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Studies on biodiesel production from local tree species oil and consequent ecological impact in rural Karnataka

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Studies on Biodiesel Production from Local Tree Species Oil and Consequent Ecological Impact in Rural Karnataka

By

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CERTIFICATE

This is to certify that the PhD Dissertation titled "Studies on Biodiesel Production from Local Tree Species Oil and Consequent Ecological Impact in Rural Karnataka" is a bonafide record of the work carried out by Mr. Adappa Chandrashekar Lokesh, in partial fulfilment of requirements for the award of Degree of Doctor of Philosophy, of Coventry University

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ABSTRACT

The Government of India has planned to substitute 20% (12-15 million metric tonnes) of fossil diesel with biodiesel, produced using non-edible oils by 2017. In addition to Jatropha, more than 300 species of oil-bearing trees have been identified as biodiesel feedstock in India, of which, around 80 species inhabit Karnataka state. The key issue is to analyse whether these biodiesel feedstock are ecologically and economically sustainable.

This dissertation attempts to address this issue by carrying out a Life Cycle Analysis (LCA) on viability of biodiesel production from tree borne oils in comparison to Jatropha and fossil diesel. Feedstock native to Karnataka state namely (1) Pongamia pinnata, (2) Madhuca longifolia, (3) Azadirachta indica and (4) Simarouba glauca, have been analysed in this research. The LCA studies were carried out at the Biofuel Park, in Hassan district of Karnataka State. The objectives were to (i) asses the energy input and output, green house gas emissions and impact of land use change on ecosystem (ii) assess the economic viability of biodiesel production and (iii) formulate strategies for sustainable biodiesel production at rural level

LCA studies revealed that non-renewable energy requirement (NRER) throughout the life cycle of Pongamia, Madhuca, Azadirachta and Simarouba systems were found to be 4 to 7 times lower than Jatropha system and 25 to 42 times lower than conventional diesel system. Similarly, Net Energy Gain has been found to be highest in Madhuca, followed by Pongamia, Simarouba and Azadirachta system, which is 42 to 24 times higher than the output from Jatropha system. Global warming potential of Pongamia, Madhuca, Azadirachta and Simarouba were found to be 3-4 times lower than Jatropha system and 7- 8 times lower than fossil diesel system. Ecosystem structure and functional quality aspects of Pongamia, Madhuca, Azadirachta and Simarouba were found to be 2-4 times better than that of Jatropha system.

Economic viability studies revealed that price of biodiesel (with 20 % profit) produced from Pongamia, Madhuca, Azadirachta and Simarouba oil was found to be 6 % less than

subsidised conventional diesel in Karnataka State (i.e. Rs.51.20/- per litre annual average 2012)

This study revealed that Pongamia and Simarouba are ecologically and economically viable while Azadirachta and Madhuca are only ecologically viable feedstock for biodiesel production in the current economic scenario. Strategies for sustainable biodiesel production were proposed based on the outcome of the LCA studies. The structured framework evolved as a part of this research may be adopted for analysing any local biodiesel feedstock in India for sustainable biodiesel production.

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NOMENCLATURE

Abbreviations

ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
AP	Acidification Potential
AP	Acidification Potential
ARAI	Automotive Research Association of India
ARS	Agriculture Research Station
ARS	Agriculture Research Station
BS	Base Saturation
BTE	Brake Thermal Efficiencies
CBG	Compressed Biogas
CEC	Cat ion Exchange Capacity
CF	Crude Fibre,
CO	Carbon Monoxide
CO_2	Carbon Di Oxide
CP	Crude Protein
cSt	Centistokes
EFQ	Ecosystem Functional Quality
EP	Eutrophication Potential
EP	Eutrophication Potential
EQ	Ecosystem Quality
ESQ	Ecosystem Structural Quality
FFA	Free Fatty Acids
FU	Functional Unit
FU	Functional Unit
FYM	Farm Yard Manure
g	Gram
GA	Gibarlic Acid
GDP	Gross Domestic Product
GHG	Green House Gas Emission
GoI	Government of India
GoK	Government of Karnataka
GWP	Global Warming Potential
ha	Hectare
HC	Hydro Carbon
HSU	Hartridge Smoke Unit
IBA	Indole Butyric Acid

IISc	Indian Institute of Science
INSEDA	Integrated Sustainable Energy and Ecological Development Association
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
kg	Kilo Gram
KSBDB	Karnataka State Biodiesel Development Board
KSRTC	Karnataka State Road Transport Corporation
LAI	Leaf Area Index
LCA	Life Cycle Analysis
LO	Land Occupation
LPNV	Local Potential Natural Vegetation
LUC	Land Use Change
LUO	Land Use Occupation
MJ	Mega Joule
MMT	Million Metric Tonnes
MNRE	Ministry of Non-Renewable Energy
MOSPI	Ministry of Statistics and Programme Implementation
MPP	Minimum Purchase Price
MSP	Minimum Support Price
NDF	Neutral Detergent fibre
NEG	Net Energy Gain
NER	Net Energy Ratio
NFE	Nitrogen Free Extract
NOVODB	National Oilseeds and Vegetable Oils Development Board
NRE	Non Renewable Energy
NRER	Non Renewable Energy Resources
OMC	Oil Marketing Companies
PNV	Potential Natural Vegetation
PPM	Parts Per Million
SC	Soil Cover
SOM	Soil Organic Matter
SuTRA	Sustainable Transformation of Rural Area
SVO	Straight Vegetable Oil
SVO	Straight Vegetable Oil
t	Tonne
TAB	Total Above-Ground Biomass (TAB)
TBO	Tree Borne Oil
tkm	Tonne Kilo Metre

TNAU	Tamil Nadu Agricultural University
UAS	University of Agricultural Sciences
USDA	United States Department of Agriculture
VSD	Vertical Space Distribution

Symbol

Ai	is the area of the specific activity under evaluation
At	is the total area of the project site
Bp	Biomass production
I	*is* the impact indicator component
IS_x	the average indicator score for mid-point impact aspect *x*
Sf	Soil fertility
Ss	Soil structure
Value proj i	is the value for the selected indicator for the project area of the specific activity under evaluation
Value ref	is the value of the selected indicator for the reference system
Vs	Vegetation structure
Wb	On site water balance
α-Bd	On site biodiversity

DISSERTATION OUTLINE

The dissertation consists of three parts.

Part 1 includes

- Chapter 1 Introduction, which gives a brief insight into biodiesel status at Global, National (India) and State level (Karnataka), followed by rationale for this research.
- Chapter 2 portrays the literature review of biodiesel feedstock, LCA methodology and its application for analysing biodiesel feedstock.
- Chapter 3 depicts LCA methodology adopted, which includes energy analysis, global warming potential analysis, land use change impact analysis and economics of biodiesel production.
- Chapter 4, 5, 6 & 7 depict LCA studies and economics of biodiesel produced from Pongamia, Madhuca, Azadiractha and Simarouba respectively.

Part 2 includes

- Chapter 8, which depicts a comparative analysis of LCA results and economics of all the four LCA studies, followed by sensitivity analysis.

Part 3 includes

- Chapter 9, which addresses the review of current biodiesel strategy followed by Biofuel Park, Hassan and portrays alternative strategies for biodiesel production at local village level based on the LCA results and socio economic feasibility.
- Chapter 10 portrays conclusion drawn from this research followed by recommendations for future work.

The outcome form this research is a framework for assessing the sustainability biodiesel feeds stock, which is as follows:

1. Identification of Biodiesel feed stock
2. LCA
3. Ecological Impact of the chosen Feed stock
4. Economic viability of the chosen Feed stock
5. Strategy formulation / policy decision based on ecological and economic viability of the biodiesel feedstock

PART 1

CHAPTER 1

INTRODUCTION

1.0 Biodiesel Sector in India

As economic growth continues to increase, India's expenditures for oil imports are also increasing drastically. With increasing oil prices in international market, India is under constant pressure to raise the price of petroleum products, which in turn affects economic growth (KSBDB 2012).

Biodiesel production from tree-borne oilseeds (TBOs) is seen as beneficial prospect for agricultural development and employment generation for many of the rural poor. In addition, it may meet a considerable quantity of the India's fuel requirement and save foreign exchange. Adopting biodiesel will also decrease greenhouse gas emissions and revitalize degraded and marginal lands (Tilman 2009, MNRE 2012 and Bioenergy 2012).

Biodiesel production has been criticised for chances of creating food fuel conflict; by utilising cultivable land for growing biodiesel feed stock in lieu of food crops. It has also been observed in some countries that green house gas emission has increased due to encroachment and clearing of forestland for biodiesel feed stock production. Hence, the main debate is about the impacts of biodiesel production, which calls for systematic investigation (Shankar 2006 andTilman 2009).

However, the biofuel policies of the (Karnataka) states and the country (India) in general have a clear expression for use of non-edible oil only, which, are grown on non-agriculture land, marginal lands and degraded lands. Hence, the criticism of fuel production at the cost of fertile land and food production is not valid (KSBDB 2012).

The biodiesel segment is in a nascent stage in India. While a considerable number of plantations and a few esterification units have been commissioned in recent years the complete picture is yet to emerge. Hence, little is known about economic viability and environmental impacts of biodiesel production

Further, little information is available about different stages of the biodiesel supply chain to achieve economic and environmental sustainability. In September 2008, the Government of India approved a national biofuels policy, exempting taxes and duties on biodiesel and setting a target to blend 20 % biodiesel with fossil diesel by 2017 (KSBDB 2012). Likewise, government funded programmes for rural development and establishment of biodiesel plantation on large scale are in practice throughout India (Tilman 2009). While the National policy has been approved recently, several state governments have taken the lead for framing their own biofuel policies (Tilman et al. 2009).

Indian biofuel policy has been very clear about using non-edible oils derived from oil-bearing trees as biodiesel feeds stock. This makes it more positive since risk of food crop replacement by biodiesel feed stock is very little and enable many small farmers and landless cultivators to generate additional income. In addition, it helps in providing a green cover for unproductive/ barren/ unused lands, preventing soil erosion and nutrient loss (Tilman et al. 2009).

While India is already the world's seventh largest ethanol producer (2.1 billion litres), biodiesel production has started only a few years ago (MOSPI- Energy Statistics 2012). Ethanol is blended with petrol at the rate of 5% in India and the source of ethanol is molasis from sugar mills (Sherya 2014). However, supply of raw material for biodiesel production is an issue to be addressed for seamless supply of biodiesel.

1.1 The Supply Chain of Biodiesel in India

1.1.1 Cultivation

Straight vegetable oil (SVO), which is used as the raw material for biodiesel production, can be obtained from different plants species. Edible oil feed stock like rapeseed, soya, and sunflower are found to be high in oil content and have been used for biodiesel production in USA and Europe (USDA).

In India, more than 300 different species of (non-edible) oil-bearing trees have been identified for biodiesel production (Tilman et al. 2009). Most of them are wild species that have not yet been cultivated scientifically for oil production on a larger scale. However, some of the TBO species have been grown traditionally for oil, which is being used for lighting lamps by rural people and in small quantities for commercial purposes in the paint, lubricant, and soap manufacturing (Tilman et al. 2009).

National Oilseeds and Vegetable Oils Development Board (NOVODB) of the Indian Ministry of Agriculture has identified Jatropha curcas, Pongamia pinnata, Simarouba glauca, Azadirachta indica and Madhuca indica as potential biodiesel feed stock. However, proponents of biodiesel in India focus very exclusively on Jatropha based two main reasons i.e. (1) Jatropha being a shrub is easier to harvest with a shorter gestation period of three years and (2) The harvesting of Jatropha seeds does not coincide with the rainy season in June-July, when most agricultural activities take place (Tilman et al. 2009).

Pongamia is considered as the second most important feedstock in India since this tree is traditionally grown in several states, for oil, manure (seed cake), firewood and medicinal uses. Farmers have included Pongamia into their agro practices since many centuries. It is also one of the popular avenue trees. It is a common practise for people to collect and sell the seeds in local market (NOVODB- Karanja 2008 and Tilman et al. 2009).

Growing TBO species on fertile lands is found to be economically unviable compared to other food crops. Hence, it is a common practise in India to grow oil-bearing trees like Jatropha and Pongamia as hedge crop (boundary). However, the amount of oilseeds produced from boundary plantation is marginal (NOVODB- Karanja 2008).

One of the most favoured suggestions is the use of underutilized land / wasteland for cultivation of TBO species. According to the Government of India, wasteland reserves estimates to 72,000 km², which may be utilised for cultivating biofuel crops (Shankar 2006). Being drought-resistant than most other crops, TBO species can help in rejuvenating wasteland / unutilised land by curbing soil erosion and improving soil structure. In reality, even unsuitable and degraded land is still cultivated illegally by the poorest section of the population for subsistence or for cattle husbandry. Therefore, claims of available land for TBO cultivation need to be reassessed (Planning Commission Report 2011).

1.1.2 Processing

Once the seeds are harvested, the first step in processing is extracting the oil and oil can be extracted by:

(1) Using animal-powered expellers known as *'Gana'* in local Kannada language,

(2) Advanced pressing machinery called expellers, which can expel 75 to 90 % of the extractable oil (KSBDB 2012) and

(3) The more efficient way to expel the oil from the kernel is to use a chemical solvent that can extract almost 100 % of the oil (Achten 2010).

The two methods, pressing and solvent extraction can also be combined. The next step in processing is transesterification i.e. conversion of SVO into biodiesel, which requires three raw materials: SVO, alcohol (usually methanol), and an alkaline catalyst (e.g. sodium or potassium hydroxide). Transesterification process separates the SVO into fatty acid methyl ester (biodiesel) and glycerol. The glycerol is a by-product of the process.

1.1.3 Consumption

Both SVO and biodiesel can be used as fuel in conventional diesel engines, with slight modification to fuel pumps (Udipi Shrinivas 2001and Lokesh et al. 2012). SVO can be used for lighting (replacing petroleum in lamps) and cooking (in specially designed cooking stoves). It can very well substitute conventional diesel in engines (e.g. electricity generators or water pumps). SVO have high viscosity (Appendix-5), which calls for modification of fuel pumps, resulting in high operational and maintenance costs of engines. The fuel properties of biodiesel, on the other hand, are a lot better than SVO. Some of the rural energy projects use SVO for electricity generation, while others convert SVO into Biodiesel and use it for the same purposes. Biodiesel has better fuel properties like higher lubrication (+230%) and lower emission of hydrocarbon (-84%), Carbon monoxide (-40%), and particulate matter (-38%) compared to conventional diesel

(Hansen 2008). There are, however, economic (Cost of oil in open market) and safety issues (Storage of Methanol, which may lead to hooch tragedies) associated with the process of transesterification.

Blending of diesel with either SVO or biodiesel reduces the viscosity of the fuel. However, SVO diesel blends, still require a modification of the engine for proper functioning in most cases (Except for slow cycle diesel engines used in genets). Seed quality and extraction method have a say on the quality / physical and chemical properties of the SVO. However, the physical and chemical properties of biodiesel are consistent irrespective of feedstock, because of the standardized transesterification process. Therefore blending diesel with biodiesel is far more efficient than SVO (Biofuel Park 2012).

1.1.4 By-products and Alternative Uses of Straight Vegetable Oil and Biodiesel

The leaves, latex and wood of oil-bearing trees can also be used apart from the seeds and fruits. Leaves of some oil-bearing trees like Pongamia serve as organic manure while leaves, bark, root and latex of some species are used for medicinal purposes. Pruned, branches can be used as firewood. Furthermore, fruit hulls also serve as organic manure, fuel, medicine and as feedstock for biogas production as well (NOVODB- Karanja 2008).

Seed cake, by-product of SVO extraction can be used as organic manure and as feedstock for producing biogas from the seed cake. Seed cakes of few TBO species also serve as animal fodder. However, seedcake of few TBO species like Pongamia has to be detoxified before using them as animal feed (detoxification has been successful only in the laboratories) (NOVODB- Karanja 2008).

Glycerol, by-product of transesterification serves as an important ingredient for cosmetics, soaps and pharmaceutical products. If glycerol can be sold at a good price (>Rs.20/- kg), biodiesel production can become a lot more cost-efficient (Achten et al. 2010).

1.1.5 Environmental Effects of Biodiesel in India

Biodiesel production in India has comparatively less impact on environment and food security. This is primarily due to strict government policy, which permits biodiesel production form non-edible oil only (TBO species with life span of 30 to 200 years), while most European and other Asian countries use annual crops for fuel production.

TBO species require less soil nutrient and fertiliser than most annual crops, which results in less negative impacts on the net carbon balance. On the contrary, countries like Malaysia, Indonesia and Brazil have invaded natural forests for biofuel plantations. TBO species is expected to sequester 2.5 to 9.5 metric tonnes of CO_2 / acre / year and aid in reducing or controlling global warming (Biofuel Park 2012 & NOVODB-Karanja 2008).

Tilman et al in their report on biodiesel in India quote "Biodiesel production in India, moreover, does not necessarily compromise food security. First, there is a broad consensus in India that biodiesel production should be restricted to non-edible oils to avoid price increases for cooking oil. Second, the focus on marginal land / wasteland also contributes to minimizing competition between fuel and food. Although biodiesel plantations on agricultural land are an option in the Indian case as well, there is large potential to integrate oil-bearing trees into farming systems and the rural countryside without necessarily replacing food crops".

Although the Indian economy has grown rapidly in the last decade, development in rural areas, has taken a back seat. In 2010/11, India's overall gross domestic product (GDP) grew by 4.1 % (World Bank 2010). The agricultural sector, however, has remained almost stagnant. The reason for the poor performance of the Indian agricultural sector may be attributed to low productivity, lack of infrastructure and over regulated agricultural markets, which have discouraged private investment. Although agricultural subsidies have increased, productive investment has steadily declined (World Bank 2010). Encouraging biodiesel production and use at rural level for energy generation may improve the standard of living, and encourage diversification in agro and allied sectors. This may result in additional employment for farmers and the landless rural population.

1.2 Energy in Indian Villages

India has 5,93,732 villages and 4,97,236 villages have been provided with electricity as on 1st Jan 2013 and 96,496 villages in inaccessible locations need decentralised solutions for energy supply (Data Portal India 2013). Electricity not only increases living standards, it is also very essential for many productive and economic activities. Access to electricity and poverty alleviation are found to be directly proportional (Sreyams et al 2008). Biodiesel, or SVO, can be one of the options as a renewable energy source for decentralised, reliable and affordable electricity supply. Long transport distance and lack of funds often makes it very difficult for farmers in remote villages to procure fossil diesel economically. Hence, biodiesel produced from TBO feedstock can be one way of meeting farmer fuel requirement in remote villages.

However, two important points to be considered are (1) Ensuring economic viability (2) Ensuring reasonable income and empowerment of the rural poor to sell the TBO seeds in the open market or to use them for their own energy security at village level.

1.3 Government Policies

Biofuel mission was started by GOI in 2003. Ministry of New and Renewable Energy (MNRE) was responsible for preparing National Policy on Biofuels but coordinated by Prime Minster of India. In view of the suggestions from the Planning Commission and other members of empowered national biofuel coordination committee, National Biofuel policy was recommended to the cabinet (MNRE 2012). After these deliberations, National biofuel policy was announced on 11th September 2008

Excerpts of the national biofuel policy are:

1. *"Blending 20% biofuels with conventional fuel by 2017*
2. *Only non-edible oil grown on wasteland / marginal lands shall be used for producing biodiesel*
3. *Indigenous biodiesel feed stock shall be permitted (import of FFA like palm oil would not be permitted)*

4. *Bio-diesel plantations would be encouraged on community / Government / forest wastelands only (and not on agriculture lands)*

5. *Minimum Support Price (MSP) would be announced for bio-diesel feed stock and would be revised periodically*

6. *Biodiesel and bio-ethanol shall come under the scope of "Declared Goods" to make sure free movement of biofuels within and outside the States*

7. *No taxes and duties shall be charged on biofuels"* (MNRE 2012)

1.4 Biofuel in Karnataka

Work on bio-fuels has been going on in Karnataka in a systematic way for over two decades. Some of the recorded efforts in practical applications of bio-fuels are as follows.

**Major source of this information is from Karnataka state biofuel development board* (KSBDB 2012)

- Use of Pongamia oil in blends with diesel & as an SVO (straight vegetable oil) fuel to run diesel generators and irrigation pumps in Ungra village of Tumkur District in early 1990`s by the sustainable transformation of rural area (SuTRA) group headed by Prof. Udupi Shrinivasa of IISc

- Use of blends of non-edible vegetable oils, biodiesel and more recently absolute alcohol with diesel in fairly large volumes for running buses in Karnataka State Road Transport Corporation (KSRTC) in the current decade

- In addition, Karnataka has also been a leading state in R&D on the entire value chain of bio-fuels. The first official policy on bio-fuels (bioethanol) in India was actually incorporated in the Millennium Biotech Policy of Government of Karnataka (GoK) in 2001

- In 2003, SuTRA in collaboration with a Karnataka based reputed NGO Samagra Vikas organized an all-India conference on Policy and Strategic issues in the bio-fuel sector of India in IISc, Bangalore. The recommendations from the conference, which were later sent to Government of India. GOI laid the foundation for the draft policy on bio-fuels. While this policy unfortunately took several years to be finalized by the central government, the Government of Karnataka came out with a draft policy of its own in 2007.

- The Government of Karnataka also took the proactive step of forming a task force on bio-fuels in September 2008.

- The task force has taken several initiatives like finalization of the Karnataka Bio-fuel Policy, formation of a new Karnataka Bio-fuel Board, massive planting of important non-edible oil species and a strategic approach to making this a mass movement by establishment of bio-fuel parks & demonstration units all over Karnataka.

1.4.1 Highlights of Biofuel Policy Statement of Karnataka:

- Only non-edible seeds would be harnessed for the purpose of producing biodiesel.

- Cultivation of non-edible oil seeds required for biodiesel would be promoted on dry land, marginal land, wasteland and degraded forestland, owned by private or government, including “Block Plantations”.
- Use of agricultural land to grow non-edible oil seeds will not be encouraged, so as not to compromise food security.
- The state will encourage use of de-oiled cake, to be used as organic manure.
- The government will encourage public-private partnership models like lease of wasteland to private agencies to promote growing of plant species producing non-edible oil seeds.
- The conversion to oil will be encouraged in a time bound and decentralized manner, where oil seed collection and processing are promoted in rural areas and small towns.
- Traditional communities involved in oil seeds collection and or oil extraction activities in rural areas, selfhelp women groups and local user groups would be encouraged to participae in the related activities.

- The state will facilitate both Governmental and Non-Governmental organisations with suitable expertise to promote research, dissemination and outreach activities in promoting biofuels use.
- The state will establish required administrative and fiscal mechanism to facilitate all the above activities.

These developments compel to answer whether biofuels for transportation / running static engines will be sustainable than conventional fossil diesel? Hence calls for systematic research on TBOs for making policy decisions / recommendations.

1.5 Rationale, Aim and Objectives

1.5.1 Rationale

In the year, 2008 Government of India had estimated that by 2017, 20% of diesel consumption must be replaced by biodiesel. To satisfy this requirement, it was estimated that more than 20 million hectares of biodiesel feedstock plantation would be required. According to government of India's biofuel policy, only non-edible oils need to be used for biodiesel production. Hence, Jatropha has been promoted as a suitable feedstock for biodiesel production and has been planned to grow this TBO species on wastelands / marginal lands across India (Lokesh & Mahesh 2009).

However, out of the total (63 million hectares) wasteland* available in India, only 17 million hectares (DOLR 2000) is considered to have the potential for cultivation with crops like Jatropha. This 17 million hectares of land fall under following three categories;

(1) Degraded pasture & grazing land,

(2) Underutilized degraded notified forestland

(3) Degraded land under plantation crop categories

According to the studies carried out by Tamil Nadu Agriculture University (TNAU), Jatropha produces higher estimated yields in irrigated land (2500 plants /ha= 3 tonnes seeds /ha) when compared to rain fed land (1600 plants / ha = 1tonne seeds /ha with 100 to 500 mm rain fall) with average oil of 25 % (Lokesh & Mahesh 2009).

If 17 million hectare of wasteland is planted with Jatropha alone, one can obtain an average yield of 17 million metric tonnes (MMT) of seeds yielding 25% oil, resulting in 3.8 MMT of biodiesel, which will only suffice for one third of biodiesel requirement (DOLR 2000 and Lokesh et al 2012).

Jatropha was depicted as the wonder shrub that could produce biodiesel, reclaim wasteland and enhance rural development without compromising food production or ecosystem services (Francis et al. 2005). A major portion of the wasteland available around villages is grassland and community forests, which provide commodities like feed for animals, Biomass as fuel, wood for construction / furniture / agricultural implements and roofing material for landless and small farmers (Lokesh & Mahesh 2009). Therefore, the combination of tree species planted in these wastelands around the villages is very important for the livelihood of the rural poor. A single species like Jatropha will deprive the poor farmers from the said outputs, hence this research to evaluate different local tree species in comparison with Jatropha and fossil diesel in view of the ecological impact and economic feasibility.

1.5.2 Aim

The aim of this research is to contribute to the knowledge on the potential sustainability of biodiesel production from identified local tree / plant species and consequent ecological impact in rural Karnataka. To achieve this aim, following objectives were set:

- Identifying oil yielding tree species, with respect to biodiesel production in Karnataka state through scientific literature (Chapter -2)
- Study the ecological impact and commercial viability of biodiesel production from identified tree oil using life cycle analysis (LCA) method (Chapter-4,5,6,7 & 8)
- Based on the LCA results formulate ecologically and economically sustainable strategies for biodiesel production at rural level (Chapter- 9 & 10)

Based on these objectives, this research proposes to contribute to the knowledge base by:

- Broad insight into the biodiesel production from local species of TBOs and its use at local level;

- A framework for evaluating environmental and socio-economic impact of biodiesel produced from local TBOs.

Based on the above mentioned objectives, LCA of Pongamia, Madhuca, Azadiractha and Simarouba biodiesel, its ecological and economical impact have been analyzed and discussed in the following chapter-4, 5, 6 & 7.

**Note: Waste land in India includes*	*(M ha)*
• *Gullied / ravinous land*	*2.06*
• *Land with / without scrub*	*19.40*
• *Waterlogged / marshy land*	*1.66*
• *Land affected by salinity*	*2.04*
• *Shifting cultivation area*	*3.51*
• *Degraded notified forest land*	*14.07*
• *Degraded pastures/grazing land*	*2.60*
• *Degraded land under plantation*	*0.58*
• *Sandy area*	*5.00*
• *Mining/industrial wasteland*	*0.12*
• *Barren rock y/stony/sheet rock*	*6.46*
• *Steep sloping area*	*0.77*
• *Snow covered/glacial area*	*5.58*
Total	*63 M ha*

(DOLR 2000)

CHAPTER 2

LITERATURE REVIEW

This chapter has been portrayed in two parts. The first part presents the literature reviewed on the four biodiesel feedstock researched i.e. (1) Pongamia Pinnata (2) Madhuca longifolia (3) Azadirachta Indica (4) Simarouba Glauca, and Jatropha as reference system feed stock. The second part presents the literature reviewed on LCA methodology and its application for analysing biodiesel feedstock.

2.1 Pongamia pinnata as a Biodiesel Feedstock

For more than two decades, various research organizations across the world have been researching to identify suitable vegetable oil yielding feedstock to produce oil and convert it into biodiesel. Working on the same lines more than 300 TBO, species have been identified in India, of which more than 80 TBO species inhabit Karnataka state. (Biofuel Park 2012 and Lokesh et al. 2012)

Pongamia pinnata is a medium sized tree with a spreading crown and is one of the promising biodiesel feedstock. Pongamia tree species is spread throughout India, except for temperate regions. Pongamia seeds contain around 30% oil (Lokesh et al. 2012). The seed cake available after oil extraction serves as good organic manure for agricultural and horticultural crops. It also serves as a nematicide. Pongamia tree is found to have nitrogen-fixing capability and is also a good soil binder (NOVODB-Karanja 2008). Apart from Jatropha, other suitable tree borne oil yielding species have also started gaining importance. The list of TBO species has been steadily growing. Due to these interesting facts and overvalued claims many investors, policy makers and clean project developers are interested in these tree species for energy generation and reduction of green house gases (GHG) emission. (Rao 2006 and Lokesh et al. 2012)

2.1.1 Botanical Description of Pongamia pinnata

Botanical Classification

Pongamia genus has only one species i.e. Pongamia pinnata (L.) which belongs to Leguminosae family. It is a medium sized glabrous, perennial tree, which is spread across South East Asia and Australia (Satyavati et al. 1987).

Kingdom:	Plantae
Division:	Magnoliophyta
Class:	Magnoliopsida
Order:	Fabales
Family:	Fabaceae / Leguminosae
Genus:	Pongamia
Species:	pinnata

Botanical Name: *Pongamia pinnata* (L.) Pierre
Synonyms

1. *Derris indica* (Lam.) Bennett
2. *Millettia novo*-guineensis Kane and Hat.
3. *Pongamia glabra* Vent
4. *Pongamia pinnata* Merr.

