STUDY ON SUSTAINABILTY OF MADHUCA BIODIESEL

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Abstract

Madhuca 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 ecological impact of a small scale biodiesel production in rural Karnataka.The environmental impacts have been benchmarked with the life cycle impacts of fossil diesel. Net Energy Gain has been found to be 17.17 MJ / functional unit. Global warming potential (GWP) was found to be (38.45 gCO_2-eq) seven times less than fossil diesel. Acidification and eutrophication potential of Madhuca system was found to be insignificant. It is also observed that one hectare of Madhuca plantation is capable of completely sequestering the CO_2 released during the life cycle (0.2 t CO_2 / hectare) with additional sequestration potential up to 5.8 t CO_2 / hectare. Moreover, the above aspects were significantly superior in Madhuca system when compared to Jatropha biodiesel system and on par with Pongamia biodiesel system. Further, it has been concluded that biodiesel production from Madhuca oil is ecologically viable.

Keywords: Madhuca biodiesel, Global warming potential, Acidification potential and Ecological impact

Abbreviations

AP	Acidification Potential
ARS	Agriculture Research Station
ARAI	Automotive Research Association of India,
EFQ	Ecological Functional Quality
ESQ	Ecological Structural Quality
FAO	Food & Agricultural Organisations
FU	Functional Unit
GHG	Green House Gas
GWP	Global Warming Potential
kJ	Kilo Joule
LCA	Life Cycle Analysis
LUC	Land Use Change
LUO	Land Use Occupation
MJ	Mega Joule
IPCC	Intergovernmental Panel on Climate Change

1. INTRODUCTION

Madhuca commonly known as the butter nut tree is a large sized deciduous trees growing up to a height of 20m distributed in Nepal, India and Sri Lanka. It is commonly known as Mahua in Hindi, Mohwa in Marathi, Ippa in Telugu, Ippi in Tamil and Heppe in Kannada. It is a large shady tree doting much of the central Indian landscape, both wild and cultivated [1].

Madhuca is a widely adaptable tree, which can be grown on wide variety of soils. Being a hardy tree, it thrives well on rocky, gravely red soil and tolerant to moderately saline and sodic soils. It even grows in pockets of soil between crevices of barren rock. For better growth and productivity, well drained deep loam or sandy loam soils are ideal. A large variability exists in its fruits and oil percentage and there are no varieties available for block plantation [2].

It is one of the promising tree species suitable for providing oil for biodiesel production, which conforms to international standards. Oil percentage in Madhuca seed varies from 35 to 45% and it is pale yellow in colour. It has a pleasant odour and taste; hence it is used as edible oil by few tribes in North India. The oil solidifies at room temperature hence the tree gets the name 'Indian butter tree" [3].

Madhuca seed cake is mainly used as detergent and organic manure. It is also known to have insecticidal and pesticidal properties, hence used as manure for lawns to act against earthworms [2]. Smoke produced from burning the seed cake is known to kill rats and insects. Powder of Madhuca seed cake is used along with soap nut powder for hair wash [4].

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 found to be need of the hour [5].

A vital requirement for bio-fuels to be a sustainable alternative fuel is that, it should be produced from renewable feedstock with a lower negative environmental impact. Consequently, a study is needed in order to conclude, whether above requirements are met. Life cycle assessment (LCA) method has been found to be suitable for evaluating the environmental impact of biodiesel produced from vegetable oils [6].

This paper addresses' an exclusive LCA of a small-scale biodiesel production system using Madhuca oil in rural Karnataka. The LCA compares the performance of the Madhuca system with fossil fuel and Jatropha biodiesel.

2. MATERIALS AND METHODS

The Madhuca biodiesel system was assessed using LCA method according to the International Organization for Standardization procedures [7]. The objective of this LCA study was to assess the sustainability of biodiesel production form Madhuca oil, for different life cycle stages and the overall life cycle under following impact categories:

- Global Warming Potential (CO_2-eq)
- Acidification Potential (SO_2-eq)
- Energy Input and Output analysis (MJ)
- Impact of land use change on ecosystem quality

This analysis focuses on studying the use of Madhuca biodiesel as a rural source of energy for transportation / water pumping / electricity generation.

