process has more effective renewable idiosyncrasies so with this procedure it will be conceivable to assess the quality and the level of the hypothetical renewable methods.

Table 2. Biodiesel and Fossil diesel models energy indicator comparison.

Life Cycle Analysis scenario	E_i
Egyptian Jatropha Biodiesel Base Scenario	-5.75
Jatropha Biodiesel Excluding Avoided Products	-2.81
Jatropha Biodiesel Human Labour Scenario A	-4.27
Fossil Diesel Model	7.85

Table 2 shows energy balance indicators values where:

E_i the energy balance indicator = MJ_{in}/ MJ_{out},
MJ_{in} global non renewable sources spent within the model [MJ],
MJ_{out} biodiesel energy specific heating value =37.7 MJ/kg.

The best energy balance indicator is that of the Jatropha biodiesel business model which makes it the most efficient renewable choice.

5. Results and discussion

The Egyptian Jatropha biodiesel model which include the base scenario and human labour scenario A represents a renewable energy source using the Energy indicator E_i presented as benchmarking with values –5.75 and –4.27, respectively. Even when excluding avoided products, the base scenario model shows an E_i value of –2.81 which confirms the Jatropha biodiesel as a source of renewable energy. Avoided products slightly improve the environmental performance of the Egyptian Jatropha biodiesel model; the main reason behind their limited environmental benefits in the Jatropha model is that its effect is relatively small if compared to the huge effect of the model itself concerning wasteland, waste water and not using fertilizers or pesticides which confirm the uniqueness of the Egyptian Jatropha biodiesel model. However, their environmental benefits can be clearly observed regarding the resources endpoint impact category.

The Jatropha biodiesel base scenario shows significant negative environmental impacts considering ionizing radiation and terrestrial eco toxicity midpoint impact categories which were primarily related to Jatropha toxicity and hexane use in the oil extraction process. However, when Jatropha human labour scenario A is applied which excludes hexane solvent from the oil extraction process, it resulted in environmental benefits considering these two midpoint impacts so it can be concluded that the use of hexane is the main reason for these significant negative environmental impacts. Unfortunately, the main drawback of scenario A is its low environmental benefits concerning human health and climate change if compared to the base scenario. It is important to mention that hexane is produced from refining crude oil so, according to Ecoinvent database in SimaPro, it is considered as a recycled by-product in our process which makes the use of hexane un-expectedly the main reason for such being environmental benefits concerning human health and climate change in the base scenario.

The fossil diesel model does not show any environmental benefits. However, it shows less significant negative environmental impacts than Jatropha biodiesel model concerning some midpoint impact categories such as ionizing radiation, terrestrial eco toxicity and land occupation. It is important to notice that non renewable energy is the most significant negative environmental impact in the fossil diesel model. Fossil diesel again shows significant negative environmental impacts considering the use of resources. Jatropha biodiesel base scenario shows slightly higher negative environmental impacts on the ecosystem quality if compared to the negligible effect of fossil diesel which is related to the effects of the use of waste water in the Jatropha base scenario and in general due to land use effect in biodiesel crops. However, Jatropha human labour scenario A shows environmental benefit concerning ecosystem quality which should be considered as excellent improvement meanwhile it shows less environmental benefit than the business model concerning human health, climate change and resources.

The Jatropha biodiesel base scenario impacts on the environment are less than that for fossil diesel model, about 94 % considering the avoided products and about 93 % not considering the avoided products.

6. Conclusion

The main achievement of Jatropha human labour scenario A is its ability to deliver environmental benefits regarding ecosystem quality considering that the main drawback of most of biodiesel production processes is its negative environmental impact on ecosystem quality. However, the main drawback for Jatropha human labour scenario A is its negative environmental impact on human health and respiratory organics which is mostly related to the manual oil extraction due to Jatropha toxicity and human effort implemented so protective masks and safety equipment should be provided to labourers in the Jatropha biodiesel projects and working schedules should include appropriate working hours with refreshing breaks and meals.

Jatropha is more than a biodiesel crop as it is considered as a method to fight desertification and prepare the desert land for forestation, so Jatropha agriculture in the desert can turn back the carbon clock, decreasing carbon dioxide in the atmosphere while also increasing soil fertility and boosting resilience from floods and drought. Consequently, it can be considered as a method to decrease global warming and fight climate change.

References

[1] El Diwani GI, Shadia R, Hawash S, Kamal N. Techno-Economic Appraisal of Biodiesel from Jatropha Curcas: An Egyptian Case Study. Egypt: Chemical Engineering and Pilot Plant Department National Research Centre; 2008.

[2] Elgamassy I. Feasibility study on growing Jatropha utilizing treated wastewater in Luxor, Report No. 57: Economic, Agricultural Research Center (ARC), Cairo, Egypt, September 2008.

[3] The national program for safe use of treated sewage water for afforestation. Ministry of state for environmental affairs and Egyptian environmental affairs agency. Available: http://www.eeaa.gov.eg/english/main/env_forests_jatropha.asp

[4] Kaewcharoensombat P. Life cycle assessment of biodiesel production from Jatropha. Journal of the Taiwan Institute of Chemical Engineers 2011;42(3):454–462.

[5] Almeida J. Generic life cycle assessment of the Jatropha biodiesel system. Master Thesis. New University of Lisboa; 2009.

[6] Achten WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Muys B (2008). Jatropha bio-diesel production and use. Biomass and Bioenergy 2008;32:1063–1084.

[7] Makkar HPS, Aderibigbe AO, Johnson COLE, Becker K, Foidel N. Chemical composition and effect of heat on organic matter- and nitrogen-degradability and some antinutritional components of Jatropha meal. Animal Feed Science and Technology 1997;67(2–3):223–243.

[8] Jongschaap REE, Corre WJ, Brandenburg WA. Claims and facts on Jatropa curcas L. Global Jatropha curcas evaluation, breeding and propagation programme. Wageningen: Plant research International BV; 2007.

[9] Hill H. Jatropha: a revolutionary biofuel. Available: http://earthuntouched.com/jatropha-revolutionary-biofuel/

[10] ISO 14040 Environmental management – life cycle assessment – principles and framework. Geneva: International organisation for otandardisation (ISO); 2006.

[11] Fawzy MA. comprehensive life cycle analysis of Jatropha and Rapeseed for biodiesel production in two different climate conditions. Master thesis. Riga Technical University: Riga; 2015.

[12] Kalannavar VN, Angadi SS, Patil VC, Angadi SG, Byadagi AS, Patil SJ. Effect of major nutrients on yield and quality of Jatropha curcas. International Journal of Agricultural Sciences 2009;5(2):390–393.

[13] Maes WH, Trabuccoa A, Achten WMJ, Muys B. Climatic growing conditions of Jatropha curcas L. Biomass and bio energy 2009;33:1481–1485.

[14] Reinhardt G, Gartner S, Rettenmaier N, Munch J, Falkensteinn E. Screening life cycle assessment of Jatropaha biodiesel. Final Report. Institute for Energy and Environmental Research Heidelberg; 2007.