Figure 2. 1Pongamia tree (Biofuel Park)

Figure 2. 2 Pongamia flower (Biofuel Park)

Figure 2. 3 Pongamia pods (Biofuel Park)

Figure 2. 4 Pongamia seeds (Biofuel Park)

Figure 2. 5 Pongamia seed cake (BiofuePark)

Figure 2. 6 Pongamia oil (Biofuel Park)

Pongamia pinnata is a fast-growing tree, which reaches 40 feet in height, forming a broad spreading canopy casting moderate shade (Figure 2.1). The botanical description of Pongamia is as shown in table 2.1.

Table 2. 1 Botanical description of Pongamia Pinnata

Plant type		Medium-sized, evergreen, perennial and deciduous tree Height:- 35 to 40 feet, Growth rate:- Fast, Texture:- Medium Chromosome number:- 22
Growing requirements		Light:-Tree grows in full sun Soil Tolerances: - clay; loam; sandy; slightly alkaline; acidic; well-drained Drought tolerance:- high Aerosol salt tolerance:- moderate Altitude:- up to 1200 m Rainfall:- 500-2500 mm
a)	**Leaf**	Alternate, odd pinnately compound, 2 to 4 inches, evergreen, hairless
b)	**Flower**	Lavender, pink; white, 2- 4 together, short-stalked, pea shaped, 15-18mm long (Figure 2.2)
c)	**Pods**	3-6 cm long and 2-3cm wide, smooth, brown, thick-walled, hard, indehiscent, 1-2 seeded.(Figure 2.3)
d)	**Seed**	Compressed ovoid or elliptical, been-like, 10-15cm long, dark brown, oily (Figure 2.4)
e)	**Root**	Well developed thick and long taproot with numerous lateral roots
f)	**Bark**	Thin grey to greyish brown on the outside and yellowish on the inside
Care and Pruning		All parts of the plant are toxic and will induce nausea and vomiting if eaten
Uses		Wood:- Used as fuel wood, agriculture implements Oil: - fuel for lamps, lubricant, water-paint binder, pesticide, and in soap making, tanning industries, folk medicine for rheumatism and skin diseases. The oil of Pongamia is also used as a substitute for diesel Oil Cake: - Organic manure and poultry feed (Figure 2.5) Tree:- Soil erosion control, soil reclamation, shade & Ornamental

(Savita Sangwan et al. 2010 and Orwa et al. 2009)

2.1.2 Pongamia Cultivation

The cultivation of Pongamia trees for oil seeds is considered as the first step towards bio-diesel production. The main inputs are land, which includes its soil characteristics, silvicultural practices including transport and power generation. The outputs are the seeds, other biomass like seed cake, fuel wood and Green house gas (GHG) emissions. (Hegde 1994)

Pongamia is a widely adaptable tree, which can be grown in areas with minimum 500 mm to maximum 2500 mm rainfall and temperatures ranging from 5° to 50°C. Too dry sandy soil and too wet clay soils are not congenial for its growth. It can moderately tolerate saline soils. It flourishes well in sandy loam soils with abundant moisture. (Savita et al. 2010)

2.1.3 Pongamia Propagation

Propagation through seeds: Pongamia can be propagated through seeds by direct sowing in nursery bed or in polyethylene bags during the month of July - August. Seed may also be sown in-situ in plantation fields (but not recommended). It is a normal practice to soak the seeds in Indole butyric acid (IBA) 30 ppm or Giberlic Acid (GA) 20 ppm for 24 hours before sowing to enhance germination and vigour. A mixture of fertile soil, sand and farm yard manure (FYM) in 2:1:1 ratio is found best and economical for producing high quality of seedlings seed germinates in month's time. (NOVODB-Karanja 2008)

Propagation through cuttings: Pongamia can be propagated using semi hard wood stem cuttings with 1-2 cm thick and 15 to 25 cm long. Soaking in 800 PPM of GA is found to enhance sprouting and root initiation. (NOVODB-Karanja 2008)

Propagation through grafting: Pongamia can also be propagated through air layering and cleft grafting. One-year-old rootstock can be grafted with superior yield trees scion. Grafting is complete within 60 days, followed by hardening and transplanting in a month's time (NOVODB-Karanja 2008).

2.1.4 Pongamia Plantation Practices

Seedlings are planted in the beginning of rainy season. Planting distances of 5 × 6 m (330 plants / ha) and pit size of 60 x 60 x 60 cm is a common practice. One-year-old seedlings are best suited for transplanting around 2-5 kg of farm yard manure (FYM) is used to fill during planting along with the soil. Three or four irrigation is given to the plantation depending on the climatic conditions for better growth and development. (NOVODB-Karanja 2008 and Hegde & Daniel 1994)

2.1.5 Plantation Management

Pongamia is grown on well-drained soil in full sun or partial shade. Once the tree is established, little maintenance is required. It is resistant to high winds and drought but susceptible to temperatures below 0°C. Growing Pongamia on soil with a pH above 7.5 will show nutritional deficiencies. Staking to increase the structural strength of the tree (Sapling) is common practice in the first year of transplanting. (Savita et al 2010 and S.V Lele 2012)

2.1.6 Inter Cropping

During the first five years, short duration oil seed and pulse crop like mustard, groundnut, sesame, chickpea, black gram, horse gram, soya bean and millets like maize and ragi can be cultivated as intercrops without affecting the growth. This practice has been found to increase the economic viability of Pongamia plantation and generate income during the gestation period (NOVODB-Karanja 2008)

2.1.7 Pests and Diseases

Pongamia is believed to be not prone to pests and disease acttack to an extent, which causes economic damage. However, damage has been observed in monocultures of Pongamia. Pests like leaf minor (*Acrocercops anthrauri*) and foliage feeder (*Eucsma balanoptycha*) (Anindita 2012) are found to be problematic. Diseases found on Pongamia are damping off, leaf rust, Alternaria leaf spot, Colleterotrichum leafspot, cercospora leaf spot and Fusicladium leaf spot. Increased pest and disease infestations in monocultures is attributed to regular irrigation and fertilizer application (Savita et al. 2010 and NOVODB-Karanja 2008)

2.1.8 Flowering and Fruiting

Pongamia sheds its leaves in April and develops new leaves from May onwards. Red to purplish flowers appear in April to July. Fruits are ready for harvest in different seasons in different parts of the country. Pongamia pods are harvested in November- December and May June months. Grafted trees start bearing seeds after 3-4 years while trees raised by seedlings start bearing from 5^{th} or 6^{th} year. The seed yield is reported to be 9 to 90 Kg / tree based on different age group. Pongamia leaves and seeds serve as good soil conditioners and fertility enhancers. The composition of leaves and seed are as shown in table 2.2 (Savita et al. 2010).

Table 2. 2 Composition of leaves and seed

Parameter	**Leaf**	**Fruit (Pod and Seed)**
Protein	-	17.4%
Fatty oil	-	27.5%
NFE	-	55.40%
CF	-	5.04%
ADF	40%	1.65%
Ash	-	2.4%
Tannin	-	2.32g/100g
ADL	-	6.67%
Trypsin	-	6.2g/100g
P	0.11, 0.14%	0.61%
Ca	1.58, 1.54%	0.65%
Mg	-	_
K	0.62, 0.49%	1.3%
CP	18%	19.5g/100g
NDF	62%	17.98%
N	0.71, 1.16%	5.1%
Moisture	-	19.0%
Starch	-	6.6%
Mucilage	-	13.5%
Na+	-	0.8%

NFE = Nitrogen free extract, CF = Crude fiber, ADF = Acid detergent fibre,

ADL = Acid detergent lignin, CP = Crude protein, NDF = Neutral detergent fibre,

2.1.9 Pongamia Seed Collection and Processing

Pongamia is found to have non-synchronous flowering and fruiting, which results in prolonged pod collection. Hence, one time harvesting is not possible. After harvesting, the pods are sun dried for two to three days. Kernels (seeds) are separated from the pod shell manually using wooden hammers or manually operated decorticator. However electrically operated decorticators are available for efficient processing of pods.

Average seed yield is about 4-9 metric tonnes / ha. On an average, one labourer can collect 120 to 180 kg of seeds / man-day. Approximately 15 – 20 man-days are required for harvesting one hectare. Normally average shell-kernel ratio of Pongamia seed on mass basis is 46:54 and it is found to have 1500-1700 numbers of seed per kg (Savita et al 2010, Biofuel Park 2012 and NOVOD Board). The shell is used as fuel in kitchen and gasifiers in rural India. It is known to have similar energy to brown coal i.e. 15 MJ / kg (Subbarao 2012).

2.1.10 Oil Extraction

The main inputs for this process are the seeds, machines, infrastructure and energy. On the output side, the products are the Pongamia oil and the seed cake. The emissions of GHGs and wastewater have to be accounted for in the outputs of the process as well.

Pongamia oil is extracted mainly by two methods (1) Mechanical extraction (2) Solvent extraction. It is a common and economical practice to extract oil from Pongamia seeds using mechanical expellers, run by either electric motors or animal draft power. Oil extraction from Pongamia oil has been through animal draft power operated expellers called Ghani / Gana since time in memorial (Wani 2006).

Prior to extraction, the seeds are sun dried or oven dried. This process enhances oil extraction and yield of oil. Fresh oil is yellow or orange in colour and gets darkened during storage. It tastes bitter and has a repulsive odour. Solvent extraction of oil yields better quality oil (Wani 2006).

Pongamia oil can be extracted using manually operated ram press e.g. Yenga or Bielenberg ram press or engine driven screw press e.g., Sundhara press. (Forson et al. 2004 and FACT Foundation 2006). Engine driven screw press is known to extract 75-80% of the available oil compared to ram press, which extracts only 60-65% (Henning 2000).

It is a common practice to go up to three passes in a screw presses to achieve 75-80% extraction efficiency. Solvent extraction is economical for large-scale oil extraction i.e. 50 tonne and above only (Lele n.d.).

Pongamia oil is composed of the following fatty acids

Table 2. 3 Composition of Pongamia oil

(NOVODB-Karanja 2008)

The fatty acid composition of Pongamia oil (Table 2.3) is dominated by oleic acid, linoleic acid and palmitic acid. The ripeness of the fruits is reported to influence the fatty acid composition of the oil (NOVODB-Karanja 2008).

2.1.11 Uses of Pongamia Oil

Pongamia oil is used as a fuel, to produce soap, and in producing ayurvedic medicine. The oil can be used directly or in blends with conventional diesel as fuel in older diesel engines or new big engines running at constant speed e.g., pumps, generator (Udupi Srinivasa 2001). The oil can also be transesterified into Pongamia methyl esters (Biodiesel) and used in conventional diesel engines as substitute for conventional diesel or in blends.

2.1.12 Pongamia Seed Cake

The Pongamia seed cake has been tested as a good source of organic manure with an average energy content of about 14.3 MJ / kg of cake (Ref. Table 2.4)

Table 2. 4 Composition of Pongamia seed Cake

Farm trials conducted in Adilabad district of Andhra Pradesh have shown that, use of Pongamia seed cake as organic manure, enhanced the yield of crops like maize and soybean (Sridevi et al. 2009).

The experimental investigation carried by Ramchandra et al has shown Pongamia seed cake has the potential to generate biogas in the range of 240 - 265 litres per kg of cake. The biogas generated from Pongamia is found have 65-70 % methane against 55 % from cattle dung (Ramchandra et al. 2006)

The reality that Pongamia seed cake can be used for enriching the soil and generate biogas makes it an important by-product. Slurry from biogas plant is a good source of soil nutrient; hence digesting the seed cake and using the digested slurry as organic manure found to be an environmental friendly practice. Slurry of Biogas produced using Pongamia seed cake is found to contain 2.39 % Nitrogen, 0.43 % phosphorus and 0.31% Potassium (Ramchandra et al. 2007). The nutrient level of the biogas slurry of Pongamia is marginally lower than that of oil cake, which is an additional benefit for farmers after generating biogas (Lokesh et al. 2012).

2.1.13 Economical and Medicinal Value of Pongamia

The plant Pongamia pinnata has immense economic and medicinal values, which are as shown in table 2.5.

Table 2. 5 Economic and medicinal importance of Pongamia pinnata

Root	
Economic value	- Root is used as fish poison
Medicinal value	Juice of roots for treating gonorrhoea, foul ulcers, closing fistulous sores, cleaning gums, teeth and ulcers Roots are also used as anti-helminthic drug and for vaginal and skin diseases
Stem	
Economic value	Used for poles, carvings, cabinet making, cart wheels, posts. Agricultural implements, tool handles and combs. Ash of wood used for dyeing.
Medicinal value	Aqueous extracts of stem bark used as sedative and antipyretic.
Leaf	
Economic value	Used as cattle fodder, to repel insects in stored grains and Used as manure for rice and sugarcane fields
Medicinal value	Juice of leaves is used for cold, cough, diarrhoea, dyspepsia, flatulence, gonorrhoea and leprosy Leaves also serve as anti-helminthic, laxative and for treating inflammations, piles, wounds, relieve rheumatism, treat itches and herpes
Fruit	
Economic value	- Fruits are non edible
Medicinal value	Used for treating abdominal tumours, illness of female genital tract, leprosy, tumour, haemorrhoids and ulcers
Seed	
Economic value	Seed cake used as manure and insecticide
Medicinal value	Used to treat keloid tumours, hypertension, skin ailments and rheumatic arthritis, bronchitis whooping cough, inflammations, chronic fevers, haemorrhoids and anaemia
Oil	
Economic value	Used as fuel for cooking, as lubricant, water-paint binder, pesticide, in soap-making, candles and leather tanning and Used in cosmetics

Medicinal value	Oil is used to treat leprosy, piles, ulcers, chronic fever, liver pain, rheumatism arthritis, scabies and whooping cough Mixture of oil and zinc oxide used for eczema
Bark	
Economic value	String and ropes made from the bark fibre. Used for paper pulp
Medicinal value	For treating bleeding piles, beriberi, swelling of the spleen, mental disorder, cough and cold
Flower	
Economic value	Good sources of pollen for honey bees flowers are edible
Medicinal value	Satisfy dipsia in diabetes, alleviating vata and kapha

(Savita et al 2010 and Satayavati etal 1987)

2.1.14 Scope of SVO as Fuel

Pongamia oil has been researched for its fuel performance from the time of its inception as suitable alternative renewable fuel as straight vegetable oil by Udupi Srinivasa (2001). Spray characterization studies of Pongamia SVO conducted by Deshmukh et al. (2011) revealed that emissions and carbon deposit on combustion chamber walls could be reduced by modifying fuel injection system and combustion chamber.

2.1.15 Transesterification

Vegetable oils are esterified into their methyl or ethyl esters in the presence of a catalyst (i.e. potassium or sodium hydroxides). Esterification process lowers the viscosity of the oil. "Transesterification is a less cost way of converting the long chained molecular structure of vegetable oils into smaller, straight-chain molecules very similar to the one found in regular diesel" (Ayhan 2008).

Engine run using biodiesel produces comparatively lower power and torque and shows higher SFC than conventional diesel. However, it is better than diesel fuel in terms of sulphur content, flash point and biodegradability (Ayhan 2008).

There are three methods for ester production

- Base catalyzed transesterification
- Acid catalyzed transesterification

- Two stage esterification i.e. acid catalyzed esterification followed by base catalysed esterification

Most of the biodiesel currently produced, use vegetable oil, methanol, and an alkaline catalyst (Ayhan 2008). Along with these three methods, another four alternative method have been reported in literature, which have been summarised in table 2.6

Table 2. 6 Summary of alternative transesterification procedures reported in literature

(Achten et al. 2010)

2.2 Madhuca Longifolia as a Biodiesel Feedstock

Madhuca Longifolia, known as the butternut tree in common language is a large deciduous tree growing up to a height of 20 m, distributed in Nepal, India and Sri Lanka. It is also 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 (Priyanka 2011).

2.2.1 Botanical Description of Madhuca Longifolia

Kingdom:	Plantae
Division:	Magnoliophyta
Class:	Magnoliopsida
Order:	Ericales
Family:	Sapotaceae
Genus:	Madhuca
Species:	longifolia

Botanical Name: *Madhuca longifolia* J.König ex L

Synonyms

1. *Bassia latifolia* Roxb
2. *Bassia longifolia* J.König ex L.

Figure 2. 7 Madhuca tree (Biofuel Park)

Figure 2. 8 Madhuca flowers (IISC)

Figure 2. 9 Madhuca fruits (plantes-botanique.org)

Figure 2. 10 Madhuca seeds and seed cake (gardentia.net)

Figure 2. 11 Madhuca oil (Biofuel Park)

The botanical description of Madhuca is as shown in table 2.7

Table 2. 7 Botanical description of Madhuca

<table>
<tr><td colspan="2">Plant type</td><td>Size:-Large deciduous tree growing to height of 65 to75 feet
Growth rate:- Fast</td></tr>
<tr><td colspan="2">Growing requirements</td><td>Light requirement: - full sun light.
Soil requirement: - clay; loam; sandy; slightly alkaline; acidic; well-drained
Drought tolerance:- high
Altitude:- up to 1200 m
Temperature:- 2 to 50°C
Rainfall:- 750-1850 mm
Mean relative humidity varying from 40-80% in January and 60-90% in July provides an optimum atmospheric moisture range for the growth of Madhuca trees.</td></tr>
<tr><td>(a)</td><td>Leaf</td><td>Leaves are 10-30 centimetre long, are thick and leathery most of leaves pointed at the tip, clustered near end of branches, epileptic or elliptic oblong 7.5 to 23 cm into 3.8 to 11.5 cm.</td></tr>
<tr><td>(b)</td><td>Flower</td><td>Flowers are small and fleshy, dull or pale white in colour and in define fascicles near end of branches. Corolla tubular, freshly pale, yellow aromatic and caduceus</td></tr>
<tr><td>(c)</td><td>Fruits</td><td>Fruits are 2-6 cm long, fleshy and greenish.</td></tr>
<tr><td>(d)</td><td>Seed</td><td>Pod to seed ratio is 30: 70. Seed contains two kernels, which are 25 mm x 17.5 mm in size.</td></tr>
<tr><td>(e)</td><td>Root</td><td>Thick and long tap root with well developed numerous lateral roots</td></tr>
<tr><td>(f)</td><td>Bark</td><td>Is rough and brownish-grey in colour, which is 1 cm thick, exuding white sticky thick latex upon peeling.</td></tr>
<tr><td colspan="3">Uses</td></tr>
<tr><td colspan="2">Wood:-</td><td>Timber and Used for medicinal purpose</td></tr>
<tr><td colspan="2">Oil: -</td><td>The oil (solid at ambient temperature) is used in skin care, to manufacture soap and used as vegetable butter. It can be used as a fuel oil as well</td></tr>
<tr><td colspan="2">Oil Cake</td><td>Organic manure (Especially for lawns)</td></tr>
<tr><td colspan="2">Tree:-</td><td>Soil erosion control, soil reclamation, shade, religious & Ornamental</td></tr>
</table>

(NOVODB-Mahua 2009 and Maitreyee 2012)

2.2.2 Madhuca Cultivation

Madhuca is a widely adaptable tree, which grows 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. There are no varieties available for block plantation. A large variability exists in its fruits and oil percentage (NOVODB-Mahua 2009).

2.2.3 Madhuca Propagation

Both seeds and vegetative method can be used for propagating Madhuca. The mature seeds, which are dispersed from the trees, germinate rapidly in wild / natural conditions. Such seeds are collected during pre monsoon rains and planted in poly bags or nursery beds (NOVODB-Mahua 2009 and Hegde 1994). Direct sowing is also practiced with 2-3 seeds per pit. More than 85% of seeds germinate in 15-20 days.

Vegetative propagation by grafting and budding experiment in Sri Lanka have showed very promising results. Grafting trials using one-year-old seedlings in the field as stock and scion taken from the defoliated tree (to have the apical buds in dormant condition) achieved a success rate of 87% after 46 days using either whip or cleft grafting methods. Budding trials were carried out using similar seedling stock and buds taken from branches with semi-hard wood were found to be suitable (INSEDA – Mahua).

2.2.4 Madhuca Plantation Practices

Saplings are planted during the beginning of rainy season. Planting distances of 6 × 6 m (277 plants / ha) and pit size of 60 x 60 x 60 cm is a common practice. One-year-old seedlings are best suited for transplanting and around 2-3 kg of FYM is mixed with soil during planting. Two or three irrigation are provided to the plantation depending on the climatic conditions for better growth and development (NOVODB-Mahua 2009 and Lele 2012).

2.2.5 Madhuca Plantation Management

Madhuca is grown in full sun. It is low maintenance tree once established and is resistant to high winds and drought. Staking is a common practice in the first year transplanting (Lele 2012).

2.2.6 Inter Cropping in Madhuca Plantation

In the initial 8 years, vegetables like ridge gourd, bottle gourd, ladies finger and Cucumber can be grown as intercrops. This practice has been found to increase the economic feasibility of the plantation and generate income during the gestation period. However, Madhuca based cropping system has not been standardised (NOVODB-Mahua 2009).

2.2.7 Pests and Diseases of Madhuca Plantation

Both domestic and wild animals browse the young plants. Monkeys and Bears relish the flowers and fruits.

The flowers and leaves of Madhuca are often defoliated by the looper, (Achaea janata, Anuga multiplicans, Bombotelia nugatris, Metanastrica harvtica) and larvae of (Acrocercops euthycolana and A. phaemorpha). Unaspis acuminata is found to feed on sap and lndarbella quadrinolota on the bark (INSEDA – Mahua).

Fungi like Aspergillus flavus, A. niger, Penicillium Sp. and Stathmopoda basiplectra known to infest seeds and fruits. Leaf spots, leaf blight and leaf rust diseases are common in nursery as well as in plantation (INSEDA – Mahua).

2.2.8 Flowering and Fruiting of Madhuca

Madhuca starts flowering in February and extends up to April. Flowers are rich in sugar (73%) and stand second to cane molasses. One tonne of dried flower yields approximately 400 litres of alcohol (95%).

Madhuca fruits are fleshy and orange brown in colour when ripe. They fall on the ground from May to July in North India and August to September in south India. The fruit measure 25 to 50 mm in length. Seed to pod ratio is 70:30 and each seed contains two kernels (Maitreyee 2012).

2.2.9 Madhuca Seed Collection and Processing

Fruits naturally drop on the ground after ripening or fall when the branches are shaken vigorously. Seeds are exposed after fleshy covering decays or when rubbed against a rough surface. Animals are known to disperse the seeds after eating the fruits. The time for seed gathering is short and calls for organized gathering; if not a significant portion of the yield is lost. Collected seeds are stored in heaps (Maitreyee 2012).

The storage condition and quality of seeds determine oil quality. The seeds are prone for infection from fungi (Aspergillus flavus and Rhizopus sp) and insect attack (Oryzaephilus surinamensis) during storage. Studies have revealed that seeds can be stored in good condition at 5 to 6% moisture without pest attack. Proper storage results in good quality oil, lower FFA and odour arising from fungal growth. (NOVODB- Mahua 2009, Maitreyee 2012 and Lele 2012)

2.2.10 Madhuca Seed Oil Extraction

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 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” (Maitreyee 2012).

Very similar to Pongamia, Madhuca seed oil is extracted by mechanical expellers. Madhuca oil has been extracted in India from time in memorial by traditional method i.e. Ghani / Gana. Now electrical motor operated expellers are used, which are more efficient. Prior to extraction, it is a practice to sundry the seeds for better oil yield (NOVODB- Mahua 2009).

2.2.11 Madhuca Oil

The oil is one of the ingredients of hydrogenated vanaspati. Madhuca oil finds its major use in manufacture of soaps, in particular laundry soaps, as illuminant and hair oil. (NOVODB – Mahua 2009) Madhuca oil is composed of the following fatty acids:

Table 2. 8 Fatty acid composition of Madhuca oil

(NOVODB- Mahua, 2009)

The fatty acid composition of Madhuca oil is dominated by oleic acid, linoleic acid and Palmatic acid (Table.2.8).

2.2.12 Madhuca Seed Cake

The seed cake of Madhuca has been tested as good source of organic manure. Madhuca seed cake is mainly used as detergent and organic fertiliser (Table 2.9). Madhuca cake is known to have insecticidal and pesticidal properties, hence used as fertiliser in lawn and saponins act against earthworms.

Table 2. 9 Madhuca seed cake composition

(NOVODB-Mahua 2009)

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 (INSEDA -Mahua).

2.2.13 Medicinal Value of Madhuca

Madhuca has immense medicinal and economical values, which are as follows

Table 2. 10 Medicinal properties of Madhuca tree

(Pushpendra et al. 2012)

Biodiesel production process and engine performance has been found to be similar to that of Pongamia (2.1.16)

2.3 Azadirachta Indica as a Biodiesel Feedstock

Azadiractha is an evergreen and deciduous tree with straight trunk and long scattering branches with a wide round or oval crown, growing to height of 12 to 18m. All parts of the tree taste bitter and the tree has sacred significance. It is spread across the whole of South Asia. Uttar Pradesh, Tamil-Nadu, Karnataka, Madhya Pradesh, Maharashtra, Andhra Pradesh, and Gujarat are important Azadiractha producing states in India (Anindita 2012).

2.3.1 Botanical Description of Azadirachta Indica (Neem)

Kingdom:	Plantae
Division:	Magnoliophyta
Class:	Magnoliopsida
Order:	Sapindales
Family:	Meliaceae
Genus:	Azadirachta
Species:	Indica

Botanical Name: *Azadirachta Indica* A.Juss

Synonyms

1. *Azadirachta indica* var. minor Valeton
2. *Melia azadirachta* L

Figure 2. 12 Azadiractha tree and flowers (Biofuel Park)

Figure 2. 13 Azadiractha fruits and seeds (Biofuel Park)

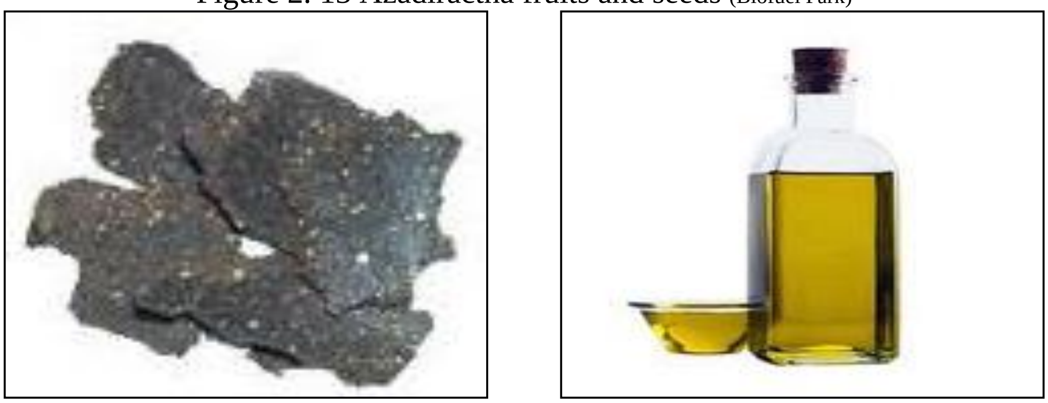


Figure 2. 14 Azadiractha seed cake and oil (Biofuel Park)

The botanical description of Azadirachta is as shown in table 4.1

Table 2. 11 Botanical description of Azadirachta

12 Botanical description of Azadirachta Continued…….

(Girish 2008)

2.3.2 Azadirachta Cultivation

Azadirachta is one of the most valuable trees in India. It has many commercially exploited by-products. The tree is medicinally valuable because of its, anti-allergic, anti-fungal, insecticidal, anti-dermatic, anti-inflammatory properties. It is cited as a tree conducive to the welfare of the family if planted in the garden or in the house. In forestry Azadiractha tree is recommended for forestations of dry areas, soil conservation, reclamation of alkaline soils and along avenues for shade and ornamental purposes. (Girish 2008 and NOVODB-Azadiractha 2009).

2.3.3 Azadiractha Propagation

Azadirachta can be propagated both by seeds and vegetative method. Natural regeneration: - Mature trees seed profusely. Azadiractha fruits and seeds ripen at the onset of rainy season. Birds disperse the seeds. Usually it takes 10 to 15 days to germinate. It attains a height of about 20-30 cm at the end of first year

Artificial regeneration: - The plant coppices well and produces root suckers in dry localities. Direct sowing, transplanting, cuttings or stump planting is a common method. Air layered branches treated with 2,6-dichloroisonicotinic acid (INA) & Napthaline acetic acid (NAA) in linoleic paste at 0.1 % root satisfactorily (Girish 2008 and NOVODB-Azadiractha 2009).

Direct sowing is also practiced, which is comparatively cost effective, but may result in poor survival in dry areas. The viability of fresh seed decreases rapidly after two weeks.

Direct sowing is practiced in pits or even trenches. After de-pulping and drying the seeds to 30% moisture, they can be stored up to four months at 15° C. Viability of the seed can be increased if the moisture is reduced to 6 to 7 % and stored in sealed containers in a refrigerator (Girish 2008).