2.1 Life Cycle Inventory

The life cycle analysis of the Madhuca system included cultivation, oil extraction, esterification, transportation and by-products. The system boundary conditions proposed (Figure 1) included the usage of by-products and the fuel locally. 1MJ energy available in Madhuca biodiesel was considered as the functional unit (FU) for life cycle impact assessment. This study concentrated on the plantations on wastelands and community lands.

This LCA study was carried out at Agriculture Research Station (ARS) located at Madenur in Hassan district of Karnataka State, named as ‘Biofuel Park’. This study focused on Madhuca plantations on wastelands, degraded lands and agricultural land bunds. The boundary conditions of LCA studies of Madhuca biodiesel in comparison with fossil fuel has been depicted in Figure 1, 2 and 3 respectively.

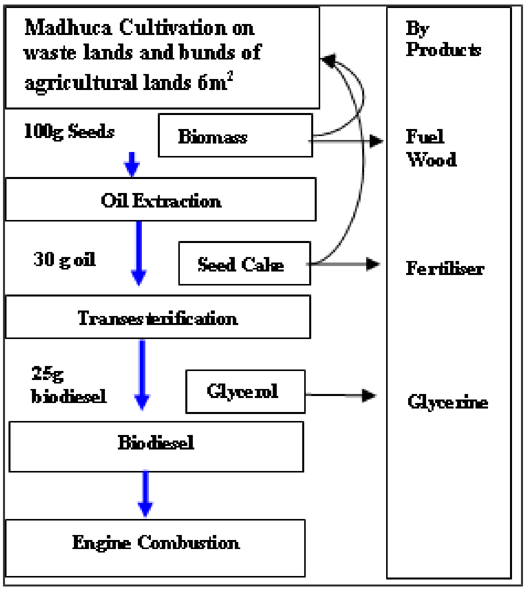

Fig. 1 System boundary for Madhuca LCA

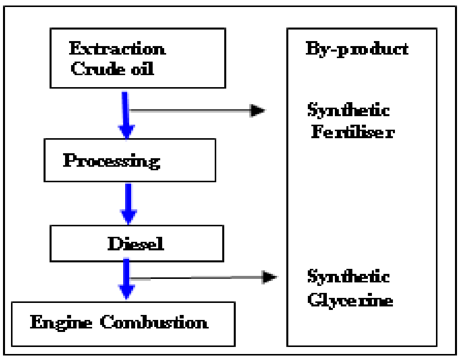

Fig. 2 System boundary- Diesel

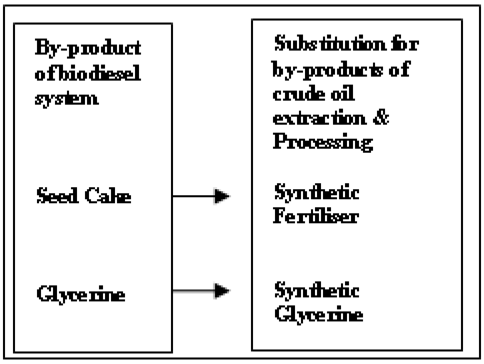

Fig. 3 System boundary for substitution

2.2 Data Collection

The data was collected by personal interviews and interaction with farmers associations (50 farmers) for calculating the global warming potential, acidification potential and energy input and output (MJ)

To assess the global warming potential and acidification potential of the neem system, the associated input factors mentioned in Table 1 were considered and duly assessed. System-specific data (e.g. fertilizer use) were collected from Biofuel Park records. General data (e.g. field emission rates: N_2O, NH_3 and N leaching from fertilizers applied to soil were taken from IPCC default factors and FAO [8, 9]. Background data (e.g. production impact of fertilizer) were collected from literature and databases. Automobile emission data was collected from literature and reports of automotive research association of India, Pune [10].

The data pertaining to energy inputs and outputs were collected from Biofuel Park. The means by which, inputs were transported to the system and intermediate outputs transported between different systems phases have been accounted for. The transport distances of the inputs (seedlings, fertilizers, seeds, equipment and machines) were collected by interacting with farmers, understanding their agronomical practices

2.3 Fossil Fuel as Reference System

For a suitable life cycle comparison, the reference system (fossil fuel) must provide the same products and functions as the biodiesel system evaluated [11]. 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 (Figure 1). In the reference system the glycerine is substituted for synthetically produced glycerine of similar quality (Figure 3).

3. RESULTS AND DISCUSSION

3.1 Energy Analysis

For production and use of one FU of Madhuca biodiesel an average 0.58MJ (580 kJ) of energy is required (Table 1), which is 12 % less compared to Pongamia System [5].

