Life Cycle Analysis For Energetic Study of Jatropha As A Biofuel

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Abstract- *The present paper deals with the energetic study of Jatropha Curcas (JC) as biofuel an energy life-cycle approach. In this analysis evaluate the energy consumption during life cycle of Jatropha Curcus is consider from its cultivation to oil extraction and trans esterification process. During life cycle study approach energy are estimated in each state of cultivation including with all the agricultural equipment's that assist the cultivation of Jatropha Curcus. This analysis used to find out the Energy ill ratio (a dimensionless quantity is ratio of energy delivered by fuel during its combustion in Compression ignition (CI) engine to the total energy consume during cultivation of Jatropha Curcus also known as net energy ratio). Energy ill ratio is obtained for Jatropha biodiesel by the ratio of the energy output in the form of fuel energy delivered to the compression ignition engine and the cumulative energy demand by Jatropha biodiesel production. Average Energy ill ratios for Jatropha biodiesel life cycles for any kind of soil are seen to be around 1.4, which shows that biodiesel from Jatropha is renewable. Study shows that Jatropha biodiesels have higher output than inputs in terms of energy. This study also includes the economics and it is seen that the price of the feedstock is one of the most significant factors in biodiesel production. Jatropha cultivaton can also act as good source of income for rural people.*

Keywords- energy ill ratio (net energy ratio), biodiesel, life-cycle analysis, Jatropha.

I. INTRODUCTION

In the present era due to continuous consumption of fossil fuels (Petrol, diesel, coal for example) and depleting continuous these fuels continuously day by day increasing the problem of fuel source. Due to this reason many researchers to force him to investigate the possibility of alternative fuel source that fill the gap of energy demand. There are many renewable sources of energy (sun energy, wind energy, ocean energy, biofuels and biomass) among them biofuels are an important source of renewable energy, that produced from different vegetable and seed oil bearing plants (soybean, sunflower, mustered, neem, karanja and jatropha for example). Most of them some plants are used for edible oil and some plants used for medicinal uses. Most usable plant for biodiesel production is Jatropha plant. It is the most valuable form of energy source. It can be used blends with diesel fuel with required percentage (e.g. 5%, 10%, 20 %...) or alone used to run the compression ignition engine.

Life-cycle analysis calculates the energy ill ratio, which is evaluated by dividing the energy output of the system in the form of fuel energy delivered to the CI engine by the cumulative energy demand for the production of Jatropha oil **[1, 6].** Jatropha (Jatropha curcas) is wild-growing, hardy, oil seed-bearing plant well adapted to varying conditions of soil and climate and best suited for waste/degraded land. It belongs to the family of Euphorbiaceous. It is shrubs type plant 5-8 meter long. In this analysis first start with seeding, then after 3 to 4 month it again replanted in field in 4 m^2 areas per plant. Due to potential demand and better marketing opportunities, cultivation of Jatropha appears viable. Jatropha adapts well to marginal lands as well as live fence, as farm animals do not browse it. All parts of the shrub are used in traditional medicine and as raw material for pharmaceutical and cosmetic industries. The use of Jatropha oil in the production of soap in rural areas gives direct benefit, whereas indirectly this will help to save edible vegetable oil. The larg scale cultivation of Jatropha curcas on wastelands with poor soils and low rainfall in drought prone areas could provide regular employment and could improve their living conditions by providing additional income of poor people.

II. ENERGETIC COMPONENTS OF JATROPHA CURCAS

The components of Jatropha Curcas (JC) from which energy can be derived are wood, fruit shells, seed husks and kernel. A schematic illustration of the production of these components is shown in Figure 1. Jatropha Curcas produces oil-rich fruits. The fruit is made up of the outer shell and seeds.