2.3.4. Azadiractha Plantation Practices

Saplings are planted in the beginning of the rainy season. Planting distances of 5.5 × 5.5 m (330 plants / ha) and pit size of 60 x 60 x 60 cm is a common practice. One-year-old seedlings are best suited for transplanting around 2-3 Kg of FYM is used to fill during planting along with the soil. Two or three irrigation is given to the plantation depending on the climatic conditions for better growth and development (NOVODB 2009 and Lele 2012).

2.3.5 Azadiractha Plantation Management

Similar to Pongamia and Madhuca, Azadiractha is grown in full sun and is resistant to high winds and drought. Staking is a common practice in the first year of transplanting (Lele 2012 and Kleeberg 2000).

The growth rate of Azadiractha is found to be fast till 5 years of age, after which it slows down. A 5-year-old tree attains a height of 4 m and gradually slows down attaining a height of 10 m by 25 years. The mean annual girth increment is 2.3 to 3 cm.

2.3.6 Inter-Cropping in Azadiractha Plantation

In the initial 4-5 years, short duration oil seed and pulse crops like groundnut, mustard, chickpea, cowpea, horse gram and soybean can be cultivated as intercrops. This practice is found to increase the economic viability of the plantation and generate additional income during the gestation period.

2.3.7 Pests and Diseases in Azadiractha

In spite of the bitter chemical like azadirachtin, the young Azadiractha plants are frequented by not less than 60 insect species across the world. In India, 38 species of pests have been recorded so far. Few pests which cause considerable damage to the seedlings and young plants are tip borer (Laspeyresia koenigiana), tea mosquito (Helopettis antmii) and scale insect (Aonidiella orientalis) (Kleeberg and Zebitz 2000 and Girish 2008).

The larvae of Enarmonia koenigana feed on rolled leaves and bore tender shoots. The larvae of Cleora cornaria and Odites atmopa defoliate the leaves. The insects like Aspidiotus orientalis, Ceroplastes ceriforus feed on the sap. Rodents devour the fruits greedily and consume most of them after they fall to the ground (Girish 2008 and NOVODB-Azadiractha 2009).

The fungi, that cause diseases in Azadiractha, are Cercospora subsessilis, Fusarium species, Colletotrichum gleosporiodes, Alternaria alternata, Rhizoctonia solanum, and Oidium azadirachtae . The species Xylaria azadirachtae has been reported on seeds. Seed in storage has been found contaminated mainly with Aspergillus species. The fungus Alternaria alternata causes leaf spot and blight during onset of winter, damaging 80% leaf area. It can be controlled by the application of blitox (Girish 2008 and NOVODB-Azadiractha 2009). Important plantation diseases of Azadiractha are Ganoderma root rot, pink disease and Phomoposis fungal infection. Twig blight root rot is caused by Ganoderma becidum, which occurs sporadically in trees when raised without removing the stump and roots of the original tree crop. It can be controlled by following good Silvicultural practices (Girish, 2008 and NOVODB-Azadiractha 2009)

2.3.8 Flowering and Fruiting in Azadiractha

The trees bear flower from February- March in southern India. The flower buds open in the afternoon and emit a strong pleasant odour during night, which attracts insects for pollination followed by fruit setting. Fruits mature during June- July, coinciding with onset of monsoon. The fruit is about 3cm long and yield per tree ranges from 30 to 100 kg based on the rainfall, soil and the genotype of the tree.

2.3.9 Azadiractha Seed Collection and Processing

Generally, ripe fruits fall to the ground naturally or when beaten with sticks. Such fruits are collected and heaped. These fruits are transported to oil mills, where they are de pulped washed and dried. De-pulping of fruits is also carried out at field level depending on the water and labour availability. Improper drying will lead to fungal infection and production of aflatoxin, which is highly toxic to human beings even at low concentrations. Seeds used for sowing purpose are air dried in shade (since sun drying will reduce the viability of the seeds). Seeds are stored in well-aerated bags to avoid fungal infection and spoilage. Shade drying followed by storage of seeds in cloth bags at 4°C is practiced to retain the seed viability. Seeds can also be stored in earthen pots filled with wet sand (30% moisture) for 3 months with 60% viability (NOVODB-Azadiractha, 2009).

2.3.10 Azadiractha Seed Oil Extraction

Very similar to Pongamia and Madhuca, Azadiractha seed oil is extracted by mechanical expellers. Azadiractha seed oil has been extracted in India from time in memorial by traditional method i.e. *Ghani / Gana*. Now electrical motor operated expellers are used, which are more efficient. Prior to extraction, it is a practice to crush the seeds for better oil yield. Whole dried fruits yield less oil upon crushing i.e. (4-6 % oil). De-pulped seeds yield around 12 -16 % oil and kernel yields around 30 - 50% oil. The seed cake is also found to have 7-12 % oil, which can be extracted through solvent extraction. (Anindita 2012)

2.3.11 Azadiractha Oil

Azadiractha oil is golden brown to dark brown in colour and tastes bitter with a strong peanut and garlic odour. The bitter taste and odour are due to presence of large amount of triterpenoid compounds like azadirachtin. Azadiractha oil is composed of the following fatty acids shown in table 2.13.

Table 2. 13 Fatty Acid content of Azadiractha Oil

(Anindita 2012)

Similar to Madhuca oil, Azadiractha oil composition is dominated by Oleic acid.

2.3.12 Azadiractha Cake

Azadiractha seed cake is used as organic manure. It works as a good nematicide hence used in fields infested with nematodes. Since being organic in origin it has little impact on soil quality, but very effective in controlling / eradicating nematodes, which cause huge loss in banana plantation.

Table 2. 14 Azadiractha cake constituents

Sl.No	Constituents	Percentage (%)
1	Crude protein	13-35
2	Carbohydrates	26-50
3	Crude fibre	8-26
4	Fat	2-13
5	Ash	5-18
6	Acid insoluble ash	1-17
7	Nitrogen	2-3
8	Phosphorus	1
9	Potassium	1.4
10	Sulphur	1.07-1.36

Azadiractha cake is also widely used as organic manure for crops like sugarcane and vegetables. It also works against termites due to the presence of Limonoids. It has been reported that Azadiractha seed cake often seems to make soil more fertile than predicted, when the cake is added to paddy fields. Application of Azadiractha cake reduces the amount of urea to be added as it contains 2-3% nitrogen (Table 2.13) (Girish 2008).

In some parts of Karnataka state, Azadiractha tree is mainly grown for its green leaves and twigs, which is puddled into the flooded rice fields before transplantation. Azadiractha leaves are also used as mulch in tobacco fields (Girish 2008).

2.3.13 Medicinal Value

Azadiractha has immense medicinal and economical values, which are as shown in the following table 2.14.

Table 2. 15 Medicinal values of Azadiractha

fibre, which is woven into ropes in Indian villages

(INSEDA- Azadiractha 2008)

2.4 Simarouba Glauca as a Biodiesel Feedstock

Simarouba glauca is a tree species growing in the forests of Central and South America. It is an evergreen tree with a round trunk and tap root system. It attains a height of 7-15 meters. National Bureau of Plant Genetic Resources, New Delhi, first introduced this tree species to India in 1960s in Maharashtra State at a research station called 'Amravathi'. Further, this tree species was introduced in Bangalore in 1986 at University of Agricultural Sciences. Structured research on Simarouba started only after 1992. (Joshi 2000)

There are two varieties in Simarouba, i.e. one, which yields purplish fruits called as 'Kaali' variety and the other, which yields yellowish fruits called as 'Gauri'. The trees start bearing fruits at age of 4-6 years and reach its peak after 10-12 years. Fruits are ready for harvesting by April / May (Joshi 2000).

2.4.1 Botanical Description of Simarouba Glauca

Kingdom:	Plantae
Division:	Magnoliophyta
Class:	Magnoliopsida
Order:	Sapidales
Family:	Simaroubaceae
Genus:	Simarouba
Species:	glauca

Botanical Name: *Simarouba glauca* DC

Synonym: *Simarouba glauca* var. latifolia Cronquist

Figure 2. 15 Simarouba tree (Biofuel Park)

Figure 2. 16 Fruits of Simarouba (Biofuel Park)

Figure 2. 17 Seeds of Simarouba (Biofuel Park)

Figure 2. 18 Simarouba oil (Joshi 2000)

Table 2. 16 Botanical description of Simarouba

Plant type		Size:-Medium sized tree growing to height of 25 to 50 feet Growth rate:- Fast
Growing requirements		Light requirement: - tree grows in full sun. Soil tolerances: - clay; loam; sandy; slightly alkaline; acidic; well drained. & tolerant up to soil pH 5.5-8 Drought tolerance:- medium to high Altitude:- up to 1500 m Temperature: - 10 to 40°C. It cannot withstand summer up to 49.5° C Rainfall:- 700 to 1000 mm for normal growth but with stand 300 to 2500 mm rainfall
(a)	**Leaf**	They have compound leaves, with between 1 and 12 pairs of alternate pinnate leaflets.
(b)	**Flower**	The plants are poly gamodioecious with about 5% of the population producing exclusively staminnate (male) flowers and 40-50% producing mainly male flowers and a few bisexual flowers (andromonoecious) while the remaining 40-50% produces only the pistillate (female) flowers.
(c)	**Fruits**	The fruit is a carpophore and has up to 5 drupaceous mericarps
(d)	**Seed**	The fruit pulp covers the seed, which is removed by soaking the fruit in water and mucilaginous substances are scrapped by rubbing against rough surface / gunny bag / mechanical de-pulper. The de-pulped seeds are then dried in shade for 2-3 days. After drying, it may be used for sowing directly, which takes 3-4 weeks for germination. To hasten the germination, scarification may be practised.
(e)	**Root**	Taproot is thick and long, lateral roots are numerous and well developed
Uses		
Wood:-		A ten-year-old tree yields 5 to 10 cft of wood. It is light in weight and moderately strong with attractive grains. It can be used in making agricultural implements, light furniture and matchsticks. It can be used as packing material as well.
Oil: -		The oil is useful for making pharmaceuticals, surfactants, detergents, soaps, shampoos, cosmetics, plasticizers, stabilizers, lubricants, grease, emulsifiers, paints, varnishes and candles. Oil is also edible.
Oil Cake		The seed cake is a good organic manure, which is rich in N P & K.
Tree:-		Soil erosion control, soil reclamation, shade, religious & Ornamental
		(Joshi 2000 and Dash 2008)

2.4.2 Simarouba Cultivation

Simarouba also known as paradise tree, Lakshmi taru and Aceituno, it is one of the valuable trees in India, introduced from central America., it is a versatile tree that can grow in variety of ecological conditions. All parts of the tree produce products, that serve as food, fuel, manure, timber, medicine and in soil management. It is also one of the good choice for avenue tree as well (NOVODB-Simarouba 2009 and Joshi 2000).

2.4.3 Simarouba Propagation

Simarouba can be propagated through seeds, grafting and tissue culture. Seeds naturally dispersed by animals like squirrel and birds regenerate naturally. The growth of such seedlings is comparatively rapid compared to artificially regenerated seedlings.

Nursery preparation: Normally Simarouba seeds have short viability of 60 to 90 days. However, seeds can be stored in airtight containers or polythene bags for a year or next season with 50 % viability. Freshly collected ripe berries are de pulped by soaking in water and rubbing the mucilaginous pulp against a rough surface/ gunny bag and dried in shade for two are three days. Drying under direct sun light with temperature above 40°C is found to reduce its viability. Scarification is practiced in Simarouba to soften the seed coat for better and fast germination (by 2 weeks) if not, seed germination is found to take 30 days. Such seeds can be directly planted in the field. General practice is to grow the seedlings in poly bags for 3 to 4 months and transplant them to main field.

Treating seedlings with microbial inoculants like Bacillus coagulans and vesicular arbuscular mycorrhiza Glomus mosseae is found to promote the growth and increase the vigour of planting material. (NOVODB- Simarouba 2009)

2.4.4 Simarouba Plantation Practices

At the onset of the rains, the seedlings are planted in the field. Planting distances of 5 × 4 m (500 plants / ha) and pit size of 60 x 60 x 60 cm is a common practice Plant population also varies from 500 to 330 based on soil and rainfall. Five months to One-year-old seedlings are best suited for transplanting around 2-5 Kg of FYM is used to fill the pits during planting along with the soil. (NOVODB- Simarouba 2009 and Lele 2012)

2.4.5 Simarouba Plantation Management

Similar to Pongamia, Madhuca and Azadiractha, Simarouba is grown in full sun. Saplings are planted during the beginning of rainy season. Planting distances of 5 × 4 m (500 plants / ha) and pit size of 60 x 60 x 60 cm is a common practice. Five months to one-year-old seedlings are best suited for transplanting. Around 2-3 kg of FYM is mixed with soil during planting. Two or three irrigations are provided to the plantation depending on the climatic conditions for better growth and development (NOVODB- Mahua 2009 and Lele 2012).

Planting grafted male plants at distance of 60 meters among female plants is practiced for better pollination. Apart from this, grafting selected female plants with high yielding romonoecious scions is found to assure better yield. Two or three irrigation is given to the plantation depending on the climatic conditions for better growth and development

2.4.6 Inter-Cropping in Simarouba Plantation

During the first 4-5 years, short duration oil seed and pulse crop like sunflower, groundnut, soya bean can be cultivated as intercrops without affecting the growth. This practice has been found to increase the economic viability of Pongamia plantation and generate income during the gestation period (NOVODB- Simarouba 2009).

2.4.7 Pest and Diseases in Simarouba

Cattle do not browse Simarouba and no serious pests have been reported on this crop, which causes major loss. Insects like mites, bark feeder (Indarbela tetraonis) and sap suckers like tea mosquito (Helopettis sp) leaf minier (Acrocercops sp) and almond moth (Ephestia cautella) are found in Simarouba plantations. Among these insects, mites are found to create serious damage in dry areas/ seasons. Seedlings in nursery is found to suffer from damping (from Pythium sp) of and wilting (from Fusarium sp), which can be controlled by proper drainage (NOVODB- Simarouba 2009 and Joshi 2000).

2.4.8 Flowering and Fruiting in Simarouba

Simarouba trees mature at the age of 5–7years and starts bearing flowers during December month and continue up to following February. Fruits mature during April to May, coinciding with onset of monsoon. The fruits turn black in pink variety and yellow in green variety, when ready to harvest (Joshi 2000).

2.4.9 Simarouba Seed Collection and Processing

Generally, ripe fruits fall to the ground naturally or when beaten with sticks such fruits are collected and heaped. De pulping of fruits and sun drying of nut lets (10 % Moisture) is carried out at field level depending on the water and labour availability. Seeds are stored in well-aerated bags to avoid fungal infection and spoilage. Fruit / Seed collection extends for 3 to 4 weeks. (NOVODB- Simarouba 2009)

2.4.10 Simarouba Oil Extraction

Simarouba seed oil is extracted using mechanical expellers. Simarouba seeds are made up of shell (60%) and Kernel (40%). The seed has to be decorticated before oil is extracted. If the shell is not decorticated, the shell particles absorb a significant quantity of oil during extraction and it affects the quality of oil. After decortications, oil is extracted from kernels by using mechanical oil expellers with heating or cooking arrangement. Simarouba seeds yield better oil when cooked with steam. As a normal practice 10 - 20 % shell is mixed with kernels for better oil extraction. (Joshi 2000 and Anil 2011)

Table 2. 17 Fatty acid composition of Simarouba oil

(Anil 2011)

As seen from table 2.16, similar to Madhuca, Azadiractha and Pongamia Simarouba oil composition is also dominated by oleic acid, followed by stearic and palmatic acid.

2.4.11 Simarouba Seed Cake

The seed cake serves as a good source of organic manure. N, P & K content of Simarouba seed cake are 7.7 - 8.1%, 1.07% and 1.24% respectively. Seed cake also contains micronutrients like calcium, magnesium, and sodium (Joshi 2000).

2.4.12 Medicinal value of Simarouba

Simarouba has immense medicinal and economical values which are as shown in table 2.17.

Table 2. 18 Medicinal and economic values of Simarouba

strong antimalarial activity

(Rain tree - Simarouba 2004)

2.5 Jatropha Curcas as a Biodiesel Feedstock and Refrence system

Jatropha curcas is a hardy shrub native to Mexico and Central America. It has been found in subtropical and tropical regions of the world (DBT-India). It has become naturalised in some area and mutated into more than fourteen species. Chattisgarh, Gujarat, Rajasthan Andhra Pradesh, Karnataka, Uttrakhand, Tamil Nadu, North Eastern states Maharashtra and Orissa are some of the states in India, where it occurs as semi wild bush or shrub. Since, it is not browsed by cattle it is also used as hedge for farm land or rural houses (NOVODB-Jatropha).

2.5.1 Botanical Description of Jatropha

Kingdom:	Plantae
Division:	Magnoliophyta
Class:	Magnoliopsida
Order:	Euphorbiales
Family:	Euphorbiaceae
Genus:	Jatropha
Species:	Curcas

Botanical Name: *Jatropha Curcas L*
Synonym: *Curcas purgans*

Common Names: Physic nut, Parvata-randa, kanananaeranda (Sanskrit); Jangliarandi, Ratanjot, Safed arand (Hindi); Purging nut (English)

Figure 2. 19 Jatropha shrub and flower (DBT- India)


Figure 2. 20 Jatropha fruits (DBT-India)


Figure 2. 21 Jatropha seeds (Biofuel Park) Figure 2. 22 Jatropha seed cake (Biofuel Park)

Figure 2. 23 Jatropha Curcas Seed oil (Biofuel Park)

Table 2. 19 Botanical description of Jatropha

Plant type	Size:-Medium sized shrub growing to height of 8 metre Growth rate:- Fast (Fig. 2.19)
Growing requirements	Light requirement: - grows in full sun. Soil tolerances: - clay; loam; sandy; slightly alkaline; acidic; well drained. & tolerant up to soil pH 5.5-8 Drought tolerance:- high (thrives on a mere 250 mm (10 in) of rain) Temperature: - 10 to 40°C. It cannot withstand summer up to 49.5° C Rainfall:- 500 to 1200 mm for normal growth
Leaf	They have 6 x 15 cm lobed *(Fig. 2.19)
Flower	Flowers are Small and yellowish green in loose panicles, unisexual with male and female flowers at the same rate. The flowering occurs twice i.e. in March-April and in September-October
Fruits	Brownish-Black capsule, 4 cm long, with 3 cells, each containing one seed (Fig. 2.20)
Seed	Seeds are black, about two cm long and one cm thick. There are 2000-2400 seeds per kg. (Fig 2.21) The seeds contain the highly poisonous substance called toxalbumin curcin. They also contain carcinogenic compound called phorbol. Eating as few as three untreated seeds can be fatal to humans
Root	Taproot is thick and long, lateral roots are numerous and well developed
Uses	
Wood:-	Hallow and has little use or as fire wood with
Oil: -	The oil is used as lubricants, manufacturing soap and candle It has been used as hair growth stimulant. Used as medicine in livestock for treating sores (Fig. 2.23)
Oil Cake	The cake (Fig.2.22) can be used for fish or animal feed (if detoxified), biomass feedstock for biogas generation or high-quality organic manure. It used as a bio-pesticide as well.
Tree:-	Soil erosion control, soil reclamation, shade, religious & Ornamental

(DBT- India and Achten et al. 2010)

2.5.2 Jatropha Cultivation

Jatropha grows wildly on degraded arid and semiarid soils of India with annual rainfall of 500-1200 mm. It can even thrive on calcareous soils. It can be grown under arid and semi-arid climatic conditions however, it cannot with stand heavy frost. (NOVODB-Jatropha 2007).

2.5.3 Jatropha Propagation:

Jatropha can be propagated by direct sowing, transplanting and stem cutting, in the similar way as practiced for Pongamia, Madhuca, Azadiractha and Simarouba (Prueksakorn et al. 2012).

2.5.4 Jatropha Plantation Practices

At the onset of the rains, eight to ten weeks old seedlings are planted in the field. A plant population of 1666 / ha in case of rainfed crop and of 2500 / ha in case of irrigated is maintained (NOVODB- Jatropha 2007).

It is a standard practice to apply 2-3 kg of FYM per pit or seedling followed by a 20 g Urea, 120 g Single Super Phosphate and 16 g Murate of Potash in India as per NOVODB recommendations during the first year of planting. From Second year onwards Nitrogen, Phosphourus and Potash are applied in the ratio of 46: 48: 24 kg / ha to obtain economic yeilds and high oil content seeds.

Since the gestation period of Jatropha crop is two years it is a recommended practice to grow short duration inter cultivation crops like pulses, vegtables and millets. Several agricultural Instittituions in India have caried out research on intercultivation practicies and have recommendations based on their agroclimatic zones, which are available with NOVODB. Three to four weeding operation / year is a general practice.

2.5.5 Pests and Diseases in Jatropha

Cattle do not browse Jatropha and no serious pests have been reported on this crop, which causes major loss. However, a few diseases like damping off, collor rot, root rot and leaf spot have been observed in waterlogged conditions. Insects like Leaf minor, blue bug and Green bug cause damage to crop with luxurious growth (Tamilnadu Agricultural University and NOVODB- Jatropha 2007).

2.5.6 Flowering and Fruiting

Jatropha flowers twice, i.e. between September-December and March–April in India. Fruit setting and maturing happens in the next two to four months.

2.5.7 Jatropha Seed Collection and Processing

The mature fruits are plucked and sun dried. The dried fruits are decorticated manually or by decorticators. One labourer can collect and decorticate 25-30 kg seed per day. Jathropa seeds have started finding market along with Pongamia, Neem, Mango stones and other tradtional oilseeds (NOVODB -Jathropa 2007 and Achten 2010). As per estimates made by NOVODB, a well-maintained and healthy one hectare of rainfed plantaion yeilds as follows (Table 2.19).

Table 2. 20 Pongamia plantation yeild

Year	Seed in kg/ ha/ Year
2	250-300
3	500-600
4	1000-1500

However, estimates made by Tamilnadu agriculture university revel an average of one tonne seed per/ ha/ year after 5th year in rain fed condtions.

2.5.8 Jatropha Seed Oil Extraction

For better oil yeild, it is a standard practice to sundry the seeds for 12 to 24 hours or roast them for 10 min before expelling the oil. Jatropha oil can be extracted by mechanical method (Screw Press) and Solvent extraction method. Mechanical method is the most preferred economical method (Shekawath 2012). Jatropha seeds are made up of shell (40%) and Kernel (60%). As per NOVODB estimates Jatropha seed weighs around 0.5-0.7 g. and measuers 1-2cms in length and contains 6.62 % moisture, 18.02 % protein, 38% fat, 17.98 % carbohydrates, 15.50% fibre and 4.5% ash. The fatty acid compostion Jatropha oil is dominated by Oleic acid (37-68%), followed by Linoleic acid (19-41%) & Palmatic acid (12-17%) (NOVODB-Jatropha 2007).

2.5.9 Jatropha Seed Cake

Jatropha seed cake serves as good organic manure and substitute for chemical fertilizers. Singh et al (2008) have reported that one kg of seed cake is equal to 0.15 kg of N:P:K (40:20:10) chemical fertilizer. A study conducted by Ramchandra et al (2006) at IIT Delhi on biogas generation using Jatropha seed cake revealed that Jatropha seed cake has potential to generate 220 to 250 litre of biogas per kg of seed cake under mesophilic temperature range. The methane content of the biogas generated from Jatropha seedcake was also found to be 65-70% more compared to cattle dung (55%).

Jatropha seed cake cannot be used as feed for live stock due to presence of toxic compounds and anti nutritional factors. The toxic compounds are (a) Phorbol esters (b) Curcin, which when ingested by live stock lead to mucosal irritation and gastrointestinal hemagglutinating action. The anti nutritional compounds are (a) Phytic Acid (b) Tannins, which inhibit the absorption of proteins and minerals (Maria et al. 2012). If ingested by humans it known to causes-burning and pain in mouth and throat, vomiting, delirium, muscle shock, decrease of visual capacity and a high pulse It is therefore advisable to use only detoxified jatropha seed cake as feed for live stock.

2.5.10 Medicinal Value of Jatropha

Jatropha has commendable medicinal and economical values, which are as shown in table 2.21.

Table 2. 21 Medicinal properties of Jathropha

Part of Plant	Medicinal Properties
Leaf	Treatment of vaginal bleeding Wound healing Fever Rheumatism Jaundice Lymphocytic leukemia Anti-parasitic activity Malaria Mouth infections, guinea worm sores Promote lactation Dysentery and colic
Stems Bark Branches Twigs	Gumboils and strengthen the gums Inhibits HIV induces cytopathic effects with low cytotoxicity Strong antimicrobial agents Aid antimicrobial activities
Fruits and seeds	Arthritis, gout and jaundice Burns, convulsions, fever and inflammation Eczema, Skin diseases, To sooth rheumatic pain and purgative action Sciatica, dropsy and paralysis Pregnancy-terminating effects in rats, Contraceptive, Aabortifacient and Syphilis
Roots	Eczema, scabies, ringworm and gonorrhea Sexually transmitted diseases (STD) Antihelmintic properties Dysentery and diarrhea Dyspepsia and diarrhea Antidiarrheal activity in albino mice Root extract from this plant Anti-inflammatory activity in albino mice Bleeding gums and toothache
	Reddy et al. 2012
Potential Anti-HIV Activity	Ritwik et al. (2013) in their research on HIV have reported, "Jatropha leaf extracts showed effective anti-viral and probable entry inhibition activity against potentially drug-resistant HIV, which has not been reported earlier. The study indicates that Jatropha curcas Linn. is a good candidate for anti-HIV therapy with further research"

The literature on Pongamia, Madhuca, Azadiractha, Simarouba and Jathropha give a fair insight into their life cycle i.e Botany, cultivation, pest and diseases, yield , life span and their medicinal properties, which help in defining their boundary conditions for LCA studies, which has been discussed in the following chapters.

2.6 Biodiesel Production from Tree borne oil Feedstock

The optimal inputs for the transesterification of TBO oil are identified to be 20% methanol (by weight of oil), 1.0 % NaOH (by weight of oil). Maximum ester yield is achieved after 60 to 90 minutes reaction time at 60°C). Optimal conversion of TBO oil with high free fatty acids and high acid number needs pre-treatment reaction with methanol using H_2SO_4 as catalyst at 60°C for 60 to 90 minutes. After pre-treatment, a maximal conversion rate of more than 90% has been achieved by transesterification with methanol and NaOH (Vivek & Gupta 2004). The best practice to maximize biodiesel yield, is to determine the optimal inputs of chemicals (i.e. methanol, sodium hydroxide, and Sulphuric acid) per oil batch that has to be transesterified.

Ramadhas et al. (2004), Van Gerpen (2005), Barnwal and Sharma (2005), Canakci et al. (2006), Meher et al. (2006) and Agarwal (2007) have thoroughly researched on transesterification of vegetable oil into biodiesel and associated engine testing and emission. TBO oil is esterified to give methyl esters (bio-diesel) and glycerol. Glycerol is burnt for producing heat or used in soap making.

Further research findings by Venkateshwar et al. (2008), Nagarhalli et al. (2010) and Murari et al. (2013) on Pongamia, Madhuca, Azadiractha, Simarouba and Jatropha biodiesel respectively have listed following conclusions

- TBO biodiesel brake thermal efficiencies (BTE) is very near to that of diesel
- Maximum efficiency for all compression ratios was observed in B20.
- Use of biodiesel in higher compression ratio engines showed better BTE
- Specific fuel consumption for biodiesel blends was found to be more than that of diesel and decreased for higher compression ratios.
- Exhaust emissions i.e. smoke, CO, HC were found to be less (22-30%) for biodiesel blends under low load conditions (and found increase with increase in the load) compared with diesel values, however HC emission has been reported increase with increase in Biodiesel percentage in the blends

- NOx emission was reported to be higher (6 to 26%) for biodiesel blends compared to diesel

From the referred studies, it can be inferred that TBO biodiesel (100%) or in its blend generally achieves the best results in comparison to the use of Straight vegetable oil (SVO). Tropical countries are believed to have great potential to use SVO, since tropical temperature lower the viscosity of the oil (FACT Foundation 2006). Stationary diesel engines / pre-chamber diesel engines which run at low speed / constant speed, (irrigation pumps and electricity generators) are suitable for using straight vegetable oil as fuel. However, biodiesel can also be used in direct injection engines with slight modification of having a two-tank system to overcome these problems (FACT Foundation 2006).

2.7 Discussion on the Literature Review

In this section, an attempt has been made to analyse the collected information on TBOs bio-diesel production and use.

2.7.1 Cultivation

Although the demand for biodiesel is increasing, the major limitation lies in the supply of raw material. Authentic data for Silvicultural practices especially water management for block plantation is required (Suhas et al. 2006 and Wani et al.). Block plantations are almost certainly the best option for SVO production from TBO species. However, such plantation can be best established only with Government and Non-Governmental participation. Non-Governmental Organizations like “Samagra Vikas” (National Biofuel Centre 2008), Biofuel Park Hassan, established by University of Agricultural sciences-Bangalore (Biofuel Park 2012) have been working on the standardization of package of practices for block plantations for oil production and establishing such plantations on community land around villages.

