Life cycle assessment of biodiesel production from pongamia oil in rural Karnataka

Lokesh Adhappa Chandrashekar[1*], N S Mahesh[1],
Balakrishna Gowda[2], William Hall[3]

(1. *M.S. Ramaiah School of Advanced Studies*, *Bangalore*, *560058*;
2. *Biofuel Park*, *Agriculture Research Station*, *Madenur*, *Hassan*, *573220*;
3. *Faculty of Engineering and Computing*, *Coventry University*, *U.K.*)

Abstract: Pongamia pinnata is one of the promising tree species suitable for providing oil for biodiesel production. This paper addresses the life cycle energy balance, global warming potential and acidification potential, of a small scale biodiesel system, in rural Karnataka. In addition, the system has also been expanded to generation and use of biogas from seed cake for electricity production and evaluated for its environmental impacts. The environmental impacts have been benchmarked with the life cycle impacts of fossil diesel. The results show that non-renewable energy requirement of Pongamia biodiesel system is twenty-eight times lower than that of fossil diesel. A significant increase in global warming potential (GWP) is indicated in Pongamia biodiesel system compared to fossil diesel if wood is used as fuel. GWP would be seven times less if wood is not used as fuel. Acidification and eutrophication potential of Pongamia system was found to be nil. Further, expanding the Pongamia biodiesel system to include biogas production exploits the energy available in the system. It is also observed that one hectare of Pongamia plantation is capable of completely sequestering the CO_2 released during the life cycle with additional sequestration potential up to 1 t CO_2 ha^{-1}. Moreover, the above aspects were significantly superior in Pongamia system when compared to Jatropha biodiesel system.

Keywords: Biodiesel, global warming potential, acidification and eutrophication potential

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1 Introduction

Global warming and swiftly declining crude oil deposits have prompted to explore environment-friendly and renewable source of fuel. Biomass-based fuel such as alcohol, biogas, biodiesel and vegetable oil are found to be possible substitutes for petroleum based fuels.

It is estimated that by 2017, 20% of energy needs of India should be met by biodiesel. To meet this expectation it would require 12 to 13 million ha of biodiesel feed stock plantation. As per government policy of India, biodiesel is to be produced using non-edible oil only. Jatropha tree seed oil is considered to be very suitable candidate for biodiesel production and it has been planned to grow this tree on waste lands across India. (MNRE, 2011)

India has around 63 million ha of waste land, of which only three categories, namely (1) degraded pastures and grazing land, (2) under utilized degraded notified forest land, and (3) degraded land under plantation crop categories totaling to 17 million ha is considered to have the potential for cultivation with crops like Jatropha (DOLR, 2000).

Waste land available in India is rain fed and if Jatropha alone is planted in 17 million hectare, one can obtain an average biodiesel yield of 3.8 million metric ton

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***Corresponding author: Lokesh A. C.,** M.S., Ramaiah, School of Advanced Studies, Bangalore, 560058. E-mail: lokesh@msrsas.org.

(MT). As on Sep 2011 Indian annual diesel consumption was 60 million MT (Business line, 2011) and 20% of 60 million MT diesel amounts to 12 million MT.

It is evident that Jathropa plantation alone can meet only one third of the estimated biodiesel requirement and would require additional 30 million ha of waste land to meet the target of 20% biodiesel.

Studies reveal that Jatropha produces estimated yields in irrigated land than rain fed. (CEB-TNAU, 2008). A majority of the waste land available around villages are grass lands and community forests, which are meant for providing land less, small and medium scale farmers with commodities like fodder, fuel wood, timber and thatching material for homes.

Therefore combination of tree species planted in these wastelands around the villages is very important for the lively hood of the rural poor. If such lands are planted with Jatropha, it is likely to create more hardship to rural community, depriving them of their daily needs, because Jatropha leaves do not serve as fodder and it does not yield enough wood as well.

Hence it is very evident that planting Jatropha as a promising biofuel crop is not a feasible strategy both economically and ecologically. Thus, there is a need to identify alternate local plant / tree species, which can add to the biodiesel feedstock without affecting the local ecology.