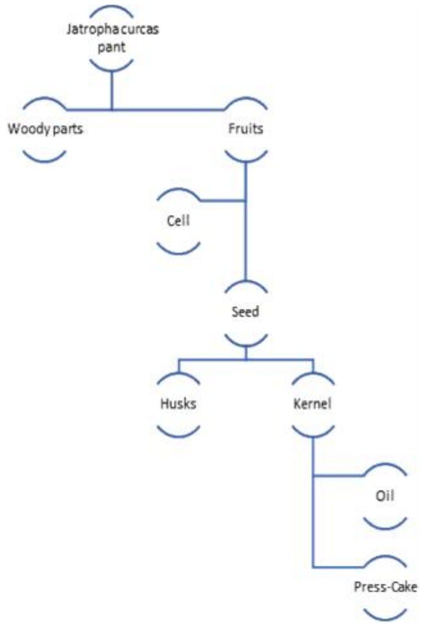

Fig.1 Energetic component of Jatropha Curcas.

2.1 The Fruit

On average the JC fruits are 2.5 cm long, and each fruit contains 2-3 seeds. It has nearly 400-425 fruits per kg and 1500-1600 seeds per kg weight **[7]**. Dry JC fruit contains about 35-40% shell and 60-65% seed by weight **[8]**. The seed is made up of about 42% husks and 58% kernel **[9]**. On fruit weight basis, JCL contains about 17-18% oil **[7]** and seeds contain up to 34% oil.

2.2 The Shell

The shell is mechanically removed from the fruit in the first step during oil extraction. About one tone of shell material per hectare can be obtained and used as a source of energy. The chemical analysis of JC shell has shown that it is made up of 34%, 10% and 12% cellulose, hemicelluloses and lignin, respectively **[9]**. Volatile matter, ash and fixed carbon content of the shell have been shown to be 69%, 15% and 16% respectively **[7]**.

2.3 Seed husks

The JC seed contains about 42% seed husks. There is limited information in literature about the use of JC seed husks for energy purposes. Analysis of the husks showed that the husks contained 4% ash, 71% volatile matter and 25% fixed carbon **[8]**. The calorific value of the husks is 16 MJ kg-1**[8]**.

2.4 Raw Seed Oil

Seeds contain about 35 % oil which can be extracted by heat, solvents or by pressure. About 1200 kg of oil can be obtained from a hectare. The seed oil is potentially the most valuable end-product of JC. Seed oil from JC has been extensively studied as an alternative stationary engine or transportation fuel. This is due to its potential to substitute fossil diesel. The calorific value of seed oil is 39.5MJ kg-1**[10]** is higher than anthracite coal and comparable to crude oil.

2.5 Press cake

After oil extraction from the seeds a residue matter or cake remains as a by-product. Generally, about 50% or up to 75% of the weight of seeds remains as press-cake **[7]**. This press-cake contains mainly proteins and carbohydrates. The cake is made up of the seed husks (42%) and kernel **[9]**. Based on the extraction efficiencies and the average oil content of the whole seed, press-cake can contain 9-12% oil by weight. This oil influences the gross energy value of press-cake, which is about 18.2 MJ kg-1**[11].**

2.6 Woody Products

Wood is a widely used source of energy. Pruning is a common practice in Jatropha production as it is used to manage canopy growth and promote lateral branching. On average, there are about 2,500 Jatropha trees Ha^{-1}**.** Pruning of these trees produces substantial amounts of wood. Over a period of 6 years, more than 20 ton of woody biomass can be produced in one hectare of Jatropha plantation from pruning **[12]**.

III. METHODOLOGY AND PROCEDURE FOR ENERGY ESTIMATIONS

The life cycle energetic study of Jatropha Curcas as biofuels is carried out to calculate the energy consumption during the life cycle of Jatropha Curcas as a biodiesel fuel for alternative source of energy. Energy life cycle analysis starts with preliminary stage of Jatropha cultivation to end with its combustion stage in Compression Ignition (CI) engine. For this, energy inputs during life cycle analysis composed of following process and sub-process are listed below.

i. Nursery (Soil preparation involving tilling and soil levelling, Seeding, Irrigation, Care and Safety, collecting the plant for plantation)
ii. Plantation (Soil preparation involving ploughing and soil levelling, Plant collection from nursery, Planting, Irrigation)
iii. Growth (Irrigation, Care and safety, Pruning and trimming)

iv. Seed Harvesting (Pod collection, Pod drying, De-podding, Seed drying, Transportation to oil extraction plant)
v. Oil Extraction (using Oil expellers machine)
vi. Transesterification