Plants propagated using seeds are found to have deep tap root system, which can absorb nutrients from deep soil and serve as good soil binder as well. However, vegetative propagated plants have superficial root carpet, which neither absorb nutrients from deep soil nor serve as good soil binders. Hence, plants propagated using seed are a better choice for establishing long lasting plantation, than vegetative propagated plants. (Savita et al. 2010, NOVODB-Karanja 2008, Mahua-2009, Azadiractha-2009 and Simarouba-2009). Current best practice followed is to use planting material collected from the local trees, which have been giving good yield and considerable oil percentage (NOVODB-Karanja 2008).

It is a known fact that application of pre treatments for seeds ensures higher germination per cent. Although nursery bags can hamper initial root formation, it is recommended to establish plantation through planting of seedlings since they can be protected in their initial growth stage. Using seedlings has proved to establish uniform plantation. It is necessary to monitor the annual seed yield in plantations. Further research is necessary to measure the effects of influencing factors on the yield (Biofuel Park 2012).

High yielding plantation can be established, provided high yielding germplasm are identified and propagated in a given agro climatic zone. This involves categorization of TBOs based on geographical background to widen the genetic base, to breed high and early yielding hybrids with high oil yield.

2.7.2 Oil Extraction

At present two extraction procedures i.e. mechanical and chemical, are in practice. Further research on improving the efficiency of mechanical oil extraction and use of alternative solvents for chemical extraction are needed. Decentralized oil extraction and transesterification set up should go hand in hand for better results.

Although the use of seed cake as organic manure & nematicide in orchards and other plantation crops is a common practice, a thorough research on biogas production, quality, bottling and usage in energy generation is required.

2.7.3 Biofuel Production and Use

The bio-diesel production from Pongamia, Madhuca, Azadiractha, and Simarouba are well documented. Vital research challenges are with the increasing biodiesel yield with minimal cost. A significant problem is in improving the catalytic process, recovery and the reuse of the catalyst. Opting for decentralized processing units, call for design and development of low-cost, robust and versatile small-scale oil transesterification units. (Savita 2010, Sridevi 2009 and Joshi 2000).

The choice of using Pongamia bio-diesel or straight vegetable oil depends on the intended use (e.g., electricity production or transport). Studies reveal that Pongamia biodiesel achieves better results than Pongamia SVO or its blends in diesel engines (Udupi Srinivasa 2001).

Measuring and reporting of emission factors contributing to global warming, acidification, eutrophication and ozone depletion is very significant for biodiesel produced from any feedstock. A thorough study on engine performance using bio-diesel produced from tree borne oils as fuel for a long term is needed.

2.7.4 Environmental Issues

Environmental issues of biodiesel production from TBOs and its use has been discussed in this section 2.7.4. The input and output of each stage of production cycle are recorded and the impacts calculated and compared with a reference system in LCA. In this LCA study, fossil energy sources (Diesel) has been taken as reference system. Most of the LCA studies of bio-energy from renewable feedstock have focused on the energy balance and the global warming potential (Hill et al. 2006) while there are several other impact categories to address (ISO 1997). Land use impact is one of those that are not often assessed (Wagendorp et al. 2006). The land use impact assessment will help in understanding the sustainability of SVO and /or bio-fuel production.

So far, land use impact assessment has not been carried out for Pongamia, Madhuca, Azadiractha & Simarouba. However, it is expected that land occupation impact of all the four TBOs on the soil will be positive since it is known to enrich the soil fertility by nitrogen fixing activity (Pongamia & Madhuca) and improve soil structure as well (NOVODB and Savita et al. 2010). It is also known to control and prevent soil erosion and sequestrate carbon. Hence, a focused research on TBOs life cycle to study the impacts of different cultivation patterns adopted till date / to be adopted in due course on the local ecology is necessary. This study addresses the same.

**Since TBOs selected are hardy in nature, they can establish well under little silvicultural practices and survive purely based on water available from rain fall. Impact of water requirement is insignificant and hence not considered in this research.*

(TBOs have Root envelop of > 30 m and they rely on water available in deep soil. Irrigated water does not percolate beyond 10 m. Irrigated water is utilised by plants having comparatively smaller root envelope. Hence, impact of water requirement has been considered insignificant).

2.7.5 Gap Identification

This review on the production and use of TBOs biodiesel identifies several gaps i.e.

- Standardization of package of practices for block plantations for oil production and establishing such plantations on community land around villages
- Research on improving the efficiency of mechanical and chemical oil extraction and their economical viability
- Research on biogas production from seed cake, quality of biogas, bottling and usage in energy generation
- Research on developing decentralized, economical and robust small scale oil transesterification units
- Measuring and reporting of emission factors contributing to global warming

These above-mentioned gaps need to be set right before framing a large-scale cultivation strategy, keeping in view the impacts on local ecology, which have been addressed in this research using LCA studies. (Except for improving the efficiency of oil extraction all other gaps have been addressed in this research)

2.8 LCA methodology and its Application for Analysing Biodiesel Feedstock

This section depicts the literature review of LCA methodology and its application to study the bio energy system of various biodiesel feed stock.

2.8.1 Origin of Life Cycle Assessment

The origin of LCA methodology took place at Midwest Research Institute in US in the year 1969 (Weidema 1997). Midwest Research Institute carried out the first LCA study for Coco Cola Company to assess the environmental impact of the packaging material used by them. Followed by this first LCA study, Ian Boustead in the year 1972 conducted a LCA study assessing the energy demand (Energy Balance) of beverage bottles in UK (Baumann and Tillman 2004). United Nations Earth Sumit in 1990s, recognised LCA as environmental tool, which in due course evolved resulting into a international standard 14040 to14044 (Baumann and Tillman 2004). This ISO standard laid out the protocols for carrying out LCAs. As per ISO, LCA is defined as compilation and assessment of inputs, outputs and potential environmental impacts of a product system, where in the term ‘product’ refers to a good or a service. LCA often involves assessing the environmental impacts of a product system through all stages of its life cycle (i.e. Cradle to grave).

2.8.2 LCA in Brief

LCA studies help in identifying the environmental impacts of all phases of the cycle, rather than concentrating on a single source of emission (Example: use of biodiesel in automobile, static engines for water pumping and electricity generation). Moreover, LCA allows evaluation of environmental impacts for comparison and improvement.

An LCA consists of four separate but interacting phases. (Fig 2.13)

In the first phase, the goal and scope of the LCA study is defined. This contains

i. The definition of the functional units of the system under research,
ii. The demarcation of the system boundaries,
iii. The selection of a procedure to allocate impacts over different products and by-products and
iv. The selection of the impact categories, which will be, assessed (Jensen et al. 1997).

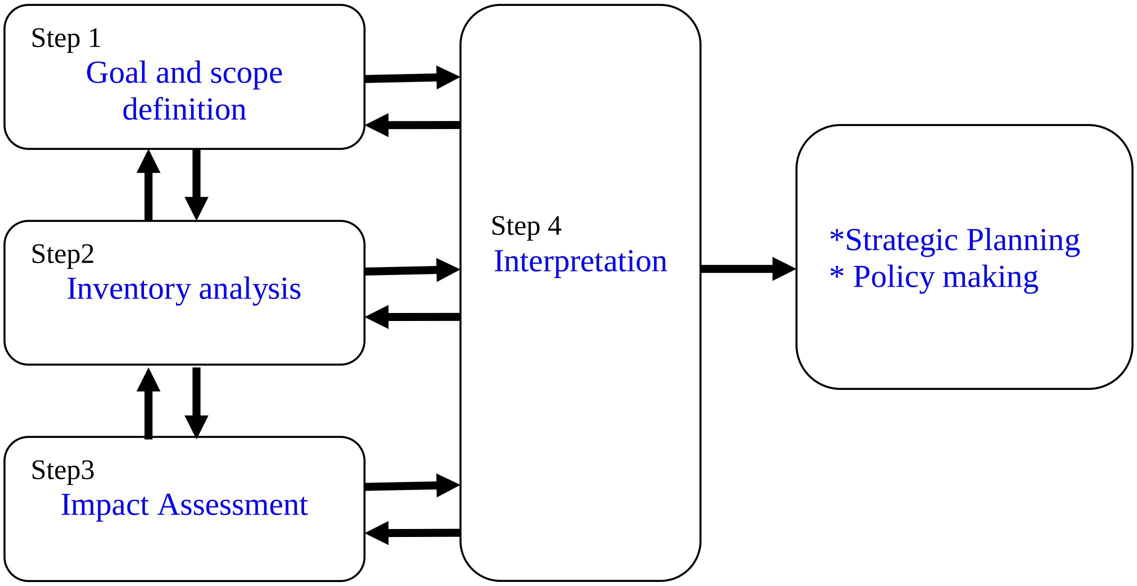


Figure 2. 24 Four steps / phases of LCA

In the second phase i.e. inventory analysis; data collection and the selection of the calculation procedures is addressed.

In the third phase, i.e. impact assessment phase the results of the inventory analyses are converted into indicator values for each impact category under consideration. Normalization, grouping and weighting of impact categories are optional elements.

In the fourth phase i.e. the interpretation phase is to

i. Analyze the results,
ii. Reach conclusions,
iii. Explain limitations, and
iv. Provide recommendations towards improvement based on the findings of the preceding phases (Jensen et al. 1997).

These interpretations form the base for strategy formulation and policy making with respect to chosen product.

2.8.3 Allocation Process

Allocation procedure is the method of dividing the input or output flows of a process to a system under research. Allocation procedures are needed when investigating systems producing multiple products / by-products (e.g. Seed cake after oil extraction, Glycerol after esterification.) The materials and energy flows and associated emission must be spread over different products / by-products according to clearly stated procedures, which need to be documented and justified (Jensen et al. 1997).

The ISO standards allow inclusion of by-products within the system boundaries. In case this by-product substitutes a product usage in the system, it avoids the conventional production of substituted product. The environmental load of this avoided production process can be subtracted from the environmental burden of the system under research (e.g. in biodiesel production seed cake is a by-product, used as organic fertilizer. The seed cake consequently avoids the production of a certain amount of inorganic fertilizer. The environmental burden of the production of that amount of inorganic fertilizer, which is avoided, can be subtracted, seen as a credit, from the overall environmental burden of the biodiesel production).

Alternatively, in case the system under research is compared to a reference system. The environmental burdens of the avoided production of the function delivered by the by-product can be added to the environmental burdens of the reference system. (e.g. In case the impact of biodiesel production and use is compared to the production and use of fossil diesel; the environmental burden of the production of inorganic fertilizer, substituting the seed cake fertilizer produced as by-product in the biodiesel system, should be added to the environmental burden of the reference system, i.e. the production and use of fossil diesel). This practice is called product substitution (ISO 2006a and 2006b).
All the LCA carried out for four crops in this research comply with ISO2006a and 2006b standards.

2.8.4 Types of LCA

As described by Baumann and Tillman (2004), there are three types of LCA

1. **Accounting type or attributional LCA:** It is used for assessing a product's environmental impact and compare different products. This type of LCA can be used to identify key processes in the life cycle, which contribute largely to the overall environmental impacts (Brander et al. 2008).
2. **Change oriented type or consequential:** It is used for assessing the best possible option among different scenarios.
3. **Stand alone type:** It is the most common type, which is used as investigative approach to get familiar with environmental characteristics of a product. highlight the hotspots: the production sub-processes which have the greatest impact on the overall process.

2.8.5 Life Cycle Assessment of Agriculture Crops and Their Products

Initially LCA was used to investigate Industrial Products and Systems. However, from last two decades it has been modified to analyse the impacts of agriculture on environment (Baumann and Tillman 2004). Agricultural operations employed for crop production and management is found to have significant environmental impacts. Agriculture is known to contribute more than 14 % of the total GHGs at global level (IPCC 2007). In addition to GHGs, agricultural operations are also known to impact soil, water and the local flora and fauna. Hence, LCA is an appropriate tool for assessing environmental impacts of agricultural systems.

In this section, a review of relevant literature on LCA of biofuel crops is presented with summary of the key findings. LCA studies have been carried out on various crops across the globe to understand environmental impacts of crop production systems and usage of their products or by products.

Summary of literature review of LCA of Biofuel crops

1	
Author :	Raymond et al. 2004
Location:	Philippines
Crop:	Coconut
System Boundary:	Cradle to Grave
Functional Unit:	1kg of biodiesel
Goal of the LCA:	"To assess the relative life-cycle CO_2 reduction benefits per unit of petroleum diesel displaced by coconut biodiesel"
Key Findings:	• Coconut biodiesel can yield reductions of 80.8–109.3% in net CO_2 emissions relative to petroleum diesel. • The extent of the benefits depend on the manner in which agricultural residues such as coconut shell and husk are utilized, but in all cases examined they exceed the benefits predicted for biodiesel derived from other vegetable oils. • The low CO_2 emissions of the biodiesel system can be attributed in part to the low-energy inputs of current agricultural practices in coconut plantations in the Philippines. • Reduction in CO_2 emissions for the maximum level of biodiesel substitution is estimated to be in the range of 3.70–5.01×106 tonnes / year for biodiesel; this is 2.85–3.85% of the Philippines' total CO_2 emission in 2010. • Benefits could increase in direct proportion to extent of substitution; however, the latter is subject to feedstock supply constraints.
2	
Author :	Zhiyuan et al. 2008
Location:	China
Crop:	Soya Bean
System Boundary:	Source to tank & Source to wheel (Cradle to Grave)
Functional Unit:	One Mega Joule (Equivalent of Biodiesel)
Goal of the LCA:	"To carry out a life cycle energy, environment and economy assessment to compare SB with CD, and to understand the advantages and disadvantages in SB implementation in China"
Key Findings:	• Soybean cultivation and biodiesel conversion stage consume high fossil energy, accounting for 55% and 31%. • Soya Bean biodiesel life cycle required 76% less fossil energy input than conventional diesel. • CO_2 emission from Soya Bean Life cycle was found to be 67% lower than conventional diesel. However, NOx emission was found to be 79% higher than conventional diesel. • The retail price of Soya Biodiesel is about 86% higher than that of Conventional Diesel, which could be one of the critical obstacles for implementing Soya Biodiesel in China.

	• It is strategically important for the Chinese government to diversify the feedstock for biodiesel and to consider other kinds of alternative fuels to substitute diesel.
3	
Author :	Stephenson et al. 2008
Location:	United Kingdom
Crop:	Rape seed
System Boundary:	Cradle to gate (Source to Filling station)
Functional Unit:	One tonne of biodiesel
Goal of the LCA:	"To compare different processes, or the functional unit, blended to a given fractional volume with conventional diesel, and delivered to a filling station in East Anglia"
Key Findings:	• Large-scale biodiesel production in UK was found to save 56% of energy requirement when compared to ultra-low sulphur diesel. • Small-scale biodiesel production in East Anglia was found save 57% of energy requirement when compared to ultra-low sulphur diesel. • Large-scale biodiesel production in UK was found to reduce the GWP by 26% when compared to ultra-low sulphur diesel. • Small-scale biodiesel production in UK was found to reduce the GWP by 32% when compared to ultra-low sulphur diesel. • Large-scale oil extraction, refining and biodiesel production was found to utilise 2600 kg water/tonne of biodiesel, whereas small-scale production was found to utilise 600 kg/tonne of biodiesel.
4	
Author :	Chiung-Lung Su et al.2009
Location:	Taiwan
Crop:	Sugarcane (Ethanol) and Soya Bean and Rape Seed (Biodiesel)
System Boundary:	Cradle to Gate
Functional Unit:	Ethanol produced from 1 ha of sugarcane farmland in 1 year, Biodiesel produced from 1 ha of soybean and rapeseed farmland in 1 year, respectively
Goal of the LCA:	"To construct the inventory of inputs of energy and materials as well as outputs of pollutant and carbon dioxide emissions while considering the environmental impacts of renewable energy i.e. biodiesel and ethanol"
Key Findings:	• The energy input to produce a litre ethanol is less than the energy content of ethanol, which is a positive energy benefit in producing ethanol. • The energy input of a litre biodiesel produced from soybean and rapeseed. which is a positive energy benefit in producing biodiesel. • The amount of CO_2 released during the combustion of ethanol

	is equal to the amount of CO_2 sequestered by the sugarcane crop during its growth. • CO_2 emissions released from burning ethanol is0.08kg/LOE in contrast to2.6kg/LOE released from burning fossil gasoline.
5	
Author :	Kian et al, 2009
Location:	Malaysia
Crop:	Palm oil
System Boundary:	Cradle to grave (Source to Engine)
Functional Unit:	The functional unit used for energy and GHG evaluation is in Giga Joule / tonne crude palm oil / year and ton CO_2/ton biodiesel/year, respectively
Goal of the LCA:	"To assess the energy balance and GHG emission associated with the production of biodiesel from palm oil in Malaysia"
Key Findings:	• Energy yield ratio of palm biodiesel was found to be 3.53, while that of rapeseed was found to be 1.44. • The energy ratio for palm biodiesel was found to be more than double the ratio for rapeseed biodiesel, which shows palm biodiesel is more sustainable feedstock than rapeseed. • In terms of CO_2 emission, it was observed that both Palm and rape seed were positive since both the crops were to sequester more CO_2 from atmosphere than the what was released to atmosphere throughout their life cycle. • Similarly, CO_2 emission from combustion of biodiesel was found to be 38 % less than conventional diesel fuel. • All the above mentioned factors in this research claim Plam biodiesel to be more sustainable than rape seed and Conventional diesel.
6	
Author :	Reijnders et al, 2009
Location:	Europe & Brazil
Crop:	European Rapeseed and Brazilian Soyabean
System Boundary:	Cradle to grave (Seed to wheel)
Functional Unit:	Mg/ ha
Goal of the LCA:	To estimate the emissions of biogenic carbonaceous gases such as CO_2 and of N_2O linked to the life cycle of biodiesel derived from European rapeseed, currently the dominant type of biodiesel, or from Brazilian soybeans, for which a large expansion of production is intended
Key Findings:	• Biogenic emissions of carbonaceous greenhouse gases and N_2O turn out to be important determinants of life cycle emissions of greenhouse gases linked to the life cycle of biodiesel from European rapeseed and Brazilian soybeans. • For biodiesel from European rapeseed and for biodiesel from Brazilian soybeans grown for up to 25 years with no tillage on

	arable soil for which tropical rainforest or Cerrado (savannah) have been cleared, the life cycle emissions of greenhouse gases are estimated to be worse compared to conventional diesel. • Improving agricultural practices should be an important focus for cleaner production of biodiesel. These may include increasing soil carbon stocks by, e.g., conservation tillage and return of harvest residues and improving N-efficiency by precision agriculture and/or improved irrigation practices.
7	
Author :	Laurent et al, 2009
Location:	France
Crop:	Micro Algae
System Boundary:	Cradle to grave
Functional Unit:	1 kg of algal biodiesel
Goal of the LCA:	To identify the parameters or the transformation steps which have the most impact on the energy balance and the environmental performance of the whole chain
Key Findings:	• This LCA study on microalgae addresses, energy balance and environmental impacts of the complete value chain (Biomass production to combustion). Two scenarios have been assessed in this research i.e. (1) Application of nitrogen fertiliser and (2) Nitrogen starving in the production phase followed by (1) Dry extraction and (2) Wet extraction in oil extraction phase. • The results / scenario have been compared with vegetable oil biodiesel and conventional diesel. Results indicate microalgae to be promising biodiesel feed stock. • It also highlights the imperative necessity to reduce energy use and fertiliser consumption, which may be achieved by controlling nitrogen stress during algae culture and optimisation of wet extraction method. • This study also highlights potential of anaerobic digestion of oilcakes to reduce external energy demand.
8	
Author :	Theocharis et al, 2010
Location:	Greece
Crop:	Rapeseed, Sunflower and Soya Bean
System Boundary:	Cradle to Gate (Cultivation to biodiesel Production)
Functional Unit:	one hectare
Goal of the LCA:	To model the environmental performance of biodiesel produced by rapeseed, sunflower, and soybean grown in Greece
Key Findings:	• In this LCA study, three energy crops grown in Greece have been considered (i.e. rapeseed, sunflower, and soybean) with regard to their biodiesel productivity. • The cultivation parameter and Greek climatic conditions have

	been taken into consideration for the study. LCA results indicate that sunflower has the lowest environmental impact per quantity of biodiesel, followed by soybean. • The LCA exercise in the research gives an inference that the whole Life Cycle should be taken into consideration before choosing and applying cultivation patterns of energy crops for biodiesel production
9	
Author :	Seksan et al. 2010
Location:	Thailand
Crop:	Palm oil
System Boundary:	Cradle to gate
Functional Unit:	1 kg of Biodiesel
Goal of the LCA:	The goal of this study was to evaluate the life cycle energy balance and potential of palm oil methyl ester (PME) production in Thailand
Key Findings:	• The NEG and NER were found to be 24.0 MJ/FU and 2.48 respectively. • The major source of energy consumption (57%) was identified to be from methanol production, which is used in transesterification of palm oil to produce biodiesel. • Crop production stage was the second highest contributor (31%) to the energy consumption, which is attributed to fertiliser production and use. Palm oil biodiesel was found to have higher energy efficiency than Rapeseed & Jatropha biodiesel. • The research has also helped in estimating the amount of palm biodiesel required for blending (5%) with conventional diesel.
10	
Author :	Michael et al, 2010
Location:	United Sates
Crop:	-NA-
System Boundary:	-NA-
Functional Unit:	-NA-
Goal of the LCA:	-NA-
Key Findings:	• This paper addresses the importance of taking co-products into account in the life-cycle analysis of biofuels. Several methods are available to include co-products into LCA. • Although ISO 14040 supports the system boundary expansion method (also known as the ‘‘displacement method’’ or the ‘‘substitution method’’) for life-cycle analyses, it is known to have limitation in identifying and quantifying potential products to be displaced by iofuel co-products.

	• Hence, five alternative methods currently employed for including co products into LCA have been evaluated in this research. The methods assessed are (1) The mass- based method (2) Energy content based method (3) Market value based method (4) The process purpose based method and (5) The displacement method. • Upon analysis it was found that , the displacement method can generate distorted LCA results if the co- products are actually main products (for the cases of biodiesel and renewable diesel from soybeans). • It is difficult to advocate whether use of a given method be recommended flatly / automatically for LCA studies. Hence from the assessment of these methods it has been concluded that a generally agreed-upon method should be applied for a given fuel production pathway. Consistency in choice of co-product method may not serve the purpose of providing reliable LCA results. • With this conclusion, the authors are of strong opinion "that the transparency of LCA method(s) selected is important in given LCA studies and sensitive cases with multiple co-product methods may be justified in LCA studies where co-products can significantly impact study outcomes".
11	
Author :	Alfredo et al, 2010
Location:	Chile
Crop:	Rape seed and Sunflower
System Boundary:	Cradle to farm gate
Functional Unit:	1 tonne of seeds per year of sunflower or rapeseed in Chile, cultivated in the major agricultural areas, taking into consideration seeds with 49% oil content (on dry weight basis) and seed moisture content of 8%.
Goal of the LCA:	To quantify and compare the environmental impacts and energy and water demand of the cultivation of sunflower and rapeseed in Chile, with a view to their potential use as energy crops for first-generation biodiesel
Key Findings:	• This research addresses cradle to farm gate LCA study to compare environmental impacts, energy and water demand of rapeseed and sunflower in Chile, as potential biodiesel feed stock. • LCA results indicated that rape seed had better environmental performance in 9 parameters out of 11impact categories evaluated. • Rapeseed also fared well with less water demand compared to

	sunflower. • The energy demand of rape seed was found to be 30% less than sunflower • It was observed that application of mineral fertilizers in both the crops had the highest environmental impact. • Hence authors' are of the opinion that "to reduce the environmental impact and energy requirement of both crops should be mainly associated with the evaluation of other types of fertilizers, low impact herbicides and employing degraded / marginal land"
12	
Author :	W.M.J. Achten et al, 2010
Location:	India
Crop:	Jatropha
System Boundary:	Cradle to grave
Functional Unit:	1 MJ equivalent of Jatropha biodiesel
Goal of the LCA:	This LCA study on Jatropha biodiesel aimed at assessing five impact categories: (i) Non-renewable energy requirement (NRER) (MJ), (ii) Global warming potential (GWP) (CO_2-eq.), (iii) Eutrophication potential (EP) (O_2-eq.), (iv) Acidification potential (AP) (SO_2-eq.) and (v) Land use impact on ecosystem quality. Additional to the NRER, life cycle energy analysis has been performed as well.
Key Findings:	• This LCA study evaluates a small scale, Jatropha biodiesel system established on wasteland in rural India for energy balance, global warming potential, acidification potential and land use impact on ecosystem quality • The uniqueness of this study is, that boundary conditions of the system has been expanded to include biogas production and using seed cake of Jatropha, which is a by product of the system • The environmental impacts of Jatropha compared to the life cycle impacts of a fossil fuel reference system show reduction of 82 % in NRER and 55% reduction in GWP • However, due to use of fertilisers the acidification cation potential was found to be 49% and 430% higher than reference system (Fossil fuel) respectively • Expanding the boundary conditions to include biogas generation from Jatropha seed cake was found to enhance the energy efficiency of the system, which little impact on the GWP even with 10 % Biogas (Methane) leakage to atmosphere. • The land use change impact showed that planting Jatropha on

	waste land improved the structural ecosystem quality however decreased the functional ecosystem quality. This decrease in functional ecosystem quality is attributed to use of inorganic fertilisers (N- Fertiliser). • Finally authors are of the opinion that optimizing fertiliser application and agronomic practices with use of better breeds of Jatropha are the major system improvement options

2.9 Findings from LCA literature

The review of literature on LCA studies of biodiesel feedstock reveal that, accept for Algae and Jatropha, all the feedstock are edible in nature and give ample scope for the debate on food fuel conflict. Majority of the studies reviewed show that biodiesel system is more energy efficient compared to conventional diesel. Major portion of the energy usage in the biodiesel systems have been attributed to use of Methanol in transesterification (Seksan et al. 2010), followed by use of fertilisers, pesticides and herbicides during cultivation (Achten et al. 2010, Kian et al. 2009 and Alfredo et al, 2010).
Similarly environmental impact through emission of GHG have been attributed to cultivation phase followed by combustion.

Literature review reveals that energy efficiency of the biodiesel system improves if the by-products are included in the boundary condition of biodiesel system (Raymond et al. 2004 and Achten et al, 2010). Literature also reveals that there is no prescribed method, on expanding the boundary conditions to include by products, which can be adapted to all kinds of LCA studies (Michel et al 2010). Consistency in choice of co-product method may not serve the purpose of providing reliable LCA results. Hence a generally agreed-upon method should be applied for a given fuel production pathway.

Stephenson et al. (2008) working on LCA of rapeseed in UK has inferred that small-scale biodiesel system is comparatively efficient in terms of energy, emission and water requirement.

Reijnders et al. (2009) have opened a new dimension of looking at the environmental impact by the emission of GHG due to land use change or replacing the tropical forest and Savannah for cultivating biodiesel feed stock. This study has revealed that the life cycle emissions of greenhouse gases of biodiesel system (on cleared lands) are estimated to be very high compared to conventional diesel.

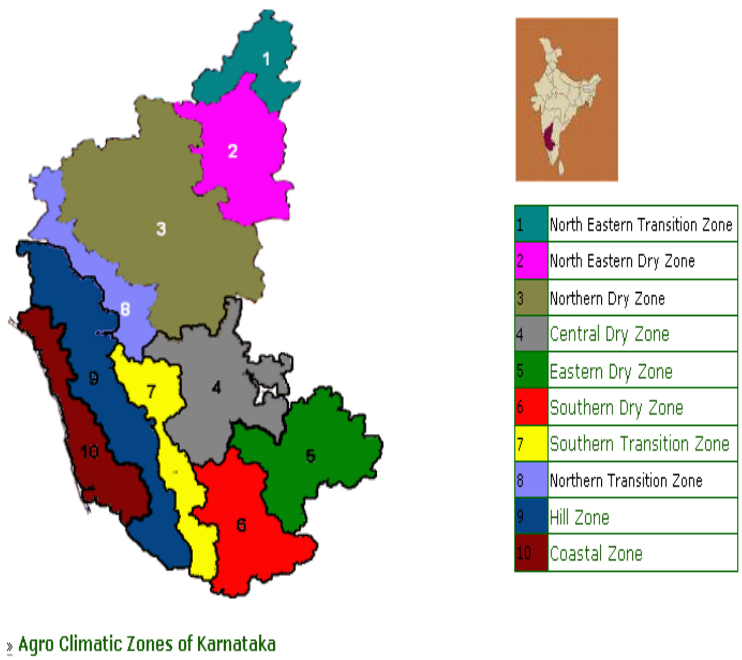
Achten et al. (2010) has proposed and used a comprehensive land use change impact analysis method, to assess the structural and functional quality of the soil upon cultivating any given biodiesel feed stock. This method is been found to be systematic and evolved compared to the one followed by Reijnders et al. (2009). Hence, method and methodology adopted by Acthen et al. (2010) for LCA study of Jatropha has been suitably adopted for carrying out sustainability study on Pongamia, Madhuca, Azadiractha and Simarouba. These methods have been explained in the following chapter.