In this context various research organisations across the world have been working for more than two decades to identify suitable vegetable oil yielding plant / tree species to produce oil and convert the same into biodiesel. As a result of this work more than 100 tree species have been identified, of which, more than 80 tree species have been identified in India alone. (Girish, 2010)

Pongamia pinnata is one of the promising tree species suitable for providing oil for biodiesel production, which conforms to international standards. This tree species is found to be well spread through out India, excluding temperate regions. Pongamia seeds are known to contain 30%-35% oil. The seed cake available after oil extraction is used as organic fertilizer. This organic fertilizer also serves as a nematicide.

Pongamia tree is a good soil binder and has nitrogen fixing capability, which enriches the soil as well. It is a medium sized tree with a spreading crown (NOVOD Board, 2008). The list of tree borne oil species has been constantly increasing. Many clean development mechanism project developers are interested in exploiting these tree species for meeting challenges of energy supply and green house gas (GHG) emission reduction. With this number increasing, a scientific approach to identify environmentally sustainable tree species is in the wanting. (Rao, 2006)

A vital requirement for bio-fuels to be a sustainable alternative fuels is that, it should be produced from renewable feed stock with a lower negative environmental impact. Consequently a study is needed in order to infer whether above requirements are met. Life cycle assessment (LCA) method has been found to be a suitable for evaluating the environmental impact of biodiesel produced from vegetable oils (Tan, Culaba and Purvis, 2004). In the present paper, LCA study of Pongamia for investigating the environmental sustainability as biofuel feed stock has been presented.

This study is a case specific LCA of a small scale biodiesel production system using Pongamia oil in rural Karnataka. The LCA compares the performance of the Pongamia system with a fossil fuel based reference system. This analysis includes assessing energy in puts, outputs, greenhouse gas emissions, acidification potential and land use change environmental impacts.

2 Methods

The total environmental impact of the complete production system was assessed using LCA according to the standard described by the International Organization for Standardization (ISO 14010/44:2006).

2.1 Goal

This LCA aims at assessing impacts in four impact categories:

1) Non-renewable energy requirement /MJ,

2) Global warming potential /CO_2- eq.,

3) Acidification potential /SO_2- eq.

4) Land use impact on ecosystem quality

In addition to the impacts mentioned above, a life cycle energy analysis was performed. i.e. (i) Net Energy Gain (NEG= energy output – energy input) and (ii) Net Energy Ratio (NER = energy output/energy input) were calculated.

The Life cycle analysis of the Pongamia system included cultivation, oil extraction, esterification, transportation, infrastructure if any and by-products (seed cake, biogas from seed cake and biogas slurry as fertilizer). The data was collected from Agriculture Research Station located at Madenur in Hassan district of Karnataka State. The system boundary conditions proposed (Figure 1) included the usage of by-products and the fuel locally. 1 MJ energy available in Pongamia biodiesel was considered as the functional unit (FU) for life cycle impact assessment. 200 g of pods or 100 g seeds are sufficient to produce 28 g biodiesel = 1 MJ of energy (Figure 1). This study concentrated on the plantations on waste lands and community lands.

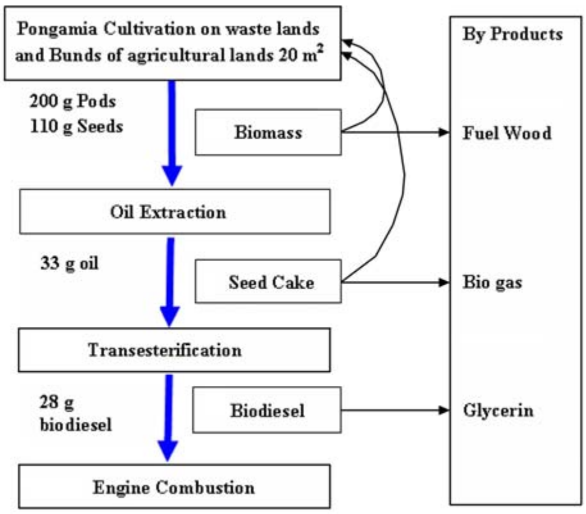

Figure 1 System boundary for Pongamia LCA

Environmental performance of the incorporation of a biogas production has also been modelled and evaluated for Pongamia seed cake. The slurry coming out of the biogas plant has been presumed to be used as organic fertilizer for near by fields. It was assumed that the biogas installation has a CH_4 leakage of around 10% of the gas produced (Eggleston et al. 2006; Pathak et al., 2009). The construction of the biogas unit is not included in the system boundaries, because of its negligible overall impact. The biogas is assumed to be used as engine fuel for electricity and heat generation, which substitutes the use of fossil-based natural gas in the reference system as shown in Figure 2 and Figure 3.