In the study, following assumption are made for evaluation of energy life cycles analysis.

i. Cultivation of Jatropha starts form nursery and planting density should be keep 2000-2500 trees per hectare.
ii. Pesticide, insecticides, or herbicide are used to protect the plant from diseases and harmful insect.
iii. Fertilizers like nitrogen-phosphorus-potassium (NPK) are used to increase the growth rate of plant and for higher yields of Jatropha seeds.
iv. The energy needed in creating and manufacturing of the materials, machinery and fertilizer used to assist for Jatropha cultivation for biodiesel production is not considered in this analysis.
v. Alternative uses of seed cake energy (i.e. its combustion to produce useable heat or power), is not considered in life cycle analysis of Jatropha Curcus as a biofuel.
vi. Life-cycle analysis is to be done for the period up to first fructification from respective trees.

3.2 Mathematical Modelling Approach

Mathematical formulation is done for different process/ sub process for each stage of Jatropha cultivation and biodiesel production during its energy life cycle analysis. For this modelling, 1 ha of land is used as a base unit. A field survey has been done, which helped in determining the coefficients used in mathematical modelling of this section. The energy used in creating/manufacturing of the materials and machinery used to assist the Jatropha cultivation is not considered in this analysis. The energy expenditure from preliminary stage to the trans- esterification process (i.e. biodiesel production), is divided into seven categories as detailed below.

3.3 Plant Nursery

It is the first stage of Jatropha cultivation which included the soil preparation, soil bag fillings, watering the soil bags, machinery and manpower used, care, and safety done up to 2 to 3 month of the plant growth. Area for plant nursery is estimated according to considered plant density. Following are the activities done to plant nursery and energy expenditure is calculated following relation.

3.4 Ploughing

First step is to prepare the soil for plant nursery. Soil is prepared by its ploughing and it's levelling, using Tractor and ploughing tool (for example disc plough, moldboard plough chisel plough and planner) for better growth of seed. Energy expenditure using a tractor for ploughing is given by

$$E_{n1} = v_f \times \rho \times CV \times h_a \times k \quad (1)$$

Where
a) k = 1.0, for normal soil;
b) k = 1.2 to 1.4, for black/stony or hardy soil;
c) k = 0.6 to 0.8, for sandy soil or soft soil.

3.5 Irrigation

Water is compulsory for all living things. It is necessary for better growing of the plant. Water. In Jatropha cultivation water is necessary for proper growth and higher plant yield. In nursery stage Jatropha plant needed 0.5 to 1.5 kg of water per plant. To irrigate the plant used Tredal pump is a simple machine and derived by human efforts. This simple, human-powered device can be manufactured and maintained at low cost in rural workshops in developing countries. Energy expenditure to drived the Tredal pumps are calculated by following mathematical relation which is explain in this equation.

$$E_{n2} = n_t \times E \times t \times r \quad (2)$$

Where;
a) r=1, for optimum rainfall;
b) r=2.5, for no rainfall
c) r=0, for heavy rainfall;

3.6 Manures and Fertilizer

These are organic and inorganic materials that apply to plant for its rapid growth and increase the yielding. Only energy expenditure to carry out the fertilizer to field and put it in the field. Energy expenditure during transportation of manure and fertilizer and drop in the cultivated field is estimated as;

$$E_{n3} = \left(v_f \times \rho \times CV \times D\right) + (n \times E \times t) \quad (3)$$

3.7 Manpower

According to 'Fundamentals of physiology: a human perspective' by Laureen Sherwood, the energy expenditure by a human worker during normal working is 1 MJ/h, low working 0.84 MJ/h, and heavy working 1.2 MJ/h **[6]**. Based on the above statement, the manpower spent in different activity in Jatropha cultivation are calculated as following relation.

$$E_{n4} = E \times (l_1 \times t_1 \times n_1 + l_2 \times n_2 \times t_2 + l_3 \times t_3 \times n_3 \times l_4 \times n_4 \times t_4 + l_5 \times n_5 \times t_5) \quad (4)$$

here,

l_1=1.0, factor of labour uses in soil preparation.

l_2=1.2, factor of labour uses in fertilizer.

l_3=1.0, factor of labour uses in irrigation.

l_4=1.0, factor of labour use seeding.

l_5=1.0, factor of labour use care & safety.

n_1, n_2, n_3, n_4, n_5 and t_1 , t_2, t_3, t_4, t_5 are indicate number of person and time consuming for their respective works.