CHAPTER 3

METHODS

3.1 Tree Borne Oil Species of Karnataka

As part of the preliminary studies, a literature review was carried out to identify Tree Borne Oil (TBO) species available in Karnataka State, suitable for serving as promising feedstock for producing biodiesel. Karnataka State ecology comprises of eight agro climatic zones. The Department of Forestry and Environmental sciences from University of Agricultural Sciences (UAS), Bangalore has carried out an extensive research and identified more than 80 TBO (Appendix-1) species inhabiting these ten agro climatic zones (Figure 3.1).



*Picture sourced from Dept of Agriculture – Karnataka state

Figure 3. 1 Agro Climatic Zones of Karnataka State

From the list (Appendix-1), four TBO species namely (1) Pongamia pinnata, (2) Madhuca longifolia, (3) Azadirachta indica and (4) Simarouba glauca were found to be local tree species of southern dry zone of Karnataka State, which also houses the Biofuel

Park at Hassan district. Therefore, these four species were selected for further research in comparison with conventional fossil diesel and Jatropha biodiesel.

The essential requirement for bio-fuels to be a sustainable alternative fuels is that they should be produced from renewable feedstock with less environmental impact. Therefore, a study is needed to infer whether both requirements i.e. renewable feedstock and lower negative environmental impact are satisfied. Life cycle assessment (LCA) is a method, which has been used to evaluate the environmental impact of biofuel from different vegetable oils (Zemanek and Reinhardt 1999, Tan et al. 2002, Tan et al. 2004 and Fredriksson et al. 2006). Hence, this LCA study of TBOS for researching the environmental & economic sustainability as biodiesel feedstock.

In general, LCA studies on biofuels concentrate on energy balance and global warming potential, but land use impacts on global warming is rarely addressed. It is not included because there is no life cycle method to distribute initial carbon loss due to land use change over the different functional units, which will be produced by the production system that triggered the land use change. Hence Fargione et al. (2008) have come out with a concept called carbon debt and repayment time.

The carbon debt is the net CO_2-eq emission caused by a certain land use change due to carbon loss from aboveground biomass and soil. The repayment time is calculated by dividing the allocated carbon debt (allocation % of product under research × total carbon debt) by the annual CO_2-eq emission reduction (e.g. in the oil palm case allocated carbon debt = 87% of 702 t CO_2-eq = 610 t CO_2-eq and repayment time = 610 ÷ 7.1 = 86 year (Fargione et al. 2008). The repayment time indicates the period the production process has to last (i.e. biodiesel production and use) before the initial carbon loss is compensated. The system will attain net CO_2-eq reduction only after the repayment time

3.2 Description of LCA Methodology Adopted

The rationale of the LCA study carried out in this research is to understand the energy balance and environmental impacts of four tree borne oil species viz: (1) Pongamia pinnata (2) Madhuca longifolia (3) Azadiractha indica (4) Simarouba glauca, as biodiesel feedstock in rural Karnataka (A southern state in India). LCA studies of all the four feedstock have been carried out individually to understand the processes / phases of the life cycle causing greater environmental impact and energy usage. In addition to assessment of environmental impact and energy balance, economics of each life cycle has been analysed. The results of each LCA have been compared with a reference system i.e. LCA results of conventional diesel and Jatropha biodiesel. Therefore, an accounting type LCA in combination with change oriented LCA is considered for this study. Accounting type LCA is used for assessing a product's environmental impact, compare the results with different products (Baumann and Tillman 2004), and change oriented LCA quantifies the potential impacts of a change in the output of a product.

3.3 Goal and Scope of LCA Defined

This LCA study has been carried out in accordance with the guidelines of the International Organization of Standardization (ISO 14040-14044, 2006) for the life cycle assessment.

The goal of this LCA study is to determine the environmental impacts, energy use and analyse the economics of Pongamia, Madhuca, Azadiractha and Simarouba biodiesel in Rural Karnataka. The objective of this study is to compare the results with reference systems and use the results for framing sustainable biodiesel strategies for rural Karnataka.

LCA of Pongamia, Madhuca, Azadiractha and Simarouba biodiesel aims at studying the use of biodiesel as a source of fuel for transportation / water pumping / electricity generation produced locally in rural Karnataka.

The results of this study may be used by:

- LCA practitioners
- Policy decision makers
- Biofuel park / renewable energy agencies

3.4 Functional Unit

The function of TBOs is to produce oil seeds, which is used to extract oil and convert the same into biodiesel to release energy when combusted in an engine. Hence, the functional unit considered for the LCA studies is one mega joule of energy available in the biodiesel produced from the chosen TBOs.

3.5 Boundary Conditions

The LCA includes three phases

1. Cultivation phase
2. Oil extraction phase
3. Biodiesel conversion and use phase

The main product of the system are seeds, oil and biodiesel. The co-product / by-product of the system are seed cake, fuel wood and glycerine (+biogas from seed cake in case of Pongamia).

The main boundary includes the three phases mentioned above. However by-product of the system plays a major role in the energy, emission and economics of the system, hence the boundary has been expanded to include the by-products as per ISO14040-44 (2006).

3.6 Allocation

Allocation is dividing of the input or output flows of a process to the (biodiesel) system under research. According to Jensen et al. (1997) the materials, energy flows and associated emissions should be spread across different phases of life cycle (Section 3.5, Table 3.1 and Table 3.2) and recorded with justification. ISO standards allow allocation based on Mass ratio, energy content ratio and economic value ratio (Achten 2010). Expanding the system boundaries helps in including the by-products into the system. If the by-product serves as a substitute for conventional function, environmental load of this conventional function production process can be subtracted from the environmental burden of the system under research (Achten 2010).

3.7 Impact Categories

The following impact categories have been assessed in this LCA

(i) Non-renewable energy requirement [MJ],

(ii) Global warming potential [CO_2- eq.],

(iii) Acidification potential [SO_2- eq.]

(iv) Eutrophication Potential[O_2-eq] and

(v) Land use impact on ecosystem quality.

In addition to the above mentioned impacts, a life cycle energy was analysed as well. i.e.

(vi) Net Energy Gain (NEG = energy output – energy input) and

(vii) Net Energy Ratio (NER = energy output/energy input) were calculated.

The impact assessment methods of all the above-mentioned impact categories have been explained in section 3.9.

3.8 Place of Work

This LCA study was carried out at Agriculture Research Station (ARS) located at Madenur in the Hassan district of Karnataka State, named as 'Biofuel Park' (Ref Figure 2.2). 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 6826.15 km². It is divided into 8 taluks*, 38 hoblies* & 2559 villages. The geography is mixed with the malnad (mountainous region) to the west and southwest called '*Bisle Ghat*' and the '*maidan*' (plains) regions in the North, South and East. There are some areas of degraded forest ranges in central portion of the district (Biofuel Park 2012 and Lokesh et al. 2012).

Biofuel Park extension services have helped in successfully establishing 465 farmers associations called "*Jaivika Indhana Beejagala Belegarara Sangha*" (Biofuel feedstock growers association). It covers more than 70 villages designated as **"**Complete Biofuel Village". Biofuel Park located at Madenur research station has around 50 acres land housing 4-5 year old block plantations of Pongamia, Madhuca, Azadiractha and Simarouba trees (Figure.2.3) associated with a full-fledged nursery for raising TBO species saplings (Figure.2.4). It houses an oil extraction unit (Figure.2.5) esterification unit of 250-litre capacity (Figure.2.6).

** Taluks & Hobli: Cluster of several Villages form a Hobli and Several Hoblis form a Taluk and several Taluks form a District in a State.*

Figure 3. 2 Biofuel Park (Biofuel Park)

Figure 3. 3TBO species block plantations (Biofuel Park)

Figure 3. 4 Nursery –TBO saplings (Biofuel Park)

Figure 3. 5 Oil extraction unit (Biofuel Park)

Biofuel Park has also been successful in running a vehicle using 100% biodiesel (Figure 3.7). This vehicle has covered more than 5000 km* till date on 100% biodiesel. The emission from the vehicle has been measured for fossil diesel, B20 and B100. HSU (Hart ridge Smoke Unit) of the three fuels was found to be 5.25, 4.38 & 2.75 respectively. This shows lower smoke emission for B100 and better combustion compared to fossil diesel.*
Refer Appendix 13, 14 and 15 for emission details of the vehicle depicted in figure 3.7

Figure 3. 6 Esterification unit (Biofuel Park)

Biofuel Park also has a full-fledged biochemistry lab to analyse biodiesel feedstock for various parameters as per international standards.

Figure 3. 7 Vehicle run on 100% biodiesel (Biofuel Park)

Figure 3. 8 Manually Operated Oil Expeller (Biofuel Park)

** The details of the vehicle travelling more than 5000 km are available on (Fig 3.7) http://www.biofuelpark.org/show-gallery.php?name=Biodiesel%20Rally*

** Manually Operated Oil Expeller (Fig 3.8) was a reverse engineered scaled down model of a motor driven expeller. However, the seed cake exit chute was modified with adjustable screws for adjusting the pressure and slot for seed cake exit (especially for TBOs seeds).*

All the four TBOs selected for this research have been analysed in the biochemistry lab at Biofuel Park for

- Oil % using manually operated miniature oil expeller, (Figure 3.8),
- Standardisation of esterification parameters (Figure 3.9, 3.10) and
- Biodiesel properties viz: Specific Gravity, Flash point, and Calorific value

Figure 3. 9 One litre capacity esterification unit (Biofuel Park)

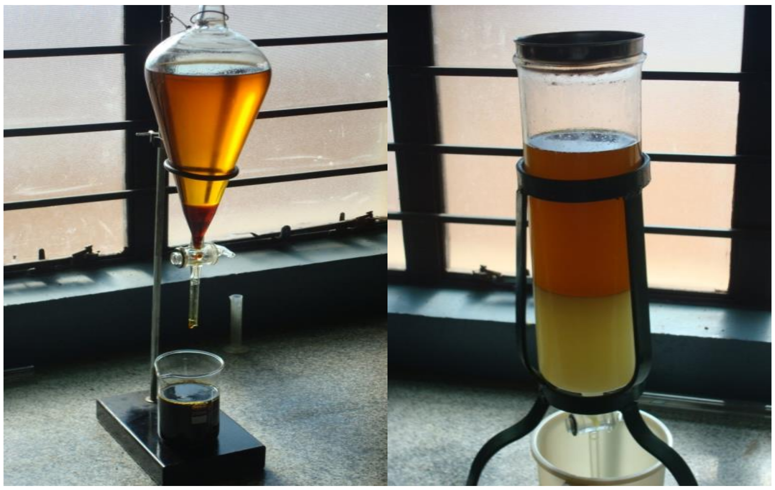


Figure 3. 10 Settling unit for separating glycerine and washing of biodiesel(Biofuel Park)

Properties of all the four TBOs feed stock where found to be within the prescribed limits as per international standards. (Appendix 6 and 5 for esterification procedure and properties of biodiesel produced from Pongamia, Madhuca, Azadiractha and Simarouba oils).

**Miniature oil expeller (Fig. 2.8) was designed and fabricated for estimating the oil % as a part of this research. Similarly, one litre oil esterification unit (Fig. 2.9) was suitably modified using electronic sensors for temperature control during esterification.*

3.9 Data Collection

The data was gathered from Biofuel park offices and by interaction with farmers associations called "*Jaivika Indhana Beejagala Belegarara Sangha*" -Biofuel feedstock growers association (Appendix-2). Data from scientific literature and automobile emission data from Automotive Research Association of India-Pune was used as well. System-specific data (e.g. fertilizer use) were collected from Biofuel park records, while general (e.g. field emission rates: N_2O, NH_3 and N leaching of applied N were taken from IPCC database), background data (e.g. production impact of fertilizer) were collected from literature. The factors considered in this study are given in the tables 3.1 to 3.5 (cultivation, oil extraction, biodiesel production and end use with respect to each production phase).

The distance travelled and the mode of transport used for moving inputs and outputs between different system phases has also been accounted. This data was collected by interacting with farmers understanding their agronomical practices.

To assess the impact of land use (for growing TBOs) on ecosystem quality, ecosystem structural quality (ESQ) and ecosystem functional quality (EFQ) were quantified by field measurement. Field measurement was carried out for three land uses i.e.

1. The land use under investigation (i.e. TBOs plantation)
2. The previous land use (i.e. waste land/degraded grassland/ Agricultural Bunds)
3. The local potential natural vegetation (LPNV) (i.e. the vegetation that would grow naturally in the long term without human intervention)

This data was collected from selected plots adjacent to currently available plantation at Biofuel Park (ESQ & EFQ). Local potential Natural Vegatation (LPNV) data was collected from literature and interaction with Biofuel park research personnel. The table 3.1 shows information collected for TBOs LCA studies.

Table 3. 1 Information collected for TBOs LCA studies from Biofuel Park

No.	Particulars	Variables	Data
1	Cultivation	Nursery practices	Poly-bag use, water use, fertilizer use, machinery use
		Field Preparation	Machinery use
		Plantation establishment	Seedlings per ha, fertilizer use
		Plantation management	Irrigation, fertilization, weeding and harvest practices
		Yield	kg seeds / ha / yr
		Transport distances	Machinery, fertilizer, Seeds
		Irrigation pump	Capacity & energy consumption
2	Oil extraction	Extraction rate	kg oil / kg seed
		Oil press	Capacity and energy consumption
		Filter Press	Capacity and energy consumption
		By-product & use	Seed cake
3	Biodiesel production	Transesterification practices	Reagents and catalyst use
		By-product use	Glycerine

(Lokesh et al. 2012)

The table 3.2 shows factors considered in the LCA of TBOs biodiesel (for combustion in an engine) for each production phase and impact category.

Table 3. 2 Factors measured in the LCA of TBOs biodiesel

NRER	**Non-renewable energy requirement [MJ] for:**			
Sl. No.	**Cultivation**	**Oil Extraction**	**Biodiesel Production**	**End Use**
1	Tractor production	Oil-press production	Transesterification unit production	
2	Pump production	Electricity production and use: - oil press - filter press	Methanol production	
3	Infrastructure: farm shed		Production of catalyst (NaOH)	
4	Poly bags production		Electricity production and use:- - transesterification unit	
5	Fertilizer production			
6	Diesel production and use*			
7	Electricity production and use:			
GWP	**Greenhouse gas emissions (CO_2, CH_4, N_2O) [CO_2-eq] caused by:**			
	Cultivation	**Oil Extraction**	**Biodiesel Production**	**End Use**
1	Poly-bags production	Electricity production and use:- oil press - filter press	Methanol production	
2	Burning waste poly-bags	Biogas leakage	Electricity production and use: - transesterification unit	
3	Fertilizer application -organic -inorganic			
4	Diesel use			
5	Electricity production and use			
AP	**NH_3, NO_X and SO_X emissions to air [SO_2 –eq] caused by:**			
	Cultivation	**Oil Extraction**	**Biodiesel Production**	**End Use**
1	N volatilization	Electricity production and use- oil press - filter press	Electricity production and use - transesterification unit	
2	Poly bag burning			
3	Diesel use			Biodiesel combustion

(Lokesh et al. 2012)

The description of the data collected for cultivation phase, oil extraction phase and esterification phase for analysing energy balance and emission from the system have been listed in the following table no 3.3, 3.4 & 3.5. The required input parameters were decided based on the operations and material involved in each phase

Table 3. 3 Input data collected for assessing cultivation Phase

Sl. No.	**Cultivation**
1	Soil type
2	Seed Collection Kg / Day / Person (Fruit)
3	Seed Storage Viz: Heaping, Gunny bag and Plastic bags
4	Propagation –Vegetative / Seeds
5	Irrigation –Manual / Drip / Tube well
6	Power Consumed for Irrigation (Units)
7	Transportation of seedlings to main field Bullock cart / Tiller / Tractor /Auto/ Mini truck. Please specify
8	Average Distance
9	Transplanting Pitting / Sowing Manual / Machine (Capacity & Fuel Usage)
10	Number of Labour required for transplanting / ha
11	FYM / pit in kg
12	N / pit in kg
13	P / pit in kg
14	K / pit in kg
15	Herbicide used if any & Quantity
16	Pesticide used if any & Quantity
17	Weeding, Manual (No of labourers /ha) Power weeder (Labour + Fuel)
18	Inter cultivation if any
19	Harvesting (Labour required)
20	Drying / Processing if required + No of labourers
21	Transportation of produce from main field to storage-Bullock cart / Tiller / Tractor /Auto/ Mini truck. Please specify
22	Average Distance
23	Seed Storage Viz: Heaping, Gunny bag, Plastic bags
24	Transportation of produce from storage to market/ oil mill-Bullock cart / Tiller / Tractor Auto/ Mini truck. Please specify
25	Average Distance
26	No of trees and Yield / ha
27	Type of root systems & N- Fixing
28	Apiculture support / Serving as support of other life- beneficial to nature and mankind
29	Medicinal value
30	Religious value
31	Fire Wood, Timber and other usage

Table 3. 4 Input data collected for assessing oil extraction Phase

Sl. No	Oil Extraction
1	Transportation of oil seeds from field / market to oil mill by bullock cart / tiller / tractor/ auto/ mini truck
2	Average Distance
3	Seed Storage Viz: Heaping, Gunny bag and Plastic bags
4	Pre Processing if any Please specify method, Labour and energy consumed if any
5	Oil extraction machine capacity
6	Power consumed for oil extraction from 100 kg of seeds
7	Oil yield / 100 kg of seeds
8	Oil storage method / container
9	Seed cake yield / 100 kg of oil seeds
10	Uses of oil
11	Uses of seed cake
12	Price of oil seed in Rs. / kg
13	Price of oil Rs. / kg
14	Price of seed cake Rs. / kg
15	Oil calorific value MJ/kg
16	Oil viscosity@40°C –cSt
17	Density g/cm3

Table 3. 5 Input data collected for assessing esterification and use Phase

Sl. No.	Esterification
1	Transportation of oil from oil mill to esterification unit- bullock cart / tiller / tractor /auto/ mini truck
2	Average Distance
3	Oil Storage method / Container
4	Esterification of 100 litres of oil (86 kg)
	Sodium hydroxide in kg
	Sulphuric acid in litres
	Acetic acid in litres
	Methanol in litres
	Electricity consumed
5	Labour requirement
6	Biodiesel yield in litres or kg
7	Glycerine yield in litres or kg
8	Glycerine usage
9	Physical properties of biodiesel (Appendix 2)
	Specific Gravity, Flash point-°C &Calorific value of Biodiesel- MJ/kg
10	Engine Emission

The land use impact assessment methodology has been adopted from Achten et al. (2009) literature, (Paper published in sixth International Conference on LCA in the Agri-food sector, Zurich in November 2008). This methodology helps in assessing both impacts from land use change (LUC) and land occupation (LO) on ecosystem quality. The methodology proposes several mid-point indicators suitable for this quantification, which are as follows.

- Total above-ground biomass (TAB) [kg dry matter / ha] and number of vascular plant species (NS)
- Soil cover (SC) [%], water infiltration rate (IR) [cm / hr] and vertical space distribution (VSD)
- The impact on the ecosystem quality is quantified by ecosystem structural quality (ESQ) and ecosystem functional quality (EFQ).

TAB, NS, SC, IR and VSD are the average mid-point indicator values for the TBOs plantation, the Local potential natural vegetation (LPNV) and the reference land use, which is degraded grassland for LUC impact and the LPNV for LO impact. Mid-point indicator measurement method for land use impact of TBOs on ecosystem quality and environmental impacts calculation method have been described in the following section.

3.10 Reference System

For life cycle comparison, the reference system (fossil fuel) must provide the same products and functions as the (TBOs biodiesel) system evaluated (Lokesh et al. 2012). 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 they are displacement products.)* 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; Achten et al. 2010 and Lokesh et al. 2012). The inventory analysis of the reference system has been built using data from the literature- Achten et al. (2010) (Table 3.6).

Table 3. 6 Reference system data compared with TBOs biodiesel system are as follows.

(Achten et al. 2010)

3.11 Impact Assessment Methods

Impact assessment methods like (1) Environmental monitoring procedures and (2) Standards with principles criteria and indicators (PC&I) were considered for assessing the impact of land use and land use change (Baitz 2007). However, one of the major drawbacks of these methods was lack of description of measurable indicators and end point impacts. This issue has been addressed in life cycle land use impact calculation methodology proposed by Achten et al (2008), which is an enhanced version of IMPACT 2002+ method developed by University of Michigan. The same has been adopted for assessing the environmental impact of TBOS in this research. Achten et al (2010) have used this method to assess the ecological Impact of Jatropha in Indian context. Adopting this method shall help in comparing the impacts of Jatropha with the LCA results Pongmaia, Madhuca, Azadiractha and Simarouba on the same platform.

The methods adopted in this LCA to assess the five impact categories have been explained in this section. The following table 3.7 gives an overview of the impact calculation and the units of the impact categories used in this study.

Table 3. 7 List of impact category

This table has been removed due to third party copyright. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University

(Achten et al. 2009)

‡ Total energy output is based on the energy content of the products and by-products

** GHG emissions: Greenhouse gas emissions, i.e. CO_2, CH_4 and N_2O emissions;

††: PNV: Potential natural vegetation;

i. Parameter considered for calculating NRER are as follows

Table 3. 8 Non-renewable energy requirement in MJ for TBOs LCA

Sl.	**Cultivation**	MJ
1	Tractor production	
2	Infrastructure: farm shed	
3	Poly bags production	
4	Fertilizer production N, P & K	
	Sub Total	
5	Diesel production and use	
6	Electricity production and use	
	Oil Extraction	
7	Oil press production	
8	Electricity production and use:	
	Sub Total	
	Biodiesel Production	
9	Transesterification unit production	
10	Production of methanol	
11	Production of catalyst (NaOH)	
12	Electricity production and use:--	
	Sub Total	
	Grand Total	
	Per FU	

NRER impact category helps in summation of non-renewable energy used in any given life cycle and helps in identifying the hot spots / key processes, which add to the major portion of the impact. However, analysing total energy input and output gives a complete picture for understanding the energy balance. Hence, net energy gain and ratio are calculated. Parameter considered for calculating energy input and output are as shown in Table 3.9 & 3.10.

Note: Wood fuel is an integral part of rural energy source in India and the TBOs considered for this research have been harvested for fuel wood in and around villages. Since the amount of wood harvested is not recorded in literature, a nominal amount of wood / tree / year has been considered (based on interaction with Biofuel park personnel) for calculation of energy output and emissions.

Table 3. 9 Parameter considered for calculating energy inputs in TBOs biodiesel system

Stage	**Energy**	**Energy in MJ**
Cultivation	Man power	
	Diesel	
	FYM	
	Poly bags	
Sub Total		
Oil	Man power	
	Diesel	
Sub Total		
Esterification	Man power	
	Electricity	
	NaOH	
	H_2SO_4	
	Acetic Acid	
	Methanol	
Sub Total		
Total		
Miscellaneous		
Grand Total		
Energy in MJ		

Table 3. 10 Parameter considered for calculating energy output from TBOs biodiesel system

Stage	**Energy**	**Energy**
Cultivation	Pod shell	
	Seed	
	Fuel Wood	
Sub Total		
Oil Extraction	Oil	
	Seed cake	
Sub Total		
Esterification	Biodiesel	
	Glycerine	
Sub Total		
Total		
Energy in MJ / FU		

Note: In addition to the energy output parameters considered in table 3.10, use of Pongamia seed cake as direct fuel and input for producing biogas and associated emission have been considered in energy output calculation of Pongamia LCA. However, comparisons between TBOs have been made on common plat form i.e. without biogas in case of pongamia.

Table 3. 11 Parameters considered for calculating global warning potential (GWP) g CO_2-eq / FU

Stage	**Particulars**	**gCO_2- eq / ha**
Cultivation	Poly-bags production& discharge	
	Organic Fertilizer application	
	Fuel Wood	
	Diesel Use for Transportation	
	Sub Total	
Oil Extraction	Electricity production	
	Biogas leakage	
	Biogas Combustion in an Engine	
	Sub Total	
Biodiesel	Methanol production	
	Electricity production and use: - transesterification	
	Biodiesel Combustion in an Engine (B100)	
	Sub Total	
	Total	
	gCO_2- eq / FU	

Table 3. 12 Parameters considered for calculating acidification potential (GWP) g SO_2-eq / FU and Eutrophication Potential gO_2-eq/FU

Stage	**Particulars**	**SO_2 / O_2 g- eq / ha** (Quantity x CO_2/ Unit)
Cultivation	N volatilization (NH_3)	
	Poly bag Production & Discharge- SO_2	
	Poly bag Production & Discharge- Nox	
	Diesel use- Nox	
	Sub Total	
Oil Extraction	Electricity production and use- Oil press + Filter Press	
	Biogas Combustion in an Engine	
	Sub Total	
Biodiesel Production	Electricity production and use- transesterification unit	
	Biodiesel Combustion	
	Sub Total	
	Total	
	gSO_2- eq/FU	

3.12 LUC and LUO Calculation Methodology

The LUC and LUO calculation methodology has been adopted from a paper titled "Proposing a life cycle land use impact calculation methodology" presented in sixth International Conference on LCA in the Agri-Food Sector held at Zurich on November 12–14, 2008, by Achten et al and suitably modified.

Methodology to quantify Ecosystem Structural Quality (ESQ) and Ecosystem Functional Quality (EFQ):

Impact of on ESQ measured by assessing a. Soil Fertility b. Biodiversity c. Biomass Production	Impact of on EFQ measured by assessing d. Soil Structure e. Vegetation Structure f. On site water balance

↓ ↓

a. Soil fertility is measured based on Cat ion exchange capacity of the soil	**d. Soil Structure** is measured based on the soil organic matter

b. Biodiversity is measured by counting number vascular plant species in a given plot	**e. Vegetation structure** is measured by vertical space distribution of a given vegetation strata in a plot

c. Biomass production is measured based on total above ground mass in a given plot*	**f. On site water balance** is measured by evapo-transpiration method

The results available from the above mentioned measurement is used to arrive at impact indicator score using the following formula

$$IS = \sum_i \left(\frac{A_i}{A_t} \times \frac{[Value_{ref} - Value_{proj,i}]}{value_{pvn}} \right) \times 100 \ldots\ldots\ldots \qquad \text{Equation 1}$$

Where

A_i = Evaluated Specific Activity

A_t = Area under evaluation

Value $_{proj,i}$ = Measured value of the particular indicator for the area under evaluation

Value $_{refi}$ = Measured value of the selected indicator for the reference system i.e. values of land used prior to biodiesel feed stock plantation for measuring LUC and values of local potential natural vegetation for measuring LUO

Using the indicator scores obtained (using equation 1), the impact of ESQ and EFQ is measured using.

$$I_{ESQ} = \frac{\overline{IS_{Sf}} + \overline{IS_{Bp}}}{2} \quad \text{............Equation 2}$$

$$I_{EFQ} = \frac{\overline{IS_{Ss}} + \overline{IS_{Vs}}}{2} \quad \text{...........Equation 3}$$

Where

- ***I*** = impact indicator
- ***IS*** $_{x}$ = average measurement of Soil Fertility, Biodiversity, Biomass Production, Soil Structure and Vegetation Structure
- Sf = Soil fertility;
- α-Bd = biodiversity;
- Bp = TAB (Green weight)
- Ss = Soil structure;
- Vs = Vegetation vertical space

Further the Impact of ESQ and EFQ per function unit is calculated using

$$F = \frac{(time \times area)}{FU} \quad \text{............. Equation 4}$$

Where

FU = Functional unit

Time x area = land required to produce biodiesel feedstock equivalent to one functional unit in a specified time

****Note: Onsite water balance has not been considered since the TBOs are grown in rain fed conditions***

3.13 Methodology for Calculating the Green Weight (TAB) and Amount of CO_2 Sequestered by a Tree Per Year

Carbon sequestration rate of any give tree species depends on its growth characteristics, local environment and wood density. Sequestration rate is found to be high in trees b/w the age of 20 to 50 years.

The process of calculating CO_2 sequestration is as follows:

1. Find out the green weight of the tree, followed by dry weight,
2. Find out weight of carbon in the wood
3. Calculate quantity of CO_2 sequestered per year

The algorithm to calculate the green weight of a tree is:

W = Weight of above-ground biomass (Pounds

D = Diameter of the trunk at chest height (Inches)

H = Height (ft)

Green weight of the trees with $D < 11$ is calculated using $W = 0.25D*H$

Green weight of the trees with $D > 11$ is calculated using $W = 0.15D*H$

The root system weighs 20 % of the TAB, hence to arrive at the total green weight of the tree; TAB is multiplied by 120%

Calculating the dry weight of the tree

It has been determined by research that, any given tree on an average has 72.5% dry matter (and the remaining 27.5 is moisture). Hence, to arrive at dry weight, multiply the total green weight of the tree by 72.5%.