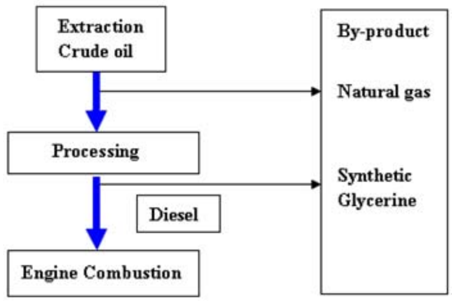

Figure 2 System boundary for Diesel (Reference)

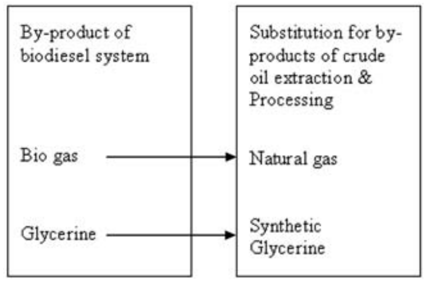

Figure 3 System boundary for substitution

2.2 Life cycle inventory

This LCA study was carried out at Agriculture Research Station (ARS) located at Madenur in Hassan district of Karnataka State, named as Biofuel Park. Biofuel Park project has been successful in establishing 325 Farmers associations for growing biofuel feedstock (seed) called "*Jaivika Indhana Beejagala Belegarara Sangha*" and covers about 57 villages designated as "Complete Biofuel Village" (Girish, 2010).

Hassan is situated 934 meters above mean sea level and located between 12°13′ and 13°33′ North latitudes and 75°33′ and 76°38′ East longitude. This district covers 6,826.15 km^2 and has 2369 villages. The geography is mixed with the mountainous region to the west and south west called Bisle Ghat and the maidan or plains regions in the north, south and east. There are some areas of degraded forest ranges in central portion of the district. (Girish, 2010)

This study focused on Pongamia plantations on waste lands, degraded lands agricultural land bunds and boundary conditions for the LCA studies are as shown in Figure 1.

2.3 Data collection

The data was collected from Biofuel park offices followed by personal interviews and interaction with farmers associations. Automobile emission data collected from literature and Automotive Research Association of India-Pune was used. System-specific data (e.g. fertilizer use) were collected from Biofuel park records while general (e.g. field emission rates: N_2O: 1%, NH_3: 10% and N leaching: 30% of applied N were taken from IPCC default factors), background data (e.g. production impact of fertilizer) were collected from literature and databases. The factors considered in this study are given in Table 1. (Cultivation, oil extraction, biodiesel production and end use on the basis of per production phase).

The means by which inputs were transported to the system and intermediate outputs transported between different systems phases also need to be accounted for. The transport distances of the seedlings, fertilizers, seeds, equipment and machines were collected by interaction with farmers understanding their agronomical practices. Table 1 shows information collected for Pongamia LCA studies from Biofuel Park Hassan through records available at park, interaction with farmers and field observations.

Table 1 Information collected for Pongamia LCA studies from Biofuel Park

Cultivation	Data
Nursery practices	Poly-bag use, water use, fertilizer use, machinery use
Field Preparation	Machinery Use
Field in puts	Seedlings per hectare, fertilizer use
Plantation management	Irrigation, fertilizer, weeding and harvest practices
Yield	kg seeds / ha / yr
Origin of inputs	Machinery, fertilizer
Transport distances	Machinery, fertilizer, Seeds
Oil Extraction	**Data**
Extraction rate	Oil % / kg seed
Oil press	Capacity and energy consumption
Filter Press	Capacity and energy consumption
By-product & use	Seed cake/ kg of seed
Biodiesel production	**Data**
Transesterification practices	Reagents and catalyst use
By-product use	Glycerine

The Table 2 shows factors considered in the LCA of Pongamia biodiesel for combustion in an engine per production phase per impact category.