Total energy expenditure in preliminary/nursery stage given same as the equation (1) to (4).

$$E_n = (E_{n1} + E_{n2} + E_{n3} + E_{n4}) \quad (5)$$

3.8 Plantation

Factors such as land type, land preparation, irrigation, care, and safety are analyses for energy consumption in plantation is same as nursery stage, so energy calculations are same as that of plant nursery, except that plantation covers the unit area (i.e. 1 ha). Manpower input and resources are more from nursery stage that needed in Jatropha cultivation. For land preparation using tractor and first ploughing is done with disc plough for deeply disturbance of soil. which helps to destroy the uneconomical shrubs and herbs and also help in proper circulation of air and water in the soil. Then after one month during planting session land again plough with chisel plough and levelling with planer, and last planting the plant in the field.

3.9 Manpower

Energy expenditure by labour that is engaged in different activity is calculated as;

$$E_{pm} = E \times (l_{p1} \times t_{p1} \times n_{p1} + l_{p2} \times n_{p2} \times t_{p2} + l_{p3} \times n_{p3} \times t_{p3} + l_{p4} \times t_{p4} \times n_{p4} + l_{p5} \times n_{p5} \times t_{p5}) \quad (6)$$

here,

l_{p1} =1.0, factor of labour use in soil preparation.

l_{p2}=1.2, factor of labour use in fertilizer.

l_{p3}=1.0, factor of labour use in irrigation.

l_{p4}=1.2, factor of labour use plant collected from nursery.

l_{p5}=1.2, factor of labour use planting.

t_{p1}, t_{p2}, t_{p3}, t_{p4}, t_{p5} and n_{p1} , n_{p2}, n_{p3}, n_{p4}, n_{p5} are the time consume and number of labours are engaged in their respective works.

Energy calculation procedure in plantation is same as nursery only difference is it done for one hectare of field. Total energy expended in plantation may be calculated using the following equation.

$$E_p = E_{p1} + E_{p2} + E_{p3} + E_{pm} \quad (7)$$

3.1.1 Growth

After plantation plant start growing day by day in this stage care and safety, irrigation, and pruning and trimming are done from the plant age of 1 year onwards up to 2 years of age of the plant. Therefore, only manpower is the input energy for growth session. . In this stage plants are needed to be irrigate 3 to 4 times for higher yielding of fruits. Total energy expenditure is estimated in growth period as this equation.

$$E_g = E \times \{(n_6 \times t_6 \times l_6) + (n_7 \times t_7 \times l_7)\} \quad (8)$$

here,

l_6=1.2, factor for labour uses in irrigation and fertilizer.

l_7=1.0, factor for labour uses in pruning and trimming of the plants.

t_6, t_7 and n_6, n_7 are the time consume and number of labours involved in their respective works in growing period.

3.1.2 Seed Harvesting

After the growth stage it is time to collect the fruits from plants. Various activities is to be done in this stage which are fruit collections, fruit drying, de-podding (de-husking/seed separation from fruit), and seed drying are done manually and hence no machinery inputs are used. There are four different activities that are considered under this category. First, seed pod/fruit collection is done. Two times during harvesting, the pods are collected. These pods are dried in sunlight at least for 4 days. 3-4 workers are needed for drying the seedpods. Third activity is the de-husking of the seed pods, which is done manually. Finally, drying of the seed is done for 2 days and transports the seeds to the oil extension plant using tractor.