Calculating weight of carbon in the wood

It has been determined by research that any given wood / tree is made up of 50% carbon hence, multiplying dry weight of the wood / tree by 50% gives the weight of the carbon in the wood.

Calculating the weight of CO_2 sequestered by a tree

- CO_2 made up one carbon and two oxygen molecules
- Atomic wt of C = 12.00115
- Atomic wt of O_2 = 15.9994
- Ratio of CO_2 to C = 3.6663
- Hence CO_2 sequestered by a tree = weight of carbon in the wood x 3.6663
- CO_2 sequestered by a tree / year = weight of carbon in the wood x 3.6663 / age of the tree

Based on the above explained method TAB and CO_2 sequestration of Pongamia, Madhuca, Azadiractha and Simarouba have been calculated and tabulated in the Appendix 8, 9, 10 and 11 (30 tree in random were selected from each block plantation for measurements)

3.14 Illustration of calculating LUC and LUO (Pongamia)

Table 3. 13 Soil sample results of Pongamia plantation

Crop	Place	***	OC	OM	CEC	Total Area in acres	Area Under Research in acres
Pongamia	Biofuel Park	Current	1.09	1.87	18.81	50	2.5
Vacant land	Biofuel Park	FLU	0.8	1.37	13.53	50	2.5
Jack	Biofuel park	LPNV	1.32	2.27	15.84	50	2.5

(Appendix -7)

***

Current: Represents samples collected from plots currently hosting the biodiesel feedstock
FLU: Represents former land use
LPNV: Represents local potential natural vegetation
OC = Organic Carbon
OM = Organic Matter
CEC = Cation exchange capacity

Note: This methodology has been adopted from https://www.broward.org/NaturalResources/ClimateChange/Documents/Calculating%20CO2%20Sequestration%20by%20Trees.pdf

Using Equation 1, (Section 3.12), the results for Pongamia feedstock LUC and LUO are as shown in table 3.14.

Table 3. 14 Impact of Pongamia feedstock on LUC and LUO

Cation Exchange Capacity	
Crop- CEC	18.81
LPNV- CEC	15.84
FLU- CEC	13.53
Impact-LUC	-1.67
Impact- LUO	-0.94
Organic Matter	
Crop- OM	1.87
LPNV- OM	2.27
FLU- OM	1.37
Impact LUC	**-1.10**
Impact LUO	**0.88**
Total Above Ground Mass	
Crop- TAB in kg	265
LPNV	1392
Ref/ FLU/Grass lands	2.4t/ha = 72kg/33 m^2
Impact LUC	**-0.69**
Impact LUO	**4.05**
Vertical Space Distribution	
Crop Dominant height	14
Strata	4
LPNV Dominant height	16
Strata	2
Ref / Dominant height Grass land	4
Impact LUC	**0.31**
Impact LUO	**2.81**
Note: One feet = One Strata	

Using Equation 2 & 3, (Section 3.9.4), the results for ESQ and EFQ of Pongamia feedstock are as shown in table 3.15.

Table 3. 15 ESQ and EFQ of Pongamia feedstock

Impact	Pongamia
Impact ESQ LUC	-1.18
Impact ESQ LUO	1.56
Impact EFQ LUC	-0.39
Impact EFQ LUO	1.85

Using Equation 4, (Section 3.12), the results of ESQ and EFQ per functional unit, for an area of $6m^2$ of Pongamia feedstock are as shown in table 3.16.

Table 3. 16 ESQ and EFQ of Pongamia feed stock per functional unit

Impact / FU	Pongamia
Impact ESQ LUC	-35.40
Impact ESQ LUO	46.66
Impact EFQ LUC	-11.83
Impact EFQ LUO	33.24

Based on the impact results of growing Pongamia on a given land, ecological impact on the structure and function of the ecosystem are interpreted to arrive at conclusions for policy decision making.

3.15 Economics of TBOs Based Biodiesel Production

Economics of TBOs based biodiesel has been analysed for understanding the viability of the same in comparison to conventional diesel. Hence, cost analysis of cultivation, oil extraction and biodiesel production has been carried out using activity based costing method.

Costing has been carried out for cultivating TBOs as a biodiesel feedstock in one hectare of wasteland under rainfed condition. Cost of cultivation has been calculated until the plantation stabilizes and starts yielding, followed by costing of one litre biodiesel.

3.16 Strength Weakness Opportunities and Threat (SWOT) Analysis

SWOT Analysis, known earlier as TOWS Matrices is a strategic tool used to estimate the Strengths, Weaknesses, Opportunities, and Threats of given project, business or a strategy. It helps in identifying internal weaknesses and external threats of the strategy or business analyzed (Dominick 2007). SWOT analysis has been carried out for evaluating the strategy followed by Biofuel Park (Chapter-7) and proposes alternate strategies overcoming the weaknesses and threats of the Biofuel park strategy.

3.17 Uncertainty Analysis and Sensitivity Analysis

The uncertainty analysis has been carried out using Monte Carlo method assuming normal distribution for all the variables (Using Microsoft Excel). Results for the chosen impact categories were calculated thousand times by randomly choosing a value for each input variable based on their mean and standard deviations.

Sensitivity analysis is a data quality analysis method. It is carried out to decide on input factor, which has main impact on model results. This information will help in eliminating least important parameters and provide a direction for further research in order to reduce uncertainties and improve the accuracy of the model (Hamby 1994). It measures the extent to which the LCI results and portrayed models affect the impact indicators results (EPA 2006). It helps to know the degree of the effect of the assumptions made in the LCA study.

Single variable method / one-at-a-time sensitivity analyses method has been adopted in this research and it has been performed for (1) Energy balance (2) Global Warming Potential and (3) Cost of biodiesel.

Energy input and output and global warming potential sensitivity analysis was carried out varying only one variable i.e. travel distance (Diesel Consumed). Sensitivity analysis for cost of biodiesel was carried out in comparison to conventional diesel using trend analysis to forecast the price of diesel and biodiesel produced from TBOs oil until the year 2020.

Pongamia, Madhuca, Azadiractha and Simarouba oil based biodiesel life cycle have been analysed using the methodologies explained in this chapter. The LCA studies in detail have been portrayed in the following chapters 4, 5, 6 & 7.

CHAPTER 4

LIFE CYCLE ASSESSMENT OF BIODIESEL PRODUCED FROM PONGAMIA PINNATA OIL

4.1 LCA of Pongamia Biodiesel Produced and Used in Rural Karnataka

This section portrays an exclusive LCA study of Pongamia biodiesel in rural Karnataka, which is being used for rejuvenating wasteland and for producing biodiesel for local consumption in transportation / water pumping / electricity generation. The LCA evaluates the performance of the Pongamia system against conventional diesel as reference system. Apart from assessing energy input / output and green house gas emission, this analysis also assess acidification, eutrophication and land use change impact. LCA of Pongamia biodiesel aims at studying the use of Pongamia biodiesel as a source of fuel for transportation / water pumping / electricity generation produced locally. The environmental impacts producing a biogas from Pongamia seed cake has been taken into consideration, in addition to biodiesel production in LCA.

The environmental impact of the Pongamia system was assessed using LCA as per standards of International Organization for Standardization (ISO 14000/44, 2006).

Goal

The following five impact categories have assessed in this LCA

(i) Non-renewable energy requirement [MJ],

(ii) Global warming potential [CO_2- eq.],

(iii) Eutrophication potential [O_2-eq.],

(iv) Acidification potential [SO_2- eq.] and

(v) Land use impact on ecosystem quality.

In addition to the above mentioned impacts, a life cycle energy was analysed as well. i.e.

(i) Net Energy Gain (NEG = energy output – energy input) and

(ii) Net Energy Ratio (NER = energy output / energy input) were calculated.

The LCA of the Pongamia biodiesel included cultivation, oil extraction, esterification, and associated by-products of each phase (Seed cake, biogas from seed cake and biogas slurry as fertilizer). The data was collected from Biofuel Park located at Madenur in Hassan district of Karnataka State (Appendix – 5).

- The system boundary conditions included the usage of biodiesel and associated by-products locally. 1MJ energy available in Pongamia biodiesel was considered as the functional unit (FU) for life cycle impact assessment. This study focused on Pongamia plantations on wastelands and village common lands.
- The environmental performance of biogas production from Pongamia seed cake has also been evaluated. The sludge coming out of the biogas plant has been assumed to be used as organic manure locally.
- As estimated by Eggleston et al. (2006) and Pathak et al. (2009), a 10% leakage of CH_4 from biogas plant has been considered for GHG emission calculation.
- It was assumed that the biogas installation has a CH_4 leakage of around 10% of the gas produced (Eggleston et al. 2006 and Pathak et al. 2009).
- Biogas plant construction has not been included in the system boundaries, because it is assumed to have insignificant effect on the overall impact.
- The biogas is accounted as engine fuel for electricity and heat generation, in lieu of fossil-based natural gas in the reference system.

4.2.1 Life Cycle Inventory

This LCA study was carried out at the Agriculture Research Station (ARS) located at Madenur in Hassan district of Karnataka State, named as ‘Biofuel Park’. The study focused on Pongamia plantations on wastelands, degraded lands and agricultural land bunds. The boundary conditions for LCA studies of Pongamia in comparison with fossil fuel has been depicted in figure 4.1, 4.2 & 4.3. The functional unit (1 MJ of energy available in Pongamia biodiesel) has been equated to 200g of pod for calculation / impact assessment.

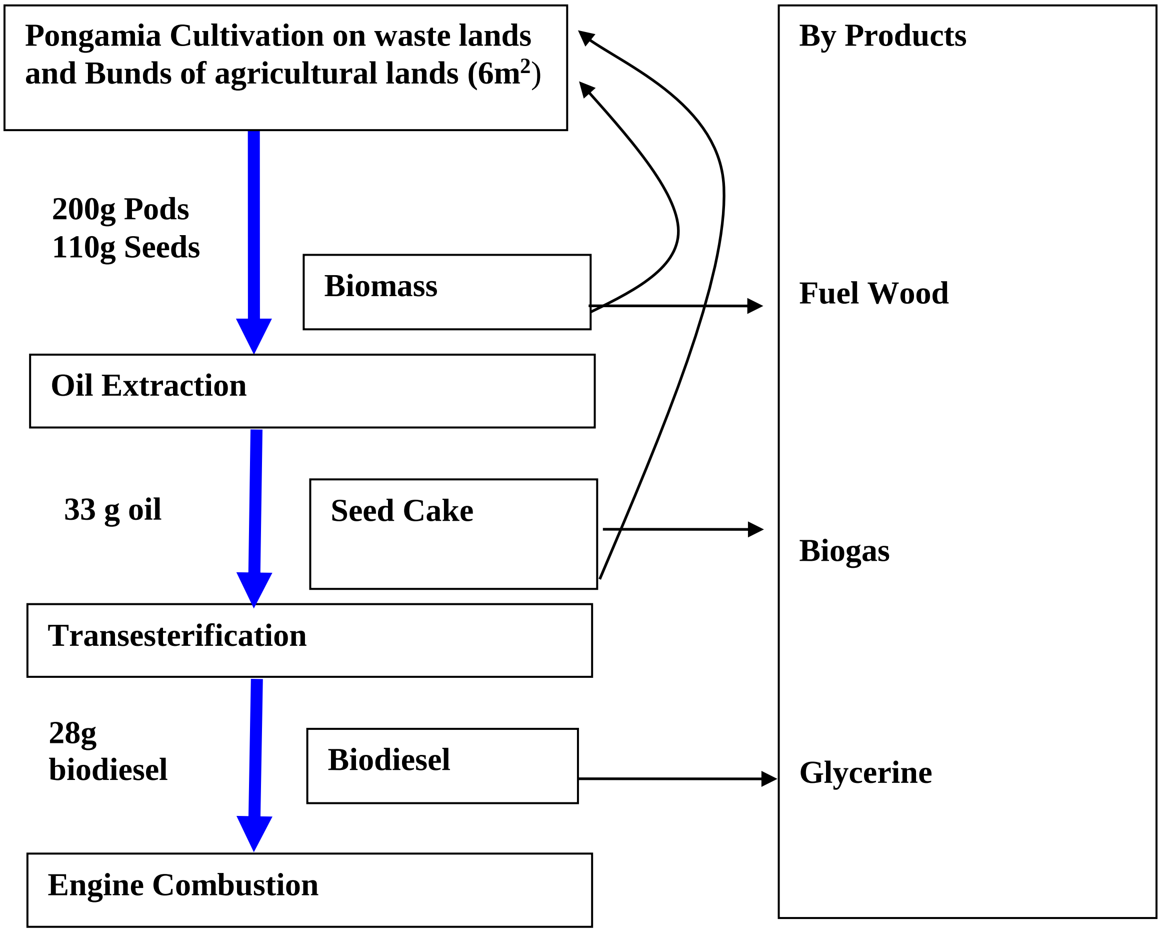


Figure 4. 1 System boundary for Pongamia LCA

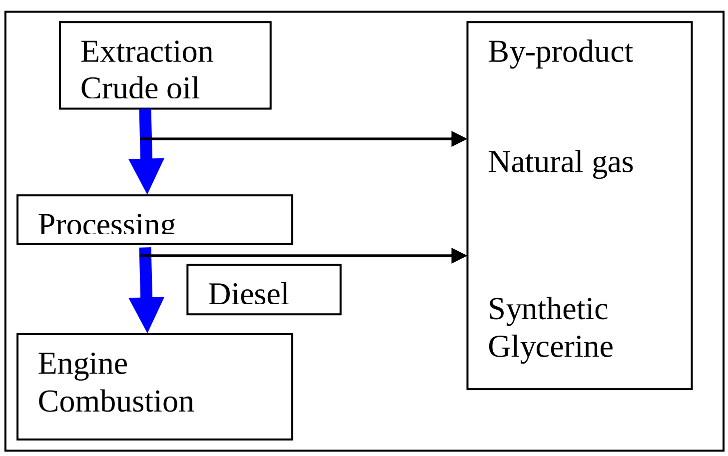


Figure 4. 2 System boundary for reference system (Fossil fuel- Diesel)

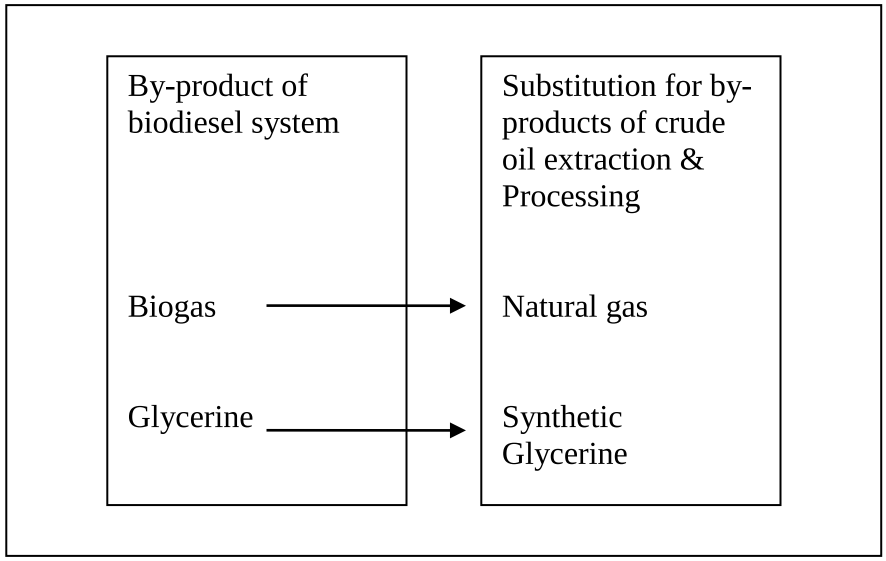


Figure 4. 3 System boundaries for substitution (Fossil fuel- Diesel)

4.2.2 Production System

This section depicts the study of production system, based on the data collected from Biofuel Park. Seedlings are raised in poly bags in the nursery. Seeds are sown in a mixture of soil and local compost and are watered manually. Saplings are transplanted on wastelands and agriculture field bunds. A tree / plant population of 300 to 330 /ha is maintained on wasteland / degraded lands. However, number of saplings planted on bunds depends on the type of farming practices. A distance of 10 to 12 m is maintained between each tree, when planted on bunds. Pongamia is a very hardy tree and it can establish successfully in almost all kind of soil due its nitrogen fixing capabilities. Hence, no extra inorganic or organic fertilizers application is practiced. However, to support seedling establishment in the initial stage, 2 to 3 kg farm yard manure is applied per pit. The trees establish very well in southern India with the prevailing rainfall and start yielding from 5th year onwards and reach its peak yield from 10th to 15th years. An Average seed yield of about 25 to 30 quintal / ha is obtained from 10 year old plantation (Lokesh et al. 2012). On an average, one labour can collect 120 to 180 kg of seeds / manday. Approximately 5 to 6 mandays are required for harvesting one hectare. Average shell: kernel ratio on mass basis of the Pongamia seeds is 46:54 and it is found to have

1500-1700 seeds per kg (Lokesh et al. 2012). Life span of Pongamia tree is found to be more than 80 years.

The extraction unit consists of an electric motor driven screw press and a filter press. One tonne seeds yield 270 to 300 kg crude Pongamia oil. Transesterification process of 100 litres (85 kg) oil consumes 20 kg of methanol and 0.80 kg NaOH. The transesterification reaction is carried out in a heated tank (60-80°C) and yields about 15-16 kg glycerine and 85 to 90 litres of biodiesel. (The glycerine is assumed to be sold in the market)

4.3 Results of Pongmaia LCA

4.3.1 Energy Analysis

Non-renewable energy requirement (NRER)

NRER is a sum fossil energy requirement throughout the life cycle [MJ/FU]. As discussed earlier the functional unit of Pongamia LCA is 200 g of pods.

Production and use of one functional unit of Pongamia biodiesel consumes 0.045 MJ of non-renewable energy (Ref. Table 4.1), which is five times less compared to reference system i.e. approximately 1250 kJ (Achten et al. 2010). The major portion of the non-renewable energy consumed is for oil extraction (43%) and transesterification process (53%). This result confirms the findings of Krishna at al. 2011, Achten et al. 2010 and Kian et al 2009 working on Jatropha and Palm oil LCA studies. The cultivation phase consumes only 4% of the NRER, which is low compared to other biodiesel production systems (Jatropha, Palm, Rapeseed and Soya), due to very little fertilizer inputs (Lokesh et al. 2012).

In the oil extraction phase, operating expeller and filter press is found to be the largest contributor (57.74 MJ = 67%). However in esterification phase, highest NRER is consumed for methanol production (50.25 MJ = 47%) followed by Transesterification process (35.18 MJ =32%) and (21.09 MJ = 20%) for manufacturing of esterification unit.

In the life cycle of Pongamia Biodiesel, transportation contributes for 3% of the total NRER, This is due to low level of inputs and local use of the products, which results in less transportation distances.

Table 4. 1 NRER of Pongamia LCA

Non-Renewable Energy Requirement in MJ for Pongamia LCA			
Sl. No	**Cultivation**	**MJ**	**Per FU**
1	Tractor production	NA	
2	Infrastructure: farm shed	NA	
3	Poly bags production	1.06 ±0.23	
4	Fertilizer production	NA	
	N, P & K		
5	Diesel production and use	7.16 ±3.24	
6	Electricity production and use	NA	
	Sub Total	**8.22±3.31**	**0.002**
	Oil Extraction		
7	Oil press production	29.08 ±5.41	
8	Electricity production and use:	57.74 ±0.88	
	Sub Total	**86.82±5.29**	**0.019**
	Biodiesel Production		
9	Transesterification unit production	21.09 ±2.56	
10	Production of methanol	50.25 ±0.33	
11	Production of catalyst (NaOH)	1.65 ±0.66	
12	Electricity production and use:-- transesterification unit	35.18 ±7.52	
	Sub Total	**108.17±7.86**	**0.024**
	Grand Total	**203.21±9.8**	**0.045±0.002**

Net Energy Gain and Net Energy Ratio

Table 4. 2 Energy inputs in Pongamia system

Stage	Energy	Quantity / Yr / ha	Units	Calorific value in MJ	Energy in MJ	Energy in MJ /FU
Cultivation	Man power	15.00	Man days	10.00	150.00±19	
	Diesel	22.00	litres	37.50	825.00±99.65	
	FYM	600.00	kg	0.03	18.18±2.16	
	Poly bags usage	330.00		0.69	229.28±26.23	
				Sub Total	**1222.46±103.3**	**0.27**
Oil Extraction	Man power	6.00	Man days	10.00	60.00±7	
	Diesel	11.00	litres	37.50	412.50±27	
	Electricity used	60.00	kWh	3.60	216.00±25.4	
				Sub Total	**688.50±36.7**	**0.15**
Esterification	Man power	4.00	Man days	10.00	40.00±4.8	
	Electricity used	34.00	kWh	3.60	122.40±14.6	
	NaOH	1.70	kg	23.30	39.61±4.6	
	H_2SO_4	0.34	kg	3.00	1.02±0.117	
	Acetic Acid	0.34	kg	13.00	4.42±0.5	
	Methanol	42.50	litres	13.23	562.28±67.47	
				Sub Total	**769.73±15.9**	**0.17**
				Total	**2680.69±105.4**	**0.05**
Miscellaneous Energy inputs (Assumption 10 % of Total Energy In puts)					**268.07**	**0.06**
				Grand Total	**2948.76±105.4**	**0.66±0.02**

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

*Therefore input energy required for producing 0.2kg=

0.2kg x 2948.6/900 kg = **0.66MJ**

From the calculation shown in table 4.2 it is evident that 0.66MJ of energy is needed for producing 0.2 kg of pods by a Pongamia tree.

Table 4. 3 Energy outputs from Pongamia System

Stage	Energy	Quantity / Yr / ha	Units	Calorific value in MJ **	Energy in MJ	Energy in MJ / FU	** References
Cultivation	Pod shell	414	kg	15	6210±738		Subbarao 2010
	Seed	504	kg		0		
	Fuel Wood	3000	kg	19.25	57750±5640		James 1983
				Sub Total	**63960±5725.7**	**13.93**	
Oil Extraction	Oil	141.12	Kg	-NA-			
	Seed cake	327.6	kg	14.3	4684.68±540		Subbarao 2010 & Raja 2011
				Sub Total	**4684.68±540**	**1.02**	
Esterification	Biodiesel	119.952	kg	36.5	4378.2±525		B. Baiju et al 2009 & Nagarhalli 2010
	Glycerine	21.16	kg	18.5	391.6±172		Kian et al. 2009
				Sub Total	**4769.85±543.28**	**1.04**	
				Grand Total	**73414.53±5526.2**	**15.99±1.2**	

* An average oil percentage of 28 has been considered for practical purpose

Ramchandra et al. (2006) have estimated that Pongamia seed cake has biogas generation potential in the range 240 - 265 litre per kg, with 65 -70% methane content. Using the same research results it has been estimated that 327.6 kg of seed cake can produce 78.6 m^3 of biogas. The energy output from Pongamia life cycle if biogas is produced from the seed cake is as shown in table 4.4.

Table 4. 4 Energy outputs from Pongamia System if seed cake used for biogas production

Stage	Energy	Quantity / Yr / ha	Units	Calorific value in MJ	Energy in MJ	Energy in MJ / FU	** References
Cultivation	Pod shell	414	kg	15	6210±738		Subbarao 2010
	Seed	504	kg		0		
	Fuel Wood	3000	kg	19.25	57750±5640		James 1983
				Sub Total	**63960±5531.27**	**13.93**	
Oil Extraction	Oil	141.12	kg	-NA-			
	Biogas from Seed cake	78.62	m^3	22	1729.72±206.8		Anonymus 2012, Chandan 2004 & Energistatistik 2002
				Sub Total	**1729.72±206.8**	**0.38**	
Esterification	Biodiesel	119.952	kg	36.5	4378.24±525		B. Baiju et al. 2009
	Glycerine	21.16	kg	18.5	391.6±172		Kian et al. 2009
				Sub Total	**4769.85±561.04**	**1.04**	
				Grand Total	**70459.58±5577.38**	**15.35±1.22**	

If biogas is used to produce electricity and heating, the energy output is as shown in table 4.5. Highest energy output is from cultivation phase (13.93 MJ / FU), followed by esterification (1.04MJ/FU) and oil extraction (0.22MJ / FU).

Table 4. 5 Energy outputs from Pongamia system if biogas is used for electricity and heat production

Stage	Energy	Quantity / Yr / ha	Units	Calorific value in MJ	Energy in MJ	Energy in MJ / FU	** References
Cultivation	Pod shell	414	kg	15	6210±738		Subbarao 2010
	Seed	504	kg		0		
	Fuel Wood	3000	kg	19.25	57750±5640		James 1983
				Sub Total	**63960±5757.2**	**13.93**	
Oil Extraction	Heat from Biogas	78.62	m^3	8.64	679.31±81.5		Anonymus 2012 & Chandan 2004
	Electricity from Biogas	78.62	m^3	4.32	339.65±40.18		Anonymus 2012 & Chandan 2004
				Sub Total	**1018.96±91.14**	**0.22**	
Esterification	Biodiesel	119.952	kg	36.5	4378.24±525		B. Baiju et al. 2009
	Glycerine	21.16	kg	18.5	391.6±167		Kian et al. 2009
				Sub Total	**4769.85±559.43**	**1.04**	
				Grand Total	**69748.82±5823.32**	**15.20±1.27**	

From table 4.6 Net energy gain and Net energy ratio is found to be high compared to Jatropha system analyzed by Achten et al. (2010). This may be attributed to consideration of work force, pod-shell and wood in energy analysis (Lokesh et al. 2012). In the study, where the system is expanded to include a biogas installation (Table 4.6), the NEG decreases to 14.70 per FU and the NER to 23.43. It is also observed that if biogas is used of generating electricity NEG (14.54) and NER (23.19) decreases further but increases energy availability from the Pongamia biodiesel system. In addition to the increase in energy availability, biogas slurry available after anaerobic digestion of seed cake is good organic manure.

Table 4. 6 Net energy gain and Net energy ratio from various scenarios of Pongamia life cycle analysis in comparison to Jatropha

	Total Energy input in MJ / FU =0.66	Biodiesel	Biodiesel+ Seed cake as fuel	Biodiesel + Biogas from seed cake	Biodiesel + Biogas from seed cake for electricity and heat generation
Net Energy Gain = Total Energy output - Total energy inputs		**0.87**	**15.34**	**14.70**	**14.54**
Net Energy Ratio = Total Energy output / total energy inputs		**6.08**	**24.41**	**23.43**	**23.19**
NEG of Jatropha (Achten 2010)		**0.078**	**NA**	**0.41**	**NA**
NER of Jatropha (Achten 2010)		**1.5**	**NA**	**2.89**	**NA**

This slurry is found to have marginally lower nutrient content (2.39 % N, 0.43 % P and 0.31% K), than oil cake (4% N, 0.9% P & 1.3% K) which is still an additional benefit for farmers after generating biogas. The biogas slurry (digestate) has nitrogen in the readily available from, which is absorbed straight away by the plants upon application. However, direct use of seed cake as manure results in delayed release of nitrogen, since it has to be acted upon by the soil microorganisms to release the N in the cake. This process also results in nitrogen losses as per N-CYCLE and comparatively reduces the availability of nitrogen to plants. Research carried out by Warnars (2014) confirms the same. Hence, it can be inferred that using seed cake to generate biogas significantly increases the nitrogen availability to plants (from Slurry) and energy (from Biogas) for use (Lokesh et al. 2012).

4.3.2 Global Warming Potential (GWP)

The Pongamia biodiesel system showed an emission of 343g CO_2-eq / FU (Ref .Table 2.22), which is 1.25 times more compared to the reference system (i.e. Fossil fuel = 280g

CO_2-eq). The cultivation phase is the biggest contributor in the system (90%), and the majority of these emissions are due to fuel wood burning (Lokesh et al. 2012), (Burning wood emits approximately 450 g of CO_2 per kg of wood burnt). However if fuel wood burning is not practiced in the life cycle, CO_{2-}eq would be around 40g which confirms previous studies carried out by Reinhardt et al. (2007). Since very little inorganic fertilizer is used in the system the GWP is very less compared to (by 6 times) Palm oil (Kina et al. 2009) and (by 4 times) Jatropha system (Achten et al. 2010), which uses a considerable amount of inorganic fertilizer for better yield.