Table 2 Factors considered in the LCA of Pongamia biodiesel

Non-Renewable Energy Requirement (NRER)		
Cultivation	**Oil Extraction**	**Biodiesel Production**
Poly bags production	Oil press production	Transesterification unit production
Diesel production and use	Electricity production and use: - oil press & - filter press	Production methanol
Electricity production and use		Production catalyst (NaOH)
		Electricity production and use:- - transesterification unit
Global Warming Potential Caused by Greenhouse Gas Emissions (CO_2, CH_4 & N_2O) [CO_2-eq]		
Cultivation	**Oil Extraction**	**Biodiesel Production**
Poly-bags production	Electricity production and use:- oil press & - filter press	Methanol production
Burning waste poly-bags	Biogas leakage	Electricity production and use: - transesterification unit
Fertilizer production		Biodiesel Combustion in an Engine
Fertilizer application -organic & inorganic		
Diesel production and use		
Electricity production and use		
Acidification Potential Caused by NH_3, NO_X and SO_X Emissions [SO_2-eq]		
Cultivation	**Oil Extraction**	**Biodiesel Production**
N volatilization	Electricity production and use - oil press & - filter press	Electricity production and use - transesterification unit
Poly bag burning		Biodiesel Combustion in an Engine
Diesel use		

2.4 Fossil fuel as reference system

For a suitable life cycle comparison, the fossil fuel reference system must provide the same products and functions as the Pongamia biodiesel system / the biodiesel system evaluated. Hence, all products and by-products of the biodiesel system should be substituted in the reference system. The substitutions reflect the local situation. Glycerine was considered the only by-product because the other by-products are ploughed back to the field as soil enrichment and are not system outputs. In the reference system the glycerine is substituted by synthetically produced glycerine of similar quality and biogas produced from seed cake is substituted for Natural gas (Wicke et al. 2008; Wouter et al. 2009).

3 Results and discussion

3.1 Production system

This section portrays the study of production system, based on the data collected from Biofuel Park at Madenur in Hassan district of Karnataka State. Seedlings are raised using poly bags in the nursery. Seeds are planted in a mixture of local compost and soil and are watered manually. Planting pits are dug on waste lands and agriculture field bunds for transplanting. Normally seedlings are planted at distance of 40 to 50 feet on bunds and number of seedlings planted depends on the type of field and farming practices of the crop grown in those fields. If the planting is carried out on waste land/ degraded lands/ silvicultural land 300 to 330 seedlings can be accommodated per hectare. Pongamia is a very hardy tree and it can establish successfully in almost all kind of soil due its nitrogen fixing capabilities. Hence any extra inorganic or organic fertilizers application is not practiced. Just to support seedling establishment in the initial stage, application of farm yard manure at the rate of 2 to 3 kg per pit is practiced. After plantation establishes no fertilizers are used since the tree has nitrogen fixing capability in its root zone. The trees establish very well in southern India with the prevailing rainfall and start yielding from 5^{th} year onwards and reach its peak yield from 10^{th} to 15^{th} years. An average seed yield of about 3 to 5 t ha^{-1} is obtained from 10 year old plantation. Life span of Pongamia tree is considered way above 80 years.

The extraction unit contains an electric screw press and a filter press and yields 270 to 300 kg crude Pongamia oil per 1,000 kg seed. During transesterification 20 kg of methanol and 0.80 kg NaOH is used per 85 kg (100 L) Pongamia oil. The reaction takes place in a heated tank (60-80℃) and yields about 15-16 kg glycerine and 85 to 90 L of biodiesel. (The glycerine is assumed to be sold in the market for soap making etc)

3.2 Energy analysis

3.2.1 Non-renewable energy requirement

For production and use of one Functional Unit (FU) of Pongamia biodiesel an average 45 kJ of non-renewable energy is required, which is twenty eight times less compared to reference system (fossil fuel system) i.e. approximately 1,250 kJ/FU (Wouter et.al 2010). The oil extraction (43%) and transesterification (53%) steps are the biggest contributors to the energy requirement. The major contribution of the transformation (oil extraction & esterification) process to the overall energy balance of the system confirms findings of Jatropha and Palm oil LCA studies (Krishan et al., 2011; Wouter et al., 2010; Kian et al., 2009). The cultivation phase represents only 4% of the non renewable energy requirement of the life cycle (203.21 MJ), which is very low compared to other biodiesel production systems, due to very little fertilizer inputs. In the oil extraction phase, electrical energy produced with fossil fuel to operate expeller and filter press is found to be the largest contributor (67% i.e. 57.74 MJ) followed by oil press production.