Energy expenditure in seed collection and transportation may be calculated:

$$E_{sh} = \left\{ E \times (t_8 \times n_8 + t_9 \times n_9 + t_{10} \times n_{10} + t_{11} \times n_{11}) + \left(\frac{\rho \times CV \times v_f \times D}{1000}\right) \right\}$$

(9)

Where;

t_8, t_9, t_{10}, t_{11} *and* n_8, n_9, n_{10}, n_{11} show the time consuming and number of labours engaged for their respective work in seed harvesting stage.

3.1.3 Oil Extraction

To extract the oil from the seeds, use oil expeller's machine this is run with 8 horse power motor. To extracting the oil with this machine it runs with electric motor which consumes 6-units electric energy and pressed 40-kg seeds per hour. During this stage 3-4 labours are involved for loading the seeds to the machine and collect the oil. Energy expenditure for the oil extraction is given by this equation.

$$E_{oe} = \{(P \times T) + E \times (n_{12} \times t_{12})\}$$

(10)

Where;

n_{12}= number of persons engaged in oil extraction.

t_{12}= time consuming in oil extraction in hr.

3.1.4 Transesterification

In these stages Jatropha oil converted in to biodiesel during this process conversion efficiency of 90 to 94 per cent obtained which are done in Harcourt Butler Technological Institute Kanpur in oil department, energy consumption rate during trans esterification is obtained as 36kWh per ton of oil [**1**]. Assuming requirement of two labour for 2 hrs, energy expenditure in transesterification process is given as:

$$E_t = \{(P \times M) + (E \times t)\} \quad (11)$$

Where t, is time consume in transesterification process. Energy contained in alcohol used for Tran's esterification process is not considered here as equivalent amount (slightly less than the mass of alcohol) of glycerine is produced as a by-product during the chemical process. All the above processes will give the total energy requirement for biodiesel production.

Total energy demand/input in the life cycle of the biodiesel production can be calculated using equations (5) to (11) and given by.

$$E_{ip} = E_{nt} + E_p + E_g + E_{sh} + E_{oe} + E_t$$

(12)

This is the total energy requirement by the system under consideration.

3.1.5 Energy Output

Energy output or the energy contained in the biodiesel produced from 1 hectare land crop of the plants is given by.

$$E_{op} = 0.25 \times CV_{bd} \times M \times 1000$$

(13)

Here the Brake thermal efficiency is considered as 0.25.

3.1.6 Energy ill Ratio or Net Energy Ratio

Based on quantification of energy consumption and energy output modelling, the dimensionless parameter named energy ratio has been estimated. It specifies the renewability of the fuel and the fraction of the energy consumed in converting into useful fuel.

$$R = {E_{op}}/{E_{ip}}$$

(14)

IV. RESULTS AND DISCUSSION

Table 1 shows the energy inputs during harvesting, biodiesel conversion, and output for the energy life cycle of the biodiesel in each stage. All the values of energy consumed in each stage (process/sub-process) shown in Table 1 are calculated from equations (1) to (13). The calorific values of biodiesels were determined using Bomb calorimeter (IS: 1448 part I, 1960) at Harcourt Butler Technological Institute (HBTI), Kanpur,in oil department and were found to be 39.5 MJ/Kg for Jatropha bio diesel. Energy output of biodiesel is calculated from equations (13) using these values. It can be evaluated from the data in Table 1 that the sum of energy inputs required to convert the energy contained in the raw material into useable form as IC engine liquid fuel is lower than the energy output by the system. Energy values represented in Table 1 are indirect energy, which are given to the system, and not direct energy like the energy contained in the soil and solar energy taken by plant. Net energy ratios for cultivation of Jatropha are calculated based on proper production management and caring. In cultivation process using proper irrigation, fertilizer and caring and safety the Net Energy ratio/ Energy ill ratio is 1.4 which represents the renewable from of energy. A detail of the energy per hectare for cultivation of Jatropha crop and conversion to the biodiesel evaluated energy life cycle analysis is given in table 1.

Table 1 Energy expenditure details in each stage.