Greenhouse Gas Emissions

Table 4. 7 Total green house gas emission from Pongamia system caused by: (CO_2, C H_4 & N_2 O) = [g CO_2-eq]

Stage	Particulars	Quantity	Units	CO_2	Unit	kg CO_2-eq *	gCO_2- eq / ha	gCO_2-eq /FU	References *
Cultivation	Poly-bags production& discharge	1.65	kg	5.50	kg	9.08	9075.00±1.04		Juerg 2009 & Graffman 2011
	Organic Fertilizer application 1 t of FYM has Approx 10 kg N = 0.01 N_20 Emission	6.00	kg	0.01	kg	0.06	60.00±0.07		IPCC-ID:1622
	Fuel Wood	3000.00	kg	0.44	kg	1320.00	1320000.0±123.4		Daniel 1992
	Diesel Use for Transportation	140.00	km	0.33	kg/km	46.62	46620.00±5.54		ARAI 2007
					Sub Total	**1375.76**	**1375755.00±125.91**	**305.72**	
Oil Extraction	Electricity production and use: - oil press + Filter press						74800.00±0.07		Achten et al. 2010
	Biogas leakage	786.24	litres	0.71	g/litres	558.23	12839.30±66.3		Achten et al. 2010
	Biogas Combustion in an Engine	339.55	kWh	0.77	kg/kWh	72.63	72648.58±0.31.3		K Suresh et al. 2008
					Sub Total	**630.86**	**160287±70.30**	**35.62**	
Biodiesel Production	Methanol production						2992.00±0.09		Achten et al. 2010
	Electricity production and use: - transesterification unit						74800.00±0.07		Achten et al. 2010
	Biodiesel Combustion in and Engine (B100)	119.95	kg	20.90	g/kg		2507.00±300.8		Martin et al. 2005
					Sub Total		**80299.00±297.86**	**17.84**	
					Total		**1616341±321.46**	**359.19 ±0.07**	

4.3.3 Acidification and Eutrophication Potential of Pongamia System

Compared to reference system Pongamia system showed 90% decrease in Acidification potential (AP). Major contribution of AP is from emission of SOx & NOx from biogas combustion in an engine. This is still very negligible (Ref. Table 2.23) or may be nil compared to Jatropha (Achten 2009), Palm oil (Kian 2010 and Seksan 2011), Soya, rapeseed biodiesel system (Cherubin et al. 2009). In view of the fact that acidification potential results are quite negligible and direct application of inorganic fertilizer and pesticides are missing / not used in the system, Eutrophication potential has not been considered.

For Indian wastelands the average annual CO_2 sequestration rate from a standing biomass per hectare is approximately 2.25 tonne CO_2 / ha / yr (Francis et al. 2005). As estimated by Karnataka Sate Biofuel Development Board (KSDB 2012), a ten-year-old Pongamia plantation has a sequestration capacity of about 1.75 t/ha. Estimates from ICRISAT – Hyderabad (Wani & Sridevi) show that a ten-year-old tree can sequestrate 74 kg CO_2. The amount of CO_2 released by Pongamia system i.e.1.5 tonnes/ ha (Table 2.22) can be sequestered by a standing plantation of Pongamia trees on waste land and can further sequester additional 0.75 tonnes of CO_2 according to estimates mentioned above.

Table 4. 8 Total SO_2 equivalent emissions from Pongamia System

Stage	**Particulars**	**Quantity**	**Unit**	**SO_2**	**Unit**	**gSO_2-eq/FU**	**References**
Cultivation	N volatilization (NH_3)	3.60	kg	0.94±0.39	g		ELV 2000
	Poly bag Production & Discharge- SO_2	330.00	numbers	117.81±27.2	g		Juerg 2009 & Graffman 2011
	Poly bag Production & Discharge- Nox	330.00	numbers	207.90±26.9	g		Juerg 2009 & Graffman 2011
	Diesel use- Nox	210.00	kg	91.14±16.1	g		ARAI 2007
			Subtotal	**417.79±40.34**	g	**0.08**	
Oil Extraction	Electricity production and use- Oil press + Filter Press	60.00	kWh	66.68±5.04	g		IPCC-ID1622
	Biogas Combustion in an Engine	411.84	kWh	15238.08±33.6			K Suresh et al. 2008
			Subtotal	**15304.76±34.37**	g	**2.81**	
Biodiesel Production	Electricity production and use- transesterification unit	640.00	kWh	711.24±74.4	g		IPCC- ID417274
	Biodiesel Combustion	141.80	kg	0.15±12.1	g		B.Baiju et al. 2009
			Subtotal	**711.39±73.56**	g	**0.13**	
			Grand Total	**16433.94±90.72**	g	**3.02**	

4.3.4 Land use change (LUC) and Land Use Occupation (LUO)

For better living, man has taken resources from nature (i.e. Forest & Cultivation) for building houses, other infrastructure and as raw material for industries. The use of land for a given purpose may change its quality in terms of life support or potentiality for other usage (Lindeijer et al. 2002).

As a part of Pongamia biodiesel LCA, land use change and its ecological impact studies were carried out. The impact percentage of planting Pongamia on wasteland and agricultural land bunds showed that both LUC and LUO with respect to ecological structural quality and ecological functional quality are found to be encouraging.

Pongamia ESQ and EFQ (Figure 2.18) indicate that, being a local tree species, it has very little impact on local ecology. Ecological impact calculation per functional unit *(i.e. Impact % **x** Area of land required to produce one functional Unit **x** No of years required to produce on functional unit)* also reveal that, Changing waste land to Pongamia triggers an improvement of the ESQ (impact of -35.4%) and EFQ (impact of -11.83%).

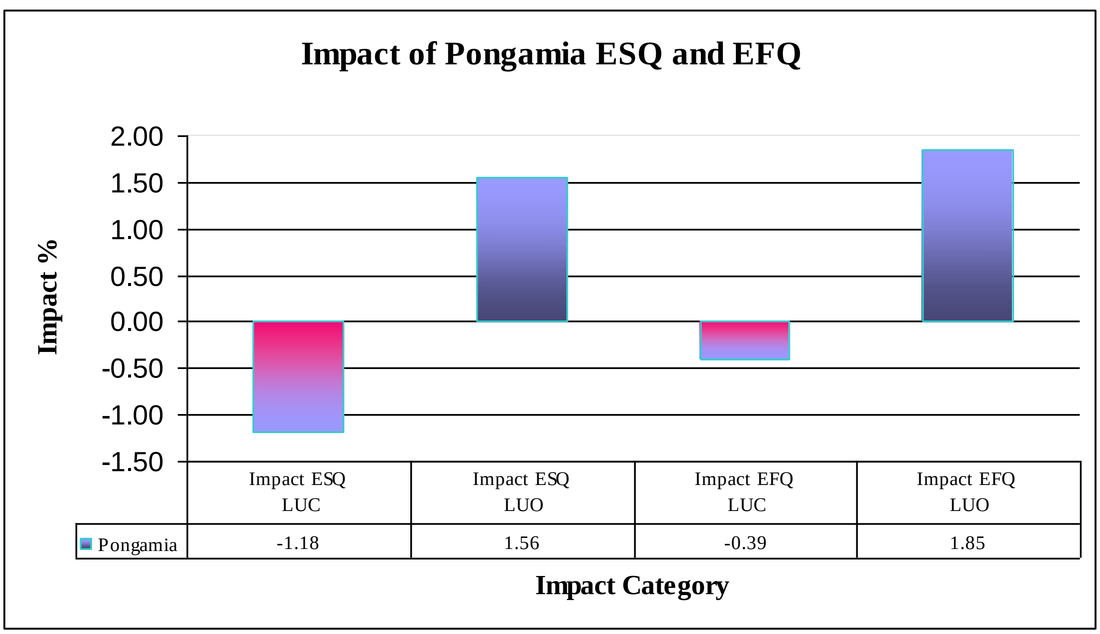


Figure 4. 4 Impact of Pongamia ecological structural quality (ESQ) and Ecological functional quality (EFQ)

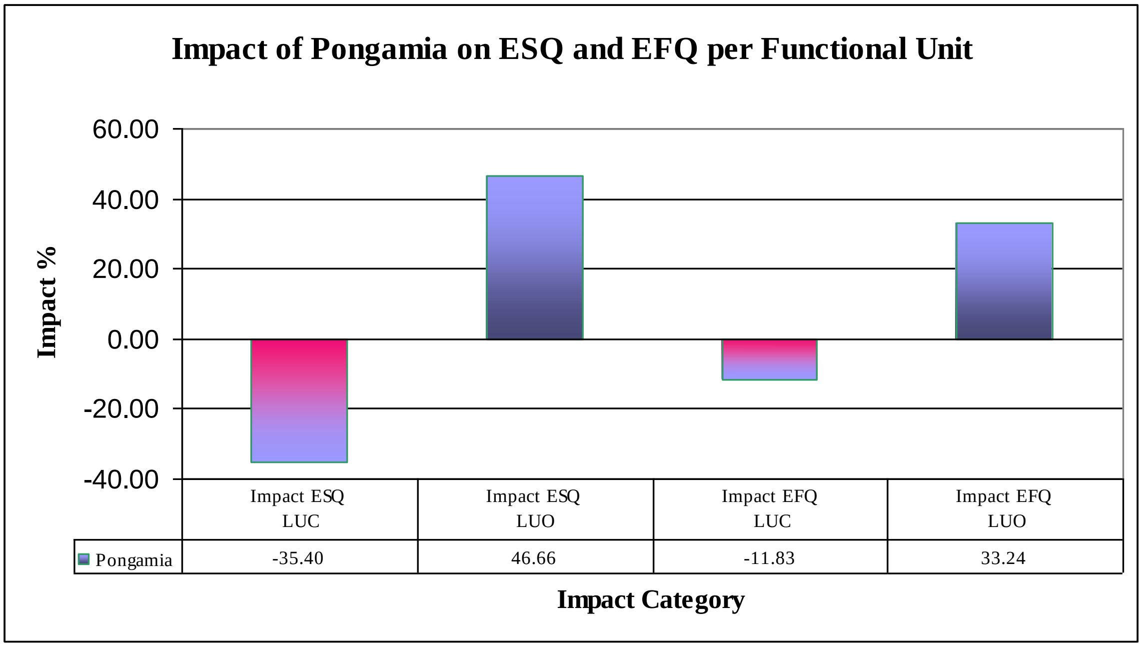


Figure 4. 5 Impact of Pongamia on ESQ and EFQ per functional unit

The improving ESQ signifies that the Pongamia plantation has better storage ability in terms of vegetation (biomass), constitution (structure) and biodiversity than the wasteland. The improving EFQ signifies that the Pongamia plantation has better control over water, organic matter and nutrient movement (absorption) than the wasteland. This is because Pongamia 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. Pongamia is a tree species capable of fixing nitrogen from atmosphere in its root zone with help of symbiotic bacteria like Rhizobium and enhance soil fertility and nutrient flux. The land occupation of Pongamia shows + ve impact on ESQ (46.6%) and an EFQ (33.24%) compared to the potential natural vegetation. These land use impacts apply to 6 m^2 * (5yr) /FU.

Note: -ve number of LUC is interpreted as an improvement, since it alters the soil strurture. Altered soil structure, results in better soil araition, water percolation and retention which, further results in enhancing the soil microflora thus enriching the soil.

+ve number of LUO is interpreted as an improvement in the biomass (vegetation growth) output compared to wasteland and LPNV. This represents the chosen TBOs capability to absorb nutrients and covert the same into readily available energy form the eco system. (Chapter 3 Methods for ESQ and EFQ calculation example)

4.4 Economics of Pongamia Cultivation

This section addresses the cost of cultivation of Pongamia followed by cost of production of biodiesel from Pongamia oil. Cost of cultivation has been carried out for cultivating Pongamia as a biodiesel feedstock in one hectare of wasteland under rain fed condition.

Cost of cultivation is normally calculated until the plantation stabilizes and starts yielding. In the case of Pongamia, the plantation starts yielding after five years and the input cost is found to be very little after five years, since the tree is self-sustaining. Hence, cost of cultivation has been calculated for first five years of plantation only (Table 2.24).

Pongamia plantation normally starts yielding after fifth year and the yield gradually increases and stabilizes after ten years. Price of seed, oil and oil cake has been found to increase at an average rate of 10 % (This estimate is based on past three year data collected from oil mills at Tumkur district and Agriculture produce market committee-Market, Bangalore). However, for the calculation of income from selling seed, oil and seed cake the prices of current market rate i.e. January 2012 have been considered and assumed to remain constant for next five to six years. (Table 2.24 & 2.25)

Table 4. 9 Cost of Pongamia cultivation in one hectare

Cost of Pongamia Cultivation in One Hectare									
	Spacing	**5.5 x 5.5**	**30**						
	No trees/ ha (10000 m^{2})		**330**						
	Survival /ha		**300**						
	Replacement		**50**						
	Average wage / day in Rs	**150**							
SL .No	**Particulars**	**Quantity**	**Cost in Rs.**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total in Rs.**
1	Cost of Plants Including Transportation		3	990					990±34.5
2	No of man days for digging 330 pits(55 pits/ Man Days)	6		900					900±73.1
3	Cost of Plants Including Transportation for replanting		3		150				150±11.8
4	Digging for replanting – Man Days	1			150				150±112.1
5	Staking – Man Days	2		300					300±23.5
6	FYM @ 2 kg / pit	600	1	600					600±72.3
7	Irrigation @ twice/ year *	2	250	500	500	500	500	500	2500±9.8
8	Contingency (10 % for first year and Rs.150/- for next four years			330	150	150	150	150	930±61.2
9	**Grand Total**			3620	950	650	650	650	**6520±208.9**

* Irrigation is only a life saving measure taken in hot summer months. Approximately 30 to 40 litres of water is used for one irrigation

Income from seed yield /ha

Table 4. 10 Earning from Pongamia seed from 5th to 10th year

Income From Seed Yield / ha					
Year	**Seed in kg / Tree**	**No of trees**	**Qty in Kg**	**Selling price ***	**Total Income**
5	2	300	600	15	**9000*±1080**
6	3	300	900	15	**13500**
7	5	300	1500	15	**22500**
8	7	300	2100	15	**31500**
9	10	300	3000	15	**45000**
10	12	300	3600	15	**54000**
11	15	300	4500	15	**67500**
12	20	300	6000	15	**90000**

* Rs.15/- is selling price as of Jan2012 obtained form oil mills at Tumkur district and assumed as average selling price for period under consideration. Seed yeild / tree data collected from Biofuel Park

As understood from the above calculations(Table 2.24 and 2.25) one can get back the investment made on Pongamia plantation in the fifth year or the first year yield and obtain a profit of Rs. 2480 (i.e. * 9000- 6520 = 2480) if seed alone is sold in open market. If the seed is used for oil extraction followed by biodiesel production the calculations are as shown in table 2.25. Income from Pongamia oil + seed cake is as shown in table 2.26

Table 4. 11 Income from Pongamia oil + seed cake

Year	Qty in kg	Oil %	Oil Yield / ha	Oil Price in Rs.	Income from oil 'A'	Seed Cake	Seed Cake Price in Rs	Income from seed cake 'B'	A + B	Income after deduction of COC in Rs.
5	600	28	168	60	10080±1209	390	15	5850±699	15930±138 4.83	**9410**
6	900	28	252	60	15120	585	15	8775	23895	**17375**
7	1500	28	420	60	25200	975	15	14625	39825	**33305**
8	2100	28	588	60	35280	1365	15	20475	55755	**49235**
9	3000	28	840	60	50400	1950	15	29250	79650	**73130**
10	3600	28	1008	60	60480	2340	15	35100	95580	**89060**
11	4500	28	1260	60	75600	2925	15	43875	119475	**112955**
12	6000	28	1680	60	100800	3900	15	58500	159300	**152780**

Inputs Cost of producing 100 litres of biodiesel from Pongamia oil is as shown in table 4.12

- Uncertinity analysis has been carried out for the first year of yield only based on the actual field data and following year calculation are based on data collected from literature, interaction with farming community and oil mills at Tumkur District.

Table 4. 12 Inputs cost of biodiesel production

Cost of Producing 100 litres of Biodiesel from Pongamia oil *						
Sl. No.	**Inputs**	**Quantity**	**Unit**	**Price in Rs.**	**Unit-per**	**Total in Rs.**
1	Seeds	350	kg	15	kg	5250±629
2	Electricity for oil extraction	28	kWh	8.5	kWh	238±26.9
3	Electricity for biodiesel production	20	kWh	8.5	kWh	170±48.6
4	Methanol	25	litres	35	litre	875±75.5
5	Sodium Hydroxide	1	kg	65	kg	65±7.8
6	Sulphuric Acid	150	ml	0.2	ml	30±2.36
7	Acetic Acid	150	ml	0.2	ml	30±2.39
					Grand Total	**6658±652.04**
					Inputs Cost for 1 litre biodiesel	**66.58±6.5**

** Data collected from esterification unit at Biofuel Park*

From the calculation shown in table 4.12 it is evident that cost of producing one litre of biodiesel with out deduction of income from by products is Rs. 66.58/- and income from by-products is found to be Rs. 37.12/- (Table 4.13).

Table 4. 13 Income from by-product of (100 litres) Pongamia biodiesel production

Sl. No.	**Inputs**	**Quantity**	**Unit**	**Price in Rs.**	**Unit-per**	**Total in Rs.**
1	Seed Cake	227.5	kg	15	kg	3412.5±408
2	Crude Glycerine	15	kg	20	kg	300±36
					Grand Total	**3712.5 ± 409.2**
					Income from 1 litre	**37.125 ± 4.09**

Assuming that biodiesel production unit will be at village level and average requirement of diesel fuel per day would be approximately 200 litres, capital cost has been calculated for a 48000 litre / year capacity (Table 4.14)

Table 4. 14 Capital cost of biodiesel production

				48000 litre/ yr Capacity
Sl . No	**Particulars**	**Cost**	**Life in Years**	**Cost for one year in Rs.**
1	Building including electrification and Water	750000	20	37500.00 ±3702
2	Oil Extraction Machine	100000	15	6666.67±67
3	Filter Press	50000	10	5000.00±507
4	Esterification unit	400000	15	26666.67±2649
5	Fuel testing equipment	150000	5	30000.00±2974
6	Total	**1450000**		**105833.33 ± 5607.82**
			Capital cost per litre	**2.2**

The details of the biodiesel production are as follows

- Plant Capacity = 200 litre /day
- Working for 20 days/ Month
- Producing 4000 litres/ Month & 48000 litres for one year
- Work force required is as follows =1 trained personal with a salary of approximately Rs.15000/- month
- 2 associates with a salary of Rs.7000/ month/ associate = Rs.14000/- Month
- Total labour cost per year = Rs.180000 + Rs. 168000 = Rs.348000 per year

Table 4. 15 Actual cost of one litre biodiesel produced from Pongamia Oil

Actual Cost of One Litre Biodiesel				
Sl.No.	**Particulars**	**Unit**	**Cost in Rs.**	**Total in Rs.**
1	Inputs cost for producing Biodiesel 'A'	48000 litres	66.58 / litre	3195840
2	Income from selling crude glycerine 'B'	7200 kg	20 / kg	144000
3	Income from selling seed cake 'C'	109200 kg	15 / kg	1638000
4	A- (B+C)			1413840
5	Capital Cost Per year			105833.33
6	Labour cost	1+2		348000
7	Maintenance per year			20000
8	Insurance per year			10000
	Total Cost per 48000 litres			1897673.33
	Cost of one litre biodiesel			**40**
	Selling price with 20 % profit			**48**

Actual cost of one litre Pongamia biodiesel is derived after deduction of the amount obtained from selling seed cake and glycerine (Table 4.15). If a modest 20 % profit margin is added to the cost of biodiesel it would be priced around Rs.48/-, which is still found to be lower than current diesel prices in Karnataka State (i.e. Rs.51.20/-).

Table 4. 16 Conversion cost of one litre biodiesel

Sl.No	**Particulars**	**Cost in Rs.**
1	Electricity for oil extraction	2.38
2	Electricity for biodiesel production	1.7
3	Methanol	8.75
4	Sodium Hydroxide	0.65
5	Sulphuric Acid	0.3
6	Acetic Acid	0.3
8	Capital Cost Per year	2.2
9	Labour cost	7.25
10	Maintenance per year	0.42
11	Insurance per year	0.21
	Total	**24.15**

When compared to current (2012) prevailing diesel prices (Rs.51.20/-) in Karnataka, biodiesel price is found to be lower by Rs. 3.20/-. Actual diesel price is higher than the prevailing price due to the fact that, it is subsidized in India i.e. Rs. 8/- per litre as on Oct. 2012 (Ministry of petroleum- GOI). One litre of diesel without government subsidy shall cost approximately Rs. 59.2/- per litre. Hence when compared with unsubsidized diesel, biodiesel is found to be cheaper by Rs.11.2/-

If higher-capacity biodiesel production plants and suitable supply chain employed with in the sustainable distance limits (Section 8.7, Fig 8.9, Fig 8.1), current conversion cost of oil to biodiesel (Rs.24.15/-) (Ref. Table 4.16) may drop further, resulting in reduced selling price. If the same subsidy as provided to fossil diesel is passed on to biodiesel as well, it would further reduce its price. As discussed earlier the challenge of biodiesel production is constant supply of feedstock to meet the demand (Tree borne or non-edible oil seeds). Hence, biodiesel is still an option as blends up to 20 % with regular diesel.

From the Pongamia LCA studies, it can be inferred that producing biodiesel from Pongamia oil is both ecologically and economically viable provided seed is purchased or cultivated and oil extracted at local / village level (Section 8.7). On the similar grounds, LCA studies of other tree borne oils selected for this research would reveal the ecological and economical viability for better decision-making / strategy formulation. The following chapter-5 addresses the LCA studies of biodiesel production from Madhuca longifolia.

Salient Outcomes of Pongamia LCA

- Gestation period of Pongamia tree — 5 years
- Pongamia has nitrogen fixing capability
- All the parts of the tree have medicinal value
- Seed cake is used as an organic fertiliser, which also serves as nematicide
- Seed cake can be further used for biogas generation — 3.5 m^3/ kg
- Life expectancy of a Pongamia tree is way above — 90 to 100 years
- NRER of Pongamia Life cycle — 0.05 MJ / FU
- Energy input — 0.66 MJ / FU
- Energy output — 16.21 MJ / FU
- LCA of Pongamia expanded to include biogas production and electricity production form biogas
- Net Energy Gain for
    - Biodiesel production and seed cake combustion — 15.56 MJ / FU
    - Biodiesel + Biogas production from seed cake — 14.91 MJ / FU
    - Biodiesel + electricity & heat from biogas — 14.76 MJ / FU
- Net Energy Ratio for
    - Biodiesel production and seed cake combustion — 24.74
    - Biodiesel + Biogas production from seed cake — 23.76
    - Biodiesel + electricity & heat from biogas — 23.52
- CO_2 Emission (Biodiesel + Biogas +fuel wood) — 343 gCO_2-eq / FU
- CO_2 Emission (Biodiesel) — 40 gCO_2-eq / FU
- SO_2 Emission (Biodiesel + Biogas) — 3 g SO_2-eq / FU
- SO_2 Emission (Biodiesel) — 0.13 g SO_2-eq / FU
- CO_2 Sequestration — 1.5 to 2 t / ha
- Impact of Pongamia on ESQ
    - LUC — -35.4 / FU
    - LOU — +46.66 / FU
- Impact of Pongamia on EFQ
    - LUC — -11.83 / FU
    - LOU — +33.24 / FU
- Economics
    - Cost of Pongamia cultivation in one hectare — Rs. 7320/-
    - Price of Pongamia seed — Rs. 15/-
    - Price of Pongamia oil — Rs. 60/-
    - Price of Pongamia seed cake — Rs. 15/-
    - Price of Glycerine — Rs. 20/-
    - Cost of Biodiesel produced from Pongamia Oil — Rs. 40/-
    - Price of Biodiesel with 20 % profit margin — Rs. 48/-
    - Annual average Price of Diesel — Rs. 51.20/-
- Credits
    - Glycerine replacing synthetic glycerine — 21 kg
    - Seed cake replacing chemical fertilisers N=13 kg, P=3 kg and K= 4.25 kg
    - Biogas replacing LPG — 15 kg

Conclusion: From the LCA studies carried out it can be inferred that producing biodiesel from Pongamia oil is both ecologically and economically viable

CHAPTER 5

LIFE CYCLE ASSESSMENT OF BIODIESEL PRODUCED FROM MADHUCA LONGIFOLIA OIL

5.1 LCA of Madhuca Biodiesel Produced and Used in Rural Karnataka

This section portrays an exclusive LCA study Madhuca biodiesel system in rural Karnataka, very similar to Pongamia LCA, which is being used for reclaiming waste land and for producing biodiesel for local consumption in transportation / water pumping / electricity generation. The LCA evaluates the performance of the Madhuca system against conventional diesel as reference system. Apart from assessing energy input / output and green house gas emission, this analysis also assess acidification, eutrophication and land use change impact. LCA of Madhuca biodiesel aims at studying the use of Madhuca biodiesel as a source of fuel for transportation / water pumping / electricity generation produced locally.

The LCA of the Madhuca, biodiesel included cultivation, oil extraction, esterification, and associated by-products of each phase (Seed cake, biogas from seed cake and biogas slurry as fertilizer). The data was collected from Biofuel Park located at Madenur in Hassan district of Karnataka State. The system boundary conditions included the usage of biodiesel and associated by-products locally. One MJ energy available in Madhuca biodiesel was considered as the functional unit (FU) for life cycle impact assessment.

5.2 Life Cycle Inventory

This LCA study was carried out at 'Biofuel Park', Hassan. 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 5.1, 5.2 and 5.3.

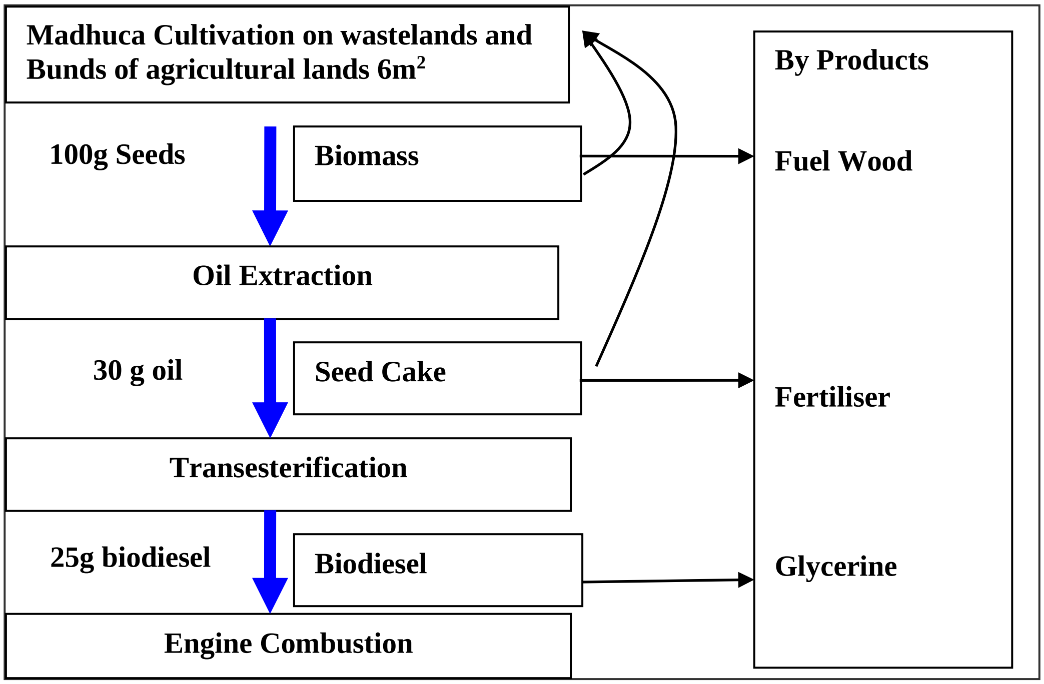


Figure 5. 1 System boundary for Madhuca LCA

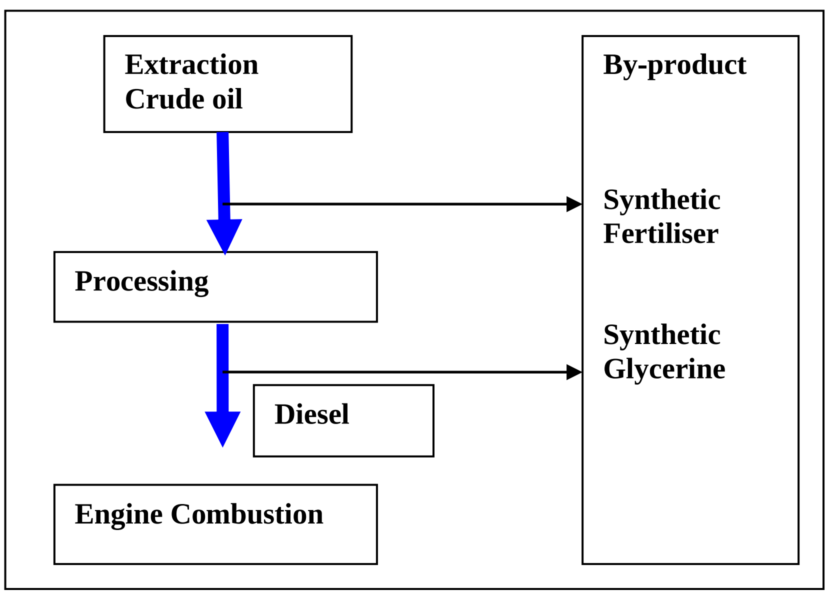


Figure 5. 2 System boundary for reference (Fossil fuel- Diesel)

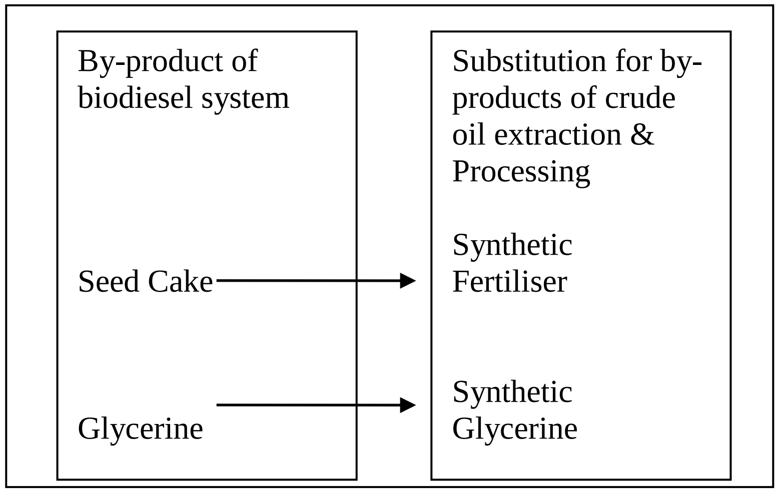


Figure 5. 3 System boundary for substitution

5.3 Data Collection

The data was gathered from Biofuel Park offices followed by interaction with farmers associations "*Jaivika Indhana Beejagala Belegarara Sangha*"*. This data was collected in line with data collected for Pongamia LCA studies (Appendix-3, 4 and 5). The factors considered in this study are given in Methods Chapter (Table 3.1 to 3.5).