In the esterification phase methanol production and use contributes to highest energy consumption (47% i.e. 50.25MJ) followed by transesterification (32% i.e. 21.09 MJ) and manufacturing of esterification unit (20% i.e. 21.09 MJ).

Over the whole life cycle, construction and maintenance of machinery accounts for 25% of the total NRER, while transportation contributes 3%. This contribution is low compared to Palm oil LCA (Kian et al., 2009) since it has low levels of inputs and aims at local use of the products. This results in low transportation distances, both for bringing inputs to the system and for distributing outputs to the market. The data for calculating NRER has been compiled from "The Intergovernmental Panel on Climate Change" database (Table 3).

Table 3 Non-renewable energy requirement in MJ for pongamia LCA

Cultivation	MJ	FU^{-1}
Tractor production	NA	
Infrastructure: farm shed	NA	
Poly bags production	1.06	
Fertilizer production	NA	
Diesel production and use	7.16	
Electricity production and use	NA	
Sub Total	8.22	0.002

Oil Extraction	MJ	FU^{-1}
Oil press production	29.08	
Electricity production and use: oil press Filter press	57.74	
Sub Total	86.82	0.019
Biodiesel Production	**MJ**	**FU^{-1}**
Transesterification unit production	21.09	
Production of methanol	50.25	
Production of catalyst (NaOH)	1.65	
Electricity production and use: -- transesterification unit	35.18	
Sub Total	108.17	0.024
Grand Total	203.21	0.045

3.2.2 Net energy gain and net energy ratio

It can be observed (Table 4) that out of 2,948.76 MJ of energy consumed by Pongamia system. Of which, 41% of energy is used up in cultivation phase, 23.35% from oil extraction and 26% from esterification phase. Major portion of energy consumption comes from usage of diesel fuel, which can be minimised by localisation and use renewable source of energy.

Energy out puts has been calculated for three scenarios i.e. biodiesel production along with seed cake as fuel (Table 5), biodiesel production and biogas generation from seed cake (Table 6) and biodiesel production and use of biogas for heat and electricity generation (Table 7). Based on these outputs the net energy gain and ratio have been calculated. It is observed that energy output from cultivation phase is comparatively high due to usage of wood as fuel. Energy output reduces by 4% (Table 6) when biogas is generated from seed cake and 5% (Table 7) when biogas is used for electricity and heat generation compared to energy output from biodiesel production.

Table 4 Energy inputs in pongamia system

Cultivation Phase	Quantity $Year^{-1}$ ha^{-1}	Unit	Calorific* value/MJ	Energy /MJ	Energy /MJ · FU^{-1}
Man power	15.00	Man days	10.00	150.00	
Diesel	22.00	L	37.50	825.00	
FYM	600.00	kg	0.03	18.18	
Poly bag usage	330.00	Numbers	0.69	229.28	
Sub total				1222.46	0.27
Oil extraction phase					
Man power	6.00	Man days	10.00	60.00	
Diesel	11.00	L	37.50	412.50	
Electricity used	60.00	kWh	3.60	216.00	
Sub Total				688.50	0.15
Esterification phase					
Man power	4.00	Man days	10.00	40.00	
Electricity used	34.00	kWh	3.60	122.40	
NaOH	1.70	g	23.30	39.61	
H_2SO_4	0.34	L	3.00	1.02	
Acetic acid	0.34	L	13.00	4.42	
Methanol	42.50	L	13.23	562.28	
Sub Total				769.73	0.17
Total				2680.69	0.05
Miscellaneous energy inputs (assumption 10% of total energy)				268.07	0.06
Grand total				2948.76	0.66

Note: *Calorific values adopted are universal;

*1MJ of energy produced = 28g of biodiesel = 33 g of oil = 110 g of seeds = 200 g of Pods;

*Therefore input energy required for producing 0.2 kg (1MJ of Energy) = 0.2kg×2948.6/900 kg = 0.66 MJ FU^{-1};

*Pod yield ha-1 from a 6 year old plantation is 900 kg.