Table 1. Energy inputs in Madhuca System

Cultivation Phase		
	Energy – MJ	**Energy - MJ / FU**
Man power	110	
Diesel	825	
FYM	18.18	
Poly bag usage	141.73	
Sub Total	1094.91	0.20
Oil Extraction Phase		
Man power	60	
Diesel	412.5	
Electricity used	216	
Sub Total	688.50	0.13
Esterification Phase		
Man power	40	
Electricity used	457.2	
NaOH	37.28	
H_2SO_4	0.97	
Acetic Acid	4.21	
Methanol	535.82	
Sub Total	1075.47	0.20
Total	2858.89	
Miscellaneous Energy inputs (Assumption 10 % of Total Energy)	285.88	0.05
Grand Total	3144.78	0.58

*1MJ of energy produced = 25g of biodiesel = 30g of oil = 100g of seeds

*Therefore input energy required for producing 0.1kg seed= 0.1kg x 3144.78/540 kg = **0.58MJ**

Energy output per functional unit is found to be 17.17MJ / FU (Table 2) and 10 % higher than Pongamia system. Net energy gain is also very high i.e. 17.17 MJ / FU compared to Jatropha system analyzed by Achten et. al.) [13] (188 kJ/FU). Net energy ratio is found to be very high as well i.e. 30.49 (Table 3).

Table 2. Energy outputs from Madhuca System

Cultivation Phase	**Energy - MJ**	**Energ y - MJ / FU**	**References**
Seed	0		
Wood	90000		[4]
Sub Total	90000	16.67	
Esterification Phase			
Biodiesel	5425.38		
Glycerine	449.55		[12]
Sub Total	5874.93	1.09	
Grand Total	95874.93	17.75	

Table 3. Net energy gain & Net energy ratio

	Biodiesel	**Total system**
Energy input / FU	0.2	0.58
Net Energy Gain	0.89	17.17
Net Energy Ratio	5.46	30.49

3.2. Global Warming Potential (GWP)

The Madhuca biodiesel system showed an emission of 34.8g CO_2-eq / FU (Table 4), which is 8 times less compared to the reference system (i.e. fossil fuel - 280g CO_2-eq analyzed by Achten et al [13]). The biodiesel production phase is the biggest contributor in the system (39%), followed by oil extraction (36%) and cultivation (25%). Madhuca tree wood is not harvested for fuel wood; hence, CO_2 emission at cultivation phase is the least when compared to Pongamia cultivation [5]. Since very little inorganic fertilizer is used in the system, the GWP is 6 times less compared to Palm oil [12] and by 4 times less compared to Jatropha system [13], which uses a considerable amount of inorganic fertilizer for better yield.

As per calculations, a five year old Madhuca plantation has a sequestration capacity of about 6 t/ ha / year (and fifteen year old plantation has a sequestration capacity of 38 t /ha /yr). The amount of CO_2 released by Madhuca system is (0.2 tons/ ha) can be sequestered by Madhuca trees of standing biomass of waste land and still can sequester surplus 5.8 ton of CO_2.

Table 4. Greenhouse gas emissions- CO_2

Cultivation Phase	Energy - MJ	Energy - MJ / FU	References
Poly-bags production & discharge	5500		[14,15]
Organic Fertilizer application -1 t (N_2O Emission)	60		[8,9]
Diesel Use	46620		[10]
Sub Total	52180	9.66	
Oil Extraction Phase			
Electricity production and use: - oil press + Filter press	74800		[13]
Sub Total	74800	13.85	
Esterification Phase			
Methanol production	2992		[13]
Electricity production and use: - transesterification unit	74800		[13]
Biodiesel Combustion in Engine (B100)	2877.9		[17]
Sub Total	80669.9	14.94	
Total	207649.9	38.45	

3.3 Acidification Potential (AP)

The Madhuca system showed a drastic decrease in AP (95%) compared to the reference system. The biggest contribution is made during the diesel combustion for transportation during cultivation phase (Table 5), which still is very negligible compared to Jatropha [13] and Palm oil [12].