Item	Energy (MJ)
Nursery	
Soil preparation	
a) Mold board plough	152.49
b) Soil leveling	81.33
c) Chisel plough	121.9
Total energy expenditure in soil preparation	437.14
Manpower	72.4
Total energy expenditure in Nursery	509.54
Plantation	
Soil preparation	
a) Mold board plough	650.62
b) Soil leveling	325.31
c) Chisel plough	487.97
Total energy expenditure in soil preparation	1789.22
Manpower	488.8
Total energy expenditure in Plantation	2278
Growth Stage (manpower)	204
Seed harvesting stage (manpower)	4738
Oil Extraction (manpower and machinary)	2205
Trans esterification	240
Total input energy	10174.15
Total output energy	14220
Net energy ratio	1.39768

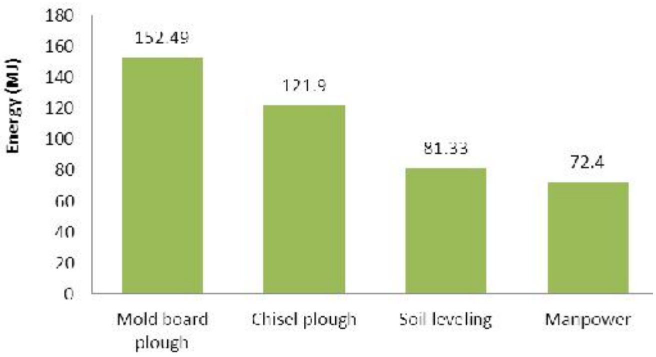

Fig.2 Energy consumption in preliminary stage

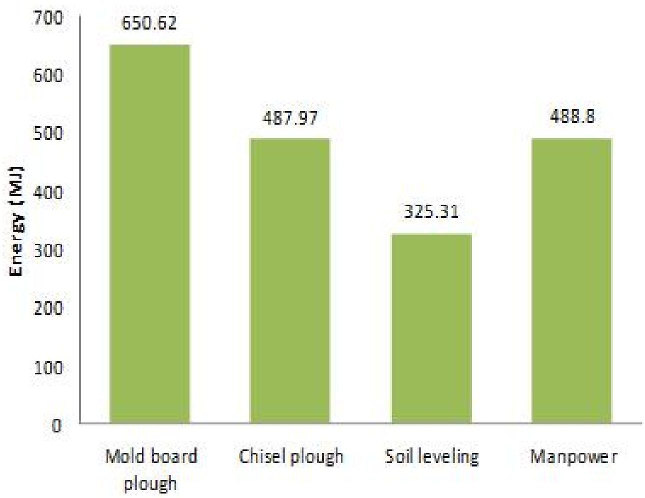

Fig.3 Energy expenditure in plantation stage

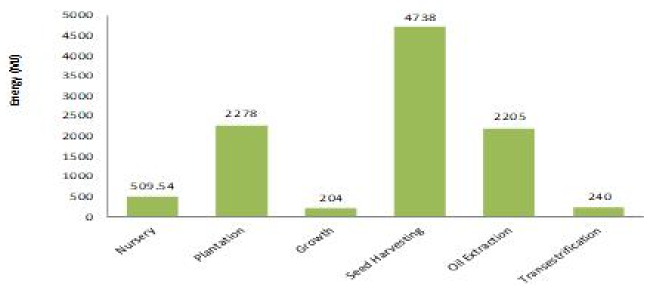

Fig.4 Energy consumption in different stage

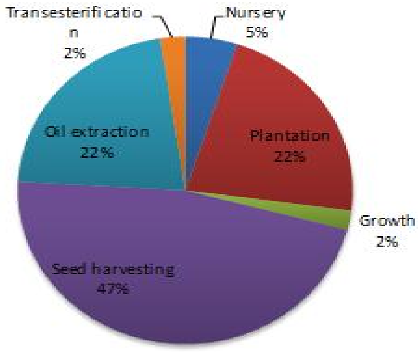

Fig. 5 Percentage of energy consumption in different stage

V. CONCLUSIONS AND FUTURE SCOPE

Present study shows that the Jatropha curcus (JC) is a robust energy crop with a lot of potentials to supply multiple energy carriers. It can be grow on barren and eroded land under the harsh climatic condition. Jatropha cultivation provides many benefits such as, provides local job, its residue like press cake used to produced soap, glycerin is also valuable products produced during oil transesterification. Following conclusions are obtained from this study.

i. Life cycle analysis energy Ill ratio shows that the Jatropha cultivation is renewable energy resources.

ii. In life cycle analysis with proper caring and safety with good management the energy ill ratio of Jatropha is 1.4.