Energy output from Pongamia system is follows:

Table 5 Energy Outputs from pongamia system

Energy	Quantity $Year^{-1}$ ha^{-1}	Unit	Calorific value in MJ **	Energy in MJ	Energy in MJ FU^{-1}	Reference**
Cultivation Phase						
Pod shell	414	kg	15	6210		Subbarao 2010
Seed	504	kg		0		
Fuel wood	3000	kg	19.25	57750		James 1983
Sub total				63960	13.93	
Oil Extraction						
Oil	141.12	kg				
Seed cake	327.60	kg	14.30	4684.68		Subbarao 2010
Sub total				4684.68	1.02	
Esterification						
Biodiesel	119.95	kg	36.50	4378.24		B. Baiju et al 2009
Glycerine	75.60	kg	18.50	1398.60		Kian et al 2009
Sub total				5776.84	1.26	
Grand total				74421.52	16.21	

If Seed cake is used to produce biogas the energy output is as follows:

Table 6 Energy outputs from pongamia system (Biogas)

Energy	Quantity Year^{-1} ha^{-1}	Unit	Calorific value in MJ **	Energy in MJ	Energy in MJ FU^{-1}	Reference**
Cultivation Phase						
Pod shell	414	kg	15	6210		Subbarao 2010
Seed	504	kg		0		
Fuel wood	3000	kg	19.25	57750		James 1983
Sub total				63960	13.93	
Oil Extraction						
Oil	141.12	kg				
Biogas from seed cake	78.60	m^3	22	1729.20		Anonymus 2012 & Chandan 2004
Sub total				1729.20	0.38	
Esterification						
Biodiesel	119.95	kg	36.50	4378.25		B. Baiju et al 2009
Glycerine	75.60	kg	18.50	1398.60		Kian et al 2009
Sub total				5776.85	1.26	
Grand total				71466.05	15.57	

If biogas is used to produce heat and electricity the energy output is as follows:

Table 7 Energy outputs from pongamia system (heat and electricity from Biogas)

Energy	Quantity Year^{-1} ha^{-1}	Unit	Calorific value in MJ **	Energy in MJ	Energy in MJ FU^{-1}	Reference**
Cultivation Phase						
Pod shell	414	kg	15	6210		Subbarao 2010
Seed	504	kg		0		
Fuel wood	3000	kg	19.25	57750		James 1983
Sub total				63960	13.93	
Oil extraction						
Heat from biogas	78.60	m^3	8.64	679.104		
Electricity from bogas	78.60	m^3	4.32	339.552		Anonymus 2012 &Chnadan 2004
Sub total				1018.656	0.22	
Esterification						
Biodiesel	119.95	kg	36.50	4378.24		B. Baiju et al 2009
Glycerine	75.60	kg	18.50	1398.60		Kian et al 2009
Sub total				5776.84	1.26	
Grand total				70755.50	15.42	

3.2.3 Net energy gain and net energy ratio from various scenarios

As observed from Table 8, net energy gain (15.56 MJ) is found to be very high compared to Jatropha system (i.e. 1,887 kJ = 0.1887 MJ) analyzed by Wouter et.al 2009. This may be due to consideration of pod shell and wood. Addition of Honey and green biomass as out put will increase net energy gain considerably. Net energy ratio is found to be very high as well (i.e. 24.74 MJ), which is very encouraging for recommending Pongamia as a promising biodiesel feed stock.

Net energy gain is the energy available after total energy output is deducted from total energy input.Net energy ratio is the ratio of total energy output to total energy input.

In the study where the system is expanded to include a biogas installation (Table 6), the NEG decreases to 14.91 MJ/FU and the NER to 23.76 MJ followed by further decrease in NEG to 14.76 MJ and NER to 23.52 MJ if biogas is employed for electricity generation

(Table 7). These results show that including biogas production from seed cake considerably enhances the energy efficiency of the Pongamia biodiesel system; in addition to the bio gas slurry is available for use as organic fertilizer. This slurry is found to have slightly lower nutrient content (2.39 % N, 0.43 % P and o.31% K), than oil cake (4% N, 0.9% P & 1.3% K) which is still a bonus for farmers after generating biogas. This argument stands good with reference to the Pongamia system, which uses seed cake as a fuel or using seed cake directly as organic fertilizer (Which is a very common practice than using it as fuel). Direct use of seed cake as fertilizer results in leaching losses and efficiency of Nitrogen utilization drastically reduces. However in a biogas plant, the organic nitrogen in the seedcake is mineralised to ammonium (NH^+) and nitrate (NO_-^3). The nitrogen is hereby made available for the plants, and the short term fertilizer value is doubled. Research on usage of biogas slurry in vegetable and other crops has shown significant results of better growth and yield (Jit, 1987). Hence using seed cake to generate biogas considerably increases the nitrogen availability to plants in the form of digested slurry, which has nitrogen in a ready to absorb form compared to seed cake and as well generate energy.