Table 5. Total SO_2 equivalent emission from Madhuca system

Cultivation Phase	g SO_2- eq / ha	g SO_2-eq / FU	References
N volatilization (NH3)	0.29		[18]
Poly-bag Production & Discharge-SO_2	71.4		[19,20]
Poly-bag Production &Discharge-NOx	126		[19,20]
Diesel use-NOx	91.14		[10]
Sub Total	288.83	0.05	
Oil Extraction Phase			
Electricity production and use- Oil press + Filter Press	66.68		[8]
Sub Total	66.68	0.01	
Esterification Phase			
Electricity production and use-transesterification unit	141.14		[9]
Biodiesel Combustion	0.14		[21,22]
Sub Total	141.28	0.02	
Grand total	496.79	0.09	

3.4 Land Use Change

The use of land for a given purpose may change its quality in terms of life support or potentiality for other land use.

As a part of Madhuca biodiesel LCA, land use change and its ecological impact studies were carried out. The impact percentage of planting Madhuca on waste land and agricultural land bunds showed that both land use change (LUC) and Land use occupation impact (LUO) with respect to ecological structural quality and functional quality were very little (Figure 4 & 5).

This indicates that Madhuca being a local tree species similar to Pongamia has very little impact on local ecology. Ecological impact calculation per functional unit also reveals that, planting Madhuca trees on waste land and agricultural land bunds has activated an improvement in ESQ impact of -44.13% and EFQ impact of 0.27% with respect to LUC / FU (Figure 4 & 5).

The improving ESQ means that the Madhuca plantation has a higher storage capacity in terms of biomass, structure and biodiversity than the wasteland. The neutral EFQ means that the Madhuca plantation has control over water, organic matter and nutrient fluxes similar to that of wasteland. This is because Madhuca serves as better soil binder with well spread root system, which is capable of holding soil intact and promote better water percolation and nutrient uptake. Vesicular-arbuscular mycorhizal associations and root colonization have been observed in Madhuca [3], which are capable of fixing nitrogen from atmosphere in its root zone and enhance soil fertility and nutrient flux However, growth rate of Madhuca is very low. Hence, EFQ impact with respect to LUC remains to be neutral or very similar to wasteland.

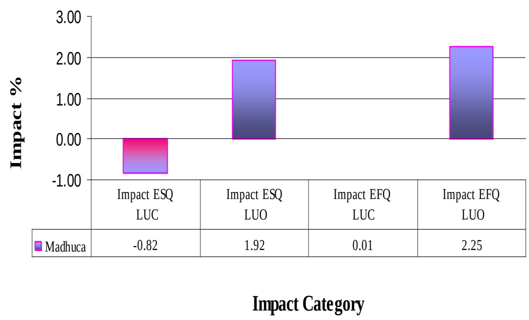

Fig. 4 Madhuca ESQ and EFQ

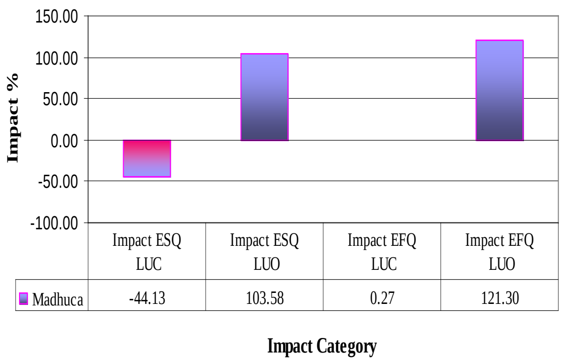

Fig. 5 Impact of Madhuca on ESQ and EFQ per functional unit

The land occupation impact of Madhuca shows an ESQ reduction of 103.58% and an EFQ reduction of 121% compared to the potential natural vegetation (Figure 5) These land use impacts apply to 6 m^2 * (9yr) / FU.

4. CONCLUSION

It can be concluded that in the prevailing economic scenario (Rs 90 / kg of Madhuca oil in open market), biodiesel production from Madhuca feedstock is ecologically viable and economically unviable.

However, Madhuca shall be available for biofuels, once the production starts increasing and their traditional markets get saturated.

Unlike Jatropha, invasion of Madhuca and Pongamia's into cultivable land as main crop is ruled out because of its perennial nature with life span above 100 years. Hence, this tree serves as a sustainable biodiesel feedstock, which can be encouraged to be grown on agriculture land bunds, street sides and waste lands to supplement agro practices of farmers. A well-planned and executed agro practice along with Madhuca plantations shall make significant contribution to local energy needs at rural level.

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