REFERENCES

[1] A Yadav and O Singh, Energy estimation for life - cycle analysis of Jatropha, Neem and Karanja biodiesel - A parametric study.

[2] ISO 14040:1997. Environmental management – life cycle assessment – principles and framework.

[3] ISO 14041:1998. Environmental management – life cycle assessment – goal and scope definition and inventory analysis.

[4] ISO 14042:2000. Environmental management – life cycle assessment – life cycle impact assessment.

[5] ISO 14043:2000. Environmental management – life cycle assessment – life cycle interpretation.

[6] Yadav, A. and Singh, O. A comparative evaluation of compression ignition engine performance using preheated jatropha, karanja, and neem oils. *Proc. IMechE, Part A: J. Power and Energy*, 2010, 224(A1), 47–57.

[7] Bernesson, S., Nilsson, D., and Hansson, P.-A. A limited LCA comparing large- and small-scale production of ethanol for heavy engines under Swedish conditions. *Biomass Bioenergy*,.

[8] Rao, D. G., Gupta, R. C., Goel, A. K., and Yadav, A. An integrated system of complete assessment of transesterified jatropha oil in CI engine starting from growth of the plant. In Proceedings of the Joint International Conference on *ASR – NSC 2009*, 27–29 November 2009, pp. 567–570 (TataMcGraw Hill Ed. Pvt. Ltd, New Delhi).

[9] Abreu, F., 2009, Alternative by-product from jatropha.Download,http://www.ifad.org/events/jatropha/harvest/f_Abreu,ppt,2009.

[10] Sotolongo, J.A., Beatón, P., Diaz, A., de Oca, S.M., del Valle, Y., Pavón ,S.G. and Zanzi ,R, 2009, *Jatropha curcas* L. as a source for the production of biodiesel:

[11] Gour, V.K., 2006, Production practices including post-harvest management of Jatropha curcas. In: B. Singh, R. Swaminathan, V. Ponraj (Eds.), Biodiesel Conference Towards Energy Independence – Focus on *Jatropha*, Rashtrapati Nilayam, Bolaram, Hyderabad; 9-10 June, pp. 223-251.

Nomenclature

GHG	Greenhouse gases
JCL	Jatropha Curcus L
CV	Calorific value of diesel fuel (MJ/kg)
v_f	Diesel fuel consume liter per hectare
ρ	Specific gravity of diesel fuel
h_a	Field area in hectare
k	Soil constant
E_{n1}	Energy expenditure in nursery stage for soil preparation (MJ)
E_{n2}	Energy expenditure in nursery stage for irrigation of the plant (MJ)
n	Number of labours
E	Human Energy expenditure rate (MJ/kg)
t	Time in hour
r	Rain fall factor
E_{n3}	Energy expenditure in nursery stage for fertilizer (MJ)
D	Distance in (Km)
E_{n4}	Manpower energy expenditure in nursery (MJ)
E_n	Total energy expenditure in nursery (MJ)
E_{pm}	Manpower energy expenditure in plantation stage (MJ)
E_{p1}	Energy expenditure in plantation for soil preparation (MJ)
E_{p2}	Energy expenditure in plantation for irrigation (MJ)
E_{p3}	Energy expenditure in plantation for fertilizer (MJ)
E_g	Total energy expenditure in growth (MJ)
E_{sh}	Total energy expenditure in growth (MJ)
E_{oe}	Energy expenditure in oil extraction (MJ)
P	Electric power consumption in oil extraction (MJ/ton of seed)
T	Quantity of seed in ton
E_t	Energy expenditure in oil trans esterification (MJ)
E_{ip}	Total input energy (MJ)
M	Mass of biodiesel in ton
E_{op}	Output energy (MJ)
R	Net energy ratio
CV_{bd}	Calorific value of biodiesel (MJ/kg)