Table 8 Net Energy Gain and Net Energy Ratio

Item	Total Energy input in MJ FU^{-1}	Biodiesel Production	Biodiesel+ Seed cake as fuel	Biodiesel + Biogas from seed cake	Biodiesel + Biogas from seed cake for electricity and heat generation
	0.66				
Net energy gain/MJ		1.09	15.56	14.91	14.76
Net energy ratio		7.36	24.74	23.76	23.52

3.3 Global warming potential (GWP)

The data w.r.t. different phases of LCA were collected form field studies at Biofuel Park and associated CO_2 emissions were collected from literature and multiplied with collected data, which has been referenced. CO_2 emissions for methanol and electricity production have been directly adopted from Wouter et al 2009. It can be observed from Table 9 that usage of wood as fuel adds to highest CO_2 emission from Pongamia system and cultivation phase in particular. Biogas (Methane) leakage also results in higher emission compared to combustion of biogas in an engine coupled to dynamo (Genset) for electricity and heat generation.

Table 9 Greenhouse gas emissions- CO_2

Particulars	Quantity $Year^{-1}$ ha^{-1}	Unit	CO_2**	Unit	g CO_2 eq ha^{-1}	g CO_2 eq FU^{-1}	References**
Cultivation Phase							
Poly-bags production & discharge	1.65	kg	5.50	kg	9075.00		Juerg 2009 & Graffman 2011
Organic Fertilizer application 1 t (N_2O Emission)	6.00	kg	0.01	kg	60.00		PCC-ID:1622
Fuel Wood	3000	kg	0.44	kg	1320000		Daniel 1992
Diesel Use	140	km	0.33	Kg km^{-1}	46620		ARAI 2007
Sub Total					1375755	305.72	
Oil Extraction Phase							
Electricity production and use: - oil press + Filter press					74800		Wouter et al 2010
Biogas leakage	786.24	L	0.71g	L	12839.30		Wouter et al 2010
Biogas Combustion in an Engine	339.55	kWh	0.77	kg kWh	55.92		K Suresh et al 2008
Sub Total					87695.22	19.49	
Biodiesel Production							
Methanol production					2992.00		Wouter et al 2010
Electricity production and use: - transesterification unit					74800.00		Wouter et al 2010
Biodiesel Combustion in Engine (B100)	119.95	kg	20.90	g kg	2507.00		Martin et al 2005
Sub Total					80299.00	17.84	
Total					1543749.22	343.06	

The Pongamia biodiesel system showed an emission of 343 g CO_2-eq FU^{-1} (Ref Figure 3), which is 1.25 times more compared to the reference system (i.e. Fossil fuel = 280g CO_2-eq)

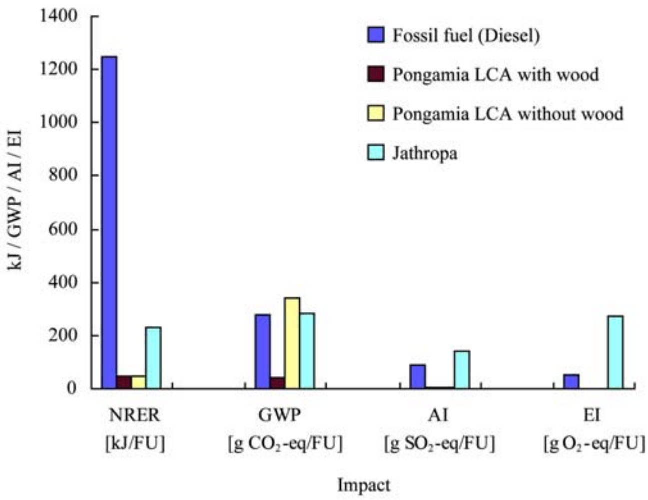

Figure 4 Comparison of Pongamia biodiesel production with Diesel and Jatropha biodiesel w.r.t. NRER, GWP, AI and EI FU^{-1}

The cultivation phase is the biggest contributor for CO_2 emission in the system (89%), and the majority of these emissions are due to burning of fuel wood. If wood is not harvested for fuel purpose GWP is be found to be seven times lesser than references systems (Figure 4). Since very little inorganic fertilizer is used in the system the CO_2-eq FU^{-1} is found to be four times less compared to Palm oil system.

For Indian waste lands the average annual CO_2 sequestration rate in the standing biomass per ha is estimated to be 2.25 t CO_2 ha^{-1} $year^{-1}$. Estimates from ICRISAT – Hyderabad (Sridevi and Wani, 2009) show carbon sequestration capacity of 74 kg from a ten year old tree. The amount of CO_2 released by Pongamia system (1.5 t ha^{-1}) can be sequestered by Pongamia trees of standing biomass of waste land and still can absorb 0.5 to 1 t of CO_2, which is very encouraging.

3.4 Acidification potential (AP) and eutrophication potential (EP)

The Pongamia system showed a drastic decrease in AP of 90% compared to the reference system. The biggest contribution is made during the biogas combustion in an engine, where 96% of the total AP is associated with SOx and NOx from biogas combustion, which still is very negligible or may be considered nil compared to Jatropha (Wouter et al. 2010), Soya, rapeseed biodiesel system (Cherubin et al., 2009). Eutrophication potential has not been considered since inorganic fertilizer and pesticides are not used in the system and in view of the fact that acidification potential results are quite negligible. From the above graph (Figure 4) it is quite evident that energy and environmental foot print of Pongamia is very less compared to fossil fuel and Jatropha biodiesel system. Hence Pongamia can be recommended as an ecologically friendly tree or tree which has very little global warming potential

Table 8 Greenhouse gas emissions- SO_2

Particulars	g SO_2- eq ha^{-1}	g SO_2- eq FU^{-1}	Reference
Cultivation			
N volatilization (NH_3)	0.94		ELV 2000
Poly bag Production & Discharge- SO_2	117.81		Juerg 2009 & Graffman 2011
Poly bag Production & Discharge- Nox	207.90		Juerg 2009 & Graffman 2011
Diesel use- Nox	91.14		ARAI 2007
Sub total	417.79	0.08	
Oil Extraction			
Electricity production and use- Oil press + Filter Press	66.68		IPCC-ID1622
Biogas Combustion in an Engine	15238.08		K Suresh et al 2008
Sub total	15304.76	2.81	
Biodiesel Production			
Electricity production and use- transesterification unit	711.24		IPCC- ID417274
Biodiesel Combustion	0.15		B.Baiju et al 2009
Sub total	711.39	0.13	
Grand total	16433.94	3.02	

4 Conclusion

The non-renewable energy requirement of Pongamia biodiesel system (45 kJ/FU) was found to be twenty-eight times lower than fossil fuel (1,250 kJ/FU) reference system and five times lesser than Jatropha biodiesel system (220 kJ/FU). In addition, Pongamia biodiesel system shows a higher global warming potential by 1.25 times compared to Fossil fuel system (280 g CO_2-eq) and Jatropha biodiesel system (283 g CO_2-eq). If fuel wood is avoided, GWP reduces by 6 times (40 g CO_2-eq) compared fossil fuel and Jathropa biodiesel system. Acidification and eutrophication potential of Pongamia system was found to be nil compared to Fossil fuel (90 g SO_2-eq & 50 g O_2-eq) and Jatropha biodiesel system (140 g SO_2-eq & 275 g O_2-eq). Expanding the Pongamia biodiesel system with biogas production exploits the energy available in the system. It is also observed that one hectare of Pongamia plantation is quite competent in sequestering the CO_2 released (1.5 t ha^{-1}) during the life cycle and extend its capabilities to further sequester about 1 t CO_2 released into atmosphere from other systems. As inorganic fertilizer application is completely nil in this system eutrophication potential of the system is also very little. Unlike Jatropha, which has been debated to invade cultivable land and create food fuel conflict, Pongamia's invasion into cultivable land as main crop is ruled out because of its perennial nature with life span way above 90 to 100 years. While Pongamia system for local use shows some hopeful results, the complete sustainability of this system can be addressed provided socio economic viability and land use change (LUC) of Pongamia biodiesel system is evaluated.

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