** Biofuel seeds growers association*

5.3.1 Production System

This section depicts the study of production system, based on the data collected from Biofuel Park. Saplings are raised in poly bags in the nursery. Seeds are sown in a mixture of soil and local compost and are watered manually. Saplings are transplanted on wastelands and agriculture field bunds. A tree population of 200 / ha is maintained on wasteland / degraded lands. However, number of saplings planted on bunds depends on the type of farming practices. When planted on bunds, a distance of 12 to 15 m is maintained between each tree. Madhuca is a very hardy tree and it can establish successfully in almost all kind of soil (NOVODB-Mahua 2009). Hence, no extra inorganic or organic fertilizers application is practiced. However, to support seedling establishment in the initial stage, 2 to 3 kg farmyard manure is applied per pit. After plantation establishes, no fertilisers 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, start yielding from 10th year onwards, and yield increases as age of the tree increases. An average seed yield of about 9 to 10 quintal / ha is obtained from a 10-year-old plantation. Life span of Madhuca tree is considered well above 100 years.

The extraction unit consists of an electric motor driven screw press and a filter press. One tonne seeds and yield 300 to 320 kg crude Madhuca oil. Transesterification process of 100 litres (85 kg) oil consumes 20 kg of methanol and 0.80 kg NaOH. The transesterification reaction is carried out in a heated tank (60-80°C) and yields about 15-16 kg glycerine and 85 to 90 litres of biodiesel. (The glycerine is assumed to be sold in the market)

5.4 Results of Madhuca LCA

5.4.1 Energy Analysis

Non-Renewable Energy Requirement

Production and use of one FU of madhuca biodiesel consumes 0.045 MJ of non-renewable energy (Table 5.1), which is very similar to Pongamia system NRER and twenty eight times lesser than reference system (fossil fuel system) i.e. approximately 1.25 MJ (Achten et al. 2010).

Table 5. 1 Non-renewable energy requirement in Madhuca LCA

Sl. No	Cultivation	MJ	Per FU
1	Tractor production	NA	
2	Infrastructure: farm shed	NA	
3	Poly bags production	1.06±0.23	
4	Fertilizer production	NA	
	N, P & K		
5	Diesel production and use	7.16±3.24	
6	Electricity production and use	NA	
	Sub Total	**8.22±0.41**	**0.002**
	Oil Extraction		
7	Oil press production	29.08±5.41	
8	Electricity production and use:	57.74±0.88	
	oil press Filter press		
9	**Sub Total**	**86.82±5.5**	**0.019**
	Biodiesel Production		
10	Transesterification unit production	21.09±2.5	
11	Production of methanol	50.25±0.3	
12	Production of catalyst (NaOH)	1.65±0.66	
13	Electricity production and use:-- transesterification unit	35.18±7.52	
	Sub Total	**108.17±7.8**	**0.024**
	Grand Total	**203.21±9.72**	**0.045±0.002**

Table 5. 2 Energy inputs in Madhuca system

Stage	Energy	Quantity / Yr / ha	Units	Calorific value in MJ	Energy in MJ	Energy in MJ / FU
Cultivation	Man power	11	Man days	10	110±9.7	
	Diesel	22	Litres	37.5	825±258	
	FYM	600	kg	0.03	18.18±2.16	
	Poly bags usage	204		0.69	141.73±27	
				Sub Total	**1094.91±263.32**	**0.20**
Oil Extraction	Man power	6	Man days	10	60±10.7	
	Diesel	11	Litres	37.50	412.5±131	
	Electricity used	60	kWh	3.6	216±26.6	
				Sub Total	**688.50±136.21**	**0.13**
Esterification	Man power	4	Man days	10	40±5.7	
	Electricity used	35.2	kWh	3.60	127.2±15.2	
	NaOH	1.6	kg	23.30	37.28±4.4	
	H_2SO_4	0.324	kg	3	0.97±0.12	
	Acetic Acid	0.324	kg	13	4.21±0.52	
	Methanol	40.5	Litres	13.23	535.82±62.1	
				Sub Total	**1075.47±17.13**	**0.20**
				Total	**2858.89±296.51**	**0.05**
Miscellaneous Energy inputs (Assumption 10 % of Total Energy In puts)					**285.88**	**0.05**
				Grand Total	**3144.78±296.51**	**0.58±0.05**

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

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

For production and use of one FU of Madhuca biodiesel on an average 0.58 MJ (580 kJ) of energy is required (Table 5.2), which is 12 % less compared to Pongamia System.

Energy output per functional unit is found to be 17.72 MJ /FU (Table 5.3) and 10 % higher than Pongamia system. Net energy gain is also very high i.e. 17.17 MJ / FU compared to Jatropha system (188 kJ/Fu -analyzed by Achten et al. 2009). Net energy ratio is found to be high as well i.e. 30.49 (Table 5.4), which is a very hopeful result for recommending Madhuca as a promising biodiesel feedstock.

Table 5. 3 Energy outputs from Madhuca System

Stage	Energy	Quantity / Yr / ha	Units	Calorific value in MJ **	Energy in MJ	Energy in MJ / FU	** References
Cultivation	Pod shell	0.00	kg	- NA-	0.00		
	Seed	540.00	kg	- NA-	0.00		
	Fuel Wood	1800.00	kg	50.00	90000.00±10800		K.T.Chandy – INSEDA 2008
				Sub Total	**90000.00±10800**	**16.67**	
Oil Extraction	Oil	162.00	Kg	-NA-			
	Seed cake	351.00	kg	-NA-	0.00		
				Sub Total	**0.00**	**0.00**	
Esterification	Biodiesel	137.70	kg	39.40	5425.38±651		
	Glycerine	24.30	kg	18.50	449.55±4.37		Kian et al. 2009
				Sub Total	**5874.93±659.13**	**1.09**	
				Grand Total	**95874.93±11203.29**	**17.75±2.07**	

Table 5. 4 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

Research on use of Madhuca seed cake for biogas generation is found to be very little. The seed cake is used as organic manure, especially in lawn maintenance, since it has insecticidal / nematicide effect on earthworms (INSEDA – Mahua , NOVODB-Mahua 2009).

5.4.2 Global Warming Potential (GWP)

The Madhuca biodiesel system showed an emission of 38.4g CO_2-eq / FU (Ref. Table 3.9), which is 7 times less than reference system (i.e. Fossil fuel has approximately 280g CO_2-eq). 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 hence, CO_2 emission at cultivation phase is the least when compared to Pongamia cultivation. Since very little inorganic fertilizer is used in the system, the GWP is 6 times less compared to Palm oil (Kina et al. 2009) and (by 4 times) Jatropha system (Achten et al. 2010), which uses a considerable amount of inorganic fertilizer for better yield.

Table 5. 5 Total CO_2 equivalent emission from Madhuca Life cycle

Stage	**Particulars**	**Quantity**	**Units**	**CO_2**	**Unit**	**kg CO_2-eq**	**gCO_2- eq / ha**	**gCO_2- eq /FU**	**References**
Cultivation	Poly-bags production& discharge	1	kg	5.5	kg	5.5	5500±0.66		Lonny Grafman et al. 2012, Juerg n.d.
	Organic Fertilizer application 1 t of FYM has Approx 10 kg N = 0.01 N20 Emission	6	kg	0.01	kg	0.06	60±0.07		IPCC-ID:417274, TNAU 2012
	Diesel Use for Transportation	140	km	0.33	kg/km	46.62	46620±5.54		ARAI 2007
					Sub Total	**52.18**	**52180±5.66**	**9.66**	
Oil Extraction	Electricity production and use: - oil press + Filter press						74800±0.07		Achten et al. 2010
					Sub Total		**74800±0.07**	**13.85**	
Biodiesel Production	Methanol production						2992±0.09		Achten et al. 2010
	Electricity production and use: - transesterification unit						74800±0.07		Achten et al. 2010
	Biodiesel Combustion in and Engine (B100)	137.7	kg	20.9	g/kg		2877.93±345		K Suresh et al. 2008
					Sub Total		**80669.93±333.32**	**14.94**	
					Total		**207649.93±329.4**	**38.45±0.06**	

Table 5. 6 Total SO_2 equivalent emission from Madhuca System

Stage	Particulars	Quantity	Unit	gSO_{2-eq} /ha	gSO_2- eq/FU	References
Cultivation	N volatilization (NH_3)	1.12	kg	0.29±0.004		ELV 2000
	Poly bag Production & Discharge- SO_2	200	Numbers	71.4±8.56		Juerg 2009 & Graffman 2011
	Poly bag Production & Discharge- NO_x	200	Numbers	126±15.4		Juerg 2009 & Graffman 2011
	Diesel use- NO_x	210	km	91.14 ±0.8		ARAI 2007
			Subtotal	**288.83±17.54**	**0.05**	
Oil Extraction	Electricity production and use- Oil press + Filter Press	60	kWh	66.68±8		IPCC-ID1622
			Subtotal	**66.68±8**	**0.01**	
Biodiesel Production	Electricity production and use- transesterification unit	127	kWh	141.14±17.26		IPCC-ID417274
	Biodiesel Combustion	137.7	kg	0.14±0.016		Sharanappa et al. 2009 & Sukumar et al. 2005
			Subtotal	**141.28±16.5**	**0.02**	
			Grand Total	**496.79±18.46**	**0.08±0.003**	

5.4.3 Acidification and Eutrophication Potential of Madhuca System

Compared to refernce system Madhuca system showed a drastic decrease (95%) in AP. Major Contribution of AP is from emission of diesel engines used for transporting inputs and outputs in cultivation phase. This is still very negligible (Table 5.6) or may be nil compared to Jatropha (Achten 2009), Palm oil (Kian 2010 and Seksan 2011), Soya, rapeseed biodiesel system

(Cherubin et al. 2009). In view of the fact that acidification potential results are quite negligible and direct application of inorganic fertilizer and pesticides are missing / not used in the system, Eutrophication potential has not been considered.

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 tonne/ ha) can be sequestered by Madhuca trees plantation on wasteland and can further sequester surplus 5 tonnes of CO_2.

5.4.4 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 (Lindeijer et al. 2002).

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 wasteland and agricultural land bunds showed that both LUC and LUO with respect to ecological structural quality and functional quality were very little (Figure 5.4).

This indicates that Madhuca being a local tree species similar to Pongamia has 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 (-24 %) and EFQ impact of (-65 %) with respect to LUC(Figure 5.5).

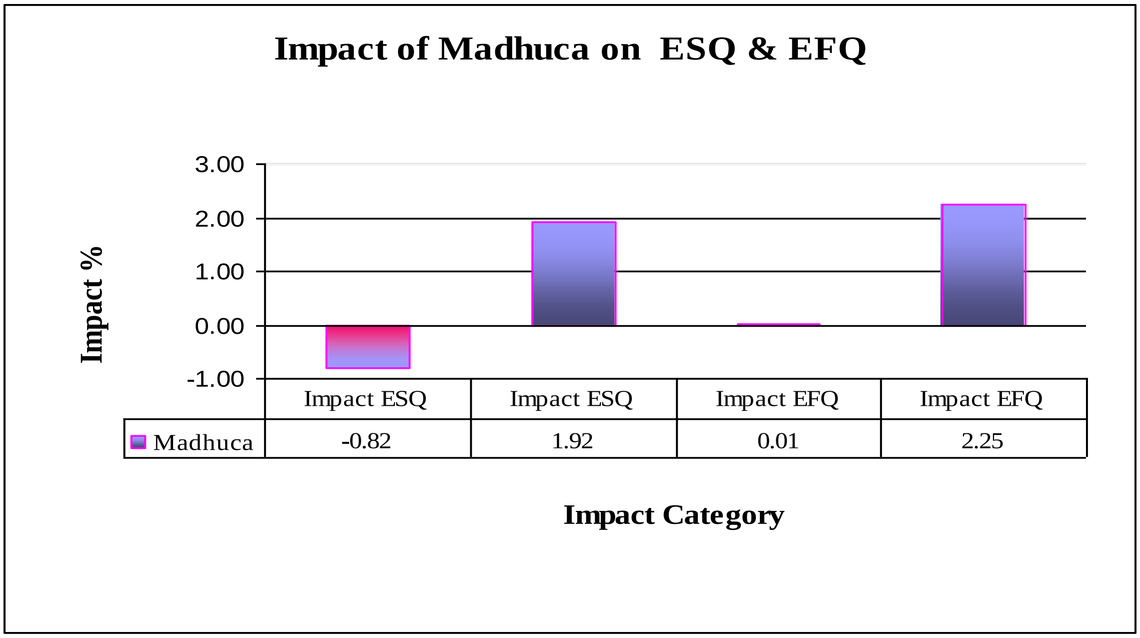


Figure 5. 4 Madhuca ESQ and EFQ

The improving ESQ signifies that the Madhuca plantation has higher storage ability in terms of vegetation (biomass), Constitution (structure) and biodiversity than the wasteland. The neutral EFQ signifies that the Madhuca plantation has control over water, organic matter and nutrient movement (absorption) similar to that of wasteland.

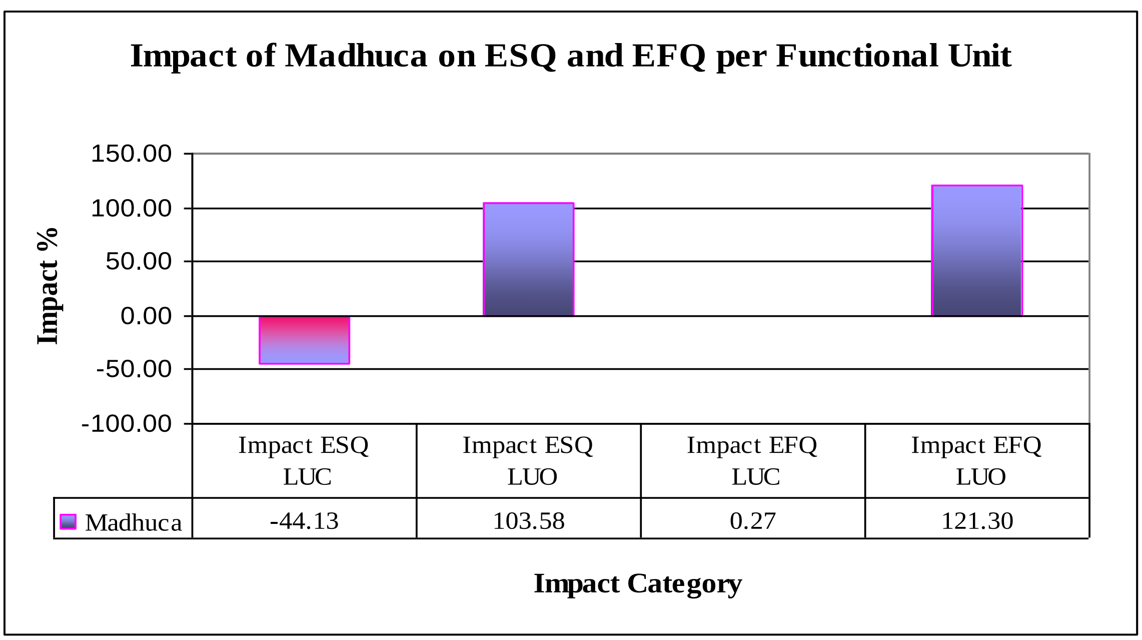


Figure 5. 5 Impact of Madhuca on ESQ and EFQ per functional unit

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. However, growth rate of Madhuca is very low hence; EFQ impact with respect to LUC remains to be neutral or very similar to wasteland when assessed for a five year old plantation. Oswal et al. (2009) have observed Vesicular-arbuscular mycorhizal associations in its root zone forming root colonization and capable of fixing nitrogen from atmosphere and enhance soil fertility and nutrient flux. The impact of land occupation by Madhuca shows a reduction in ESQ (103.58%) and EFQ (121%) compared to the potential natural vegetation. These land use impacts apply to 6 m^2 * (9yr) /FU

5.5 Economics of Madhuca Cultivation

This section addresses the cost of cultivation of Madhuca followed by cost of production of biodiesel from Madhuca oil.

Cost of cultivation has been calculated for cultivating Madhuca as a biodiesel feedstock in one hectare of wasteland under rain fed condition. Cost of cultivation is normally calculated till the plantation stabilizes and starts yielding. In the case of Madhuca, the plantation starts yielding after eight years and the input cost is found to be very little after five years, since the tree is self-sustaining. Hence, cost of cultivation has been calculated for first five years of plantation only (Table 5.7).

Madhuca plantation normally starts yielding after eight years and the yield gradually increases after ten or twelve years (Yield of Madhuca tree is found to increase with age). Price of seed, oil and oil cake has been collected from oil mills at Tumkur district and Agriculture produce market committee- Market, Bangalore.

For the calculation of returns from selling seed oil and seed cake, the prices of current market rate i.e. January 2012 have been considered.

Table 5. 7 Cost of Madhuca cultivation in one hectare

Cost of Madhuca Cultivation in One Hectare									
	Spacing	**7 x 7 m**							
	No trees/ ha	**204**							
	Survival /ha	**180**							
	Replacement	**50**							
	Average wage / day in Rs	**150**							
SL .No	**Particulars**	**Unit**	**Cost Rs.**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total in Rs.**
1	Cost of plants including transportation for 204 plants		3	612					612±36
2	No of man days for digging 204 pits(50 pits/ man day)	4		600					600±48
3	Cost of plants including transportation for replanting		3		150				150±12.3
4	Digging for replanting in man days	1			150				150±11.9
5	Staking in man days	2		300					300±23.4
6	FYM @ 2 kg / pit	400	1	400					400±47.3
7	Irrigation @ twice/ year*	2	250	500	500	500	500	500	2500±73.5
8	Contingency (10 % for first year and Rs 150 for next four years			230	150	150	150	150	830±60.5
9	Grand Total			2570	950	650	650	650	**5542±79.21**

* Irrigation is only life saving measure taken in hot summer months. Approximately 30 to 40 litres of water is used for one irrigation

Income from seed yield /ha

Table 5. 8 Earning from Madhuca seed

Year	Seed / tree (kg)	No. of trees (Survived)	Qty of seed (kg)	Selling Price / kg Assuming the Selling price will be constant	Total Income(Rs.)
9	3	180	540	14	**7560±302**
10	5	180	900	14	**12600**
11	9	180	1620	14	**22680**
12	15	180	2700	14	**37800**
13	20	180	3600	14	**50400**

* Rs 14/- is selling price as of Jan 2012 obtained form oil mills at Tumkur district

Seed yeild / tree data collected from Biofuel Park

Income from Madhuca cake is as shown in table 5.8

As understood from the above calculations (Ref. Table 5.8), one can obtain profit from 9th year onwards (Rs.7560-5542 = 2018). If the seed is used for oil extraction, the calculations are as revealed in Table 5.9, which shows a profit of Rs.12512/- after deducting cost of cultivation.

Table 5. 9 Income from Madhuca cake

Year	Qty of seed (Kg)	Oil Yield @35 % / kg of seed	Selling price of oil in Rs	Income from oil 'A' in Rs.	Seed cake yield in kg	Sellin g Price Of seed cake in Rs.	Income from seed cake 'B' in Rs.	A+B	Income after deduction of cost of cultivation *
9	540	30	85	13770±1652.4	351	12	4212±502	17982± 1691.69	**12512**
10	900	30	85	22950	585	12	7020	29970	**24500**
11	1620	30	85	41310	1053	12	12636	53946	**48476**
12	3600	30	85	91800	2340	12	28080	119880	**114410**

Inputs cost of producing 100 litres of biodiesel from Madhuca oil is as follows

Table 5. 10 Cost of biodiesel production

Sl.No.	Inputs	Quantity	Unit	Price in Rs.	Unit	Total Price
1	Seeds	330	kg	14	Per kg	4620.00±554
2	Electricity for oil extraction	26.4	kWh	8.5	Per kWh	224.40±27.2
3	Electricity for biodiesel production	18.85	kWh	8.5	Per kWh	160.29±19.22
4	Methanol	25	litres	35	Per litre	875.00±4.2
5	Sodium Hydroxide	1	kg	65	Per kg	65.00±7.8
6	Sulphuric Acid	150	ml	0.2	Per ml	30.00±2.36
7	Acetic Acid	150	ml	0.2	Per ml	30.00±2.36
					Grand Total	**6004.69±551.8**
					Input cost for 1 litre biodiesel	**60±5.5**

Input cost of biodiesel production from Madhuca oil is Rs 60/- (Table 5.10), which is found to be less by 11% compared to Pongamia. Income from by products of Madhuca biodiesel is less due to lower price (Rs. 12/-) of seed cake (Table 5.11) as compared to Pongamia i.e. Rs.17/-. This variation results in Rs. 40.64/- as biodiesel cost (of Madhuca is very near to that of Pongamia (Table 5.12).

Table 5. 11 Income from by-product of (100 litres) biodiesel production

Sl.No	Inputs	Quantity	Unit	price in Rs.	Unit	Total in Rs.
1	Seed Cake	214.5	kg	12	kg	2574±308.8
2	Crude Glycerine	15	kg	20	kg	375±36
					Total	**2949±309.24**
	Income from by products for producing 1 litre					**29.49±3.09**

Capital cost is consideredc to be constant for biodiesel produced from the same infrastructure used for Pongamia and other feedstock (Table 4.14)

Actual cost of one litre biodiesel

Table 5. 12 Actual cost of one litre biodiesel from Madhuca oil

Actual Cost of One Liter Biodiesel				
Sl.No	**Particulars**	**Unit**	**Cost of BD/100 liters**	**Total in Rs**
1	Inputs cost for producing Biodiesel 'A'	48000.00	60.05	2882249.14
2	Income from selling crude glycerin 'B'	7200.00	25.00	180000.00
3	Income from selling seed cake 'C'	102960.00	12.00	1235520.00
4	A- (B+C)			1466729.14
5	Capital Cost Per year			105833.33
6	Labour cost	1+2		348000.00
7	Maintenanace per year			20000.00
8	Insurance per year			10000.00
	Total Cost per 48000 liters			1950562.48
	Cost of one liter biodiesel			**40.64**
	Selling price with 20 % profit			**48.76**

When compared to current prevailing diesel prices (Rs.51.20/-) in Karnataka, Madhuca biodiesel price is found to be lower by Rs.2.44/-. Actual diesel price is higher than the prevailing price because, it is subsidized in India i.e. Rs.8/- per litre as on Oct. 2012 (Ministry of petroleum- GOI). One litre of diesel without government subsidy shall cost approximately Rs.59.2/- per litre (Table 5.12). Hence when compared with unsubsidized diesel, biodiesel is found to be cheaper by Rs.10.44/-

From table 3.13 it is evident that farmer gets a profit of Rs. 24,500/- from 900 kg of seed (i.e. 270 kg of Oil + 585 kg of seed cake) compared to profit of Rs.561/-, from 230 litres of biodiesel and hence he may get lured to extract oil and sell in open market rather than produce biodiesel.

From the Madhuca LCA studies, it can be inferred that producing biodiesel from Madhuca oil is both ecologically and economically viable provided seed is purchased or cultivated and oil extracted at local / village level. Sensitivty analysis carried out in section 8.7 confirms the same (Fig.8.9, 8.10 &8.11)

Madhuca oil is found to have market for medicinal purpose, soap and paint manufacturing; hence, feedstock for biodiesel production shall be available after this market gets saturated. Hence, in the current scenario producing biodiesel from Madhuca oil may seem to be economically unviable. Therefore, strategies for producing Madhuca in large quantities to meet the requirement of both traditional market and biodiesel requirement would be of prime importance. Similar LCA study has been carried out for Neem oil as biodiesel feedstock, which has been discussed in the following chapter 6.

Salient Outcomes of Madhuca LCA

• Gestation period of Madhuca tree	10 years
• Madhuca tree has Nitrogen fixing capability	
• All the parts of the tree have medicinal value	
• Seed cake is used as an organic fertiliser, which also serves as nematicide	
• Life expectancy of a Madhuca tree is above	100 years
• NRER of Pongamia Life cycle	0.45 MJ / FU
• Energy input	0.58 MJ / FU
• Energy output	17.75 MJ / FU
• Net Energy Gain	17.17 MJ /FU
• Net Energy Ratio	30.5
• CO_2 Emission	38.45CO_2-eq / FU
• SO_2 Emission	0.09g SO_2-eq / FU
• CO_2 Sequestration (5 year old Plantation)	6 t / ha / year
• Impact of Madhuca on ESQ	
○ LUC	-23.98 / FU
○ LOU	+58.08 / FU
• Impact of Madhuca on EFQ	
○ LUC	-65.06 / FU
○ LOU	+1.31 / FU
• Economics	
○ Cost of Madhuca cultivation in one hectare	Rs. 5600/-
○ Price of Madhuca seed	Rs. 14/-
○ Price of Madhuca oil	Rs. 85/-
○ Price of Madhuca seed cake	Rs. 12/-
○ Price of Glycerine	Rs. 20/-
○ Cost of Biodiesel produced from Madhuca oil	Rs. 40.64/-
○ Price of Biodiesel with 20 % profit margin	Rs. 48.76/-
○ Annual average Price of Diesel	Rs. 51.20/-
• Credits	
○ Glycerine replacing synthetic glycerine	24.3 kg
○ Seed Cake replacing chemical fertilisers	N=5.8 kg, P=1.7 kg & K= 7 kg

Conclusion: From the LCA studies carried out it can be inferred that producing biodiesel from Madhuca oil is both ecologically and economically viable provided seed is purchased or cultivated and oil extracted at local level.

CHAPTER 6

LIFE CYCLE ASSESSMENT OF BIODIESEL PRODUCED FROM AZADIRACHTA INDICA OIL

6.1 LCA of Azadiractha Biodiesel Produced and Used in Rural Karnataka

This section portrays an exclusive LCA study of Azadiractha biodiesel in rural Karnataka similar to Pongamia and Madhuca, which is being used for rejuvenating wasteland and for producing biodiesel for local consumption in transportation / water pumping / electricity generation. The LCA evaluates the performance of the Azadiractha system against conventional diesel as reference system. Apart from assessing energy input / output and green house gas emission, this analysis also assess acidification, eutrophication and land use change impact. LCA of Azadiractha biodiesel aims at studying the use of Azadiractha biodiesel as a source of fuel for transportation / water pumping / electricity generation produced locally.

The LCA of the Azadiractha, biodiesel included cultivation, oil extraction, esterification, and associated by-products of each phase (Seed cake, biogas from seed cake and biogas slurry as fertilizer). The data was collected from Biofuel Park located at Madenur in Hassan district of Karnataka State. The system boundary conditions included the usage of biodiesel and associated by-products locally. One MJ of energy available in Azadiractha biodiesel was considered as the functional unit (FU) for life cycle impact assessment. This study focused on Azadiractha plantations on wastelands and village common lands

6.2 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. This study focused on Azadiractha plantations on wastelands, degraded lands and agricultural land bunds

The boundary conditions of LCA studies of Azadiractha biodiesel in comparison with fossil fuel has been depicted in figure 6.1, 6.2 and 6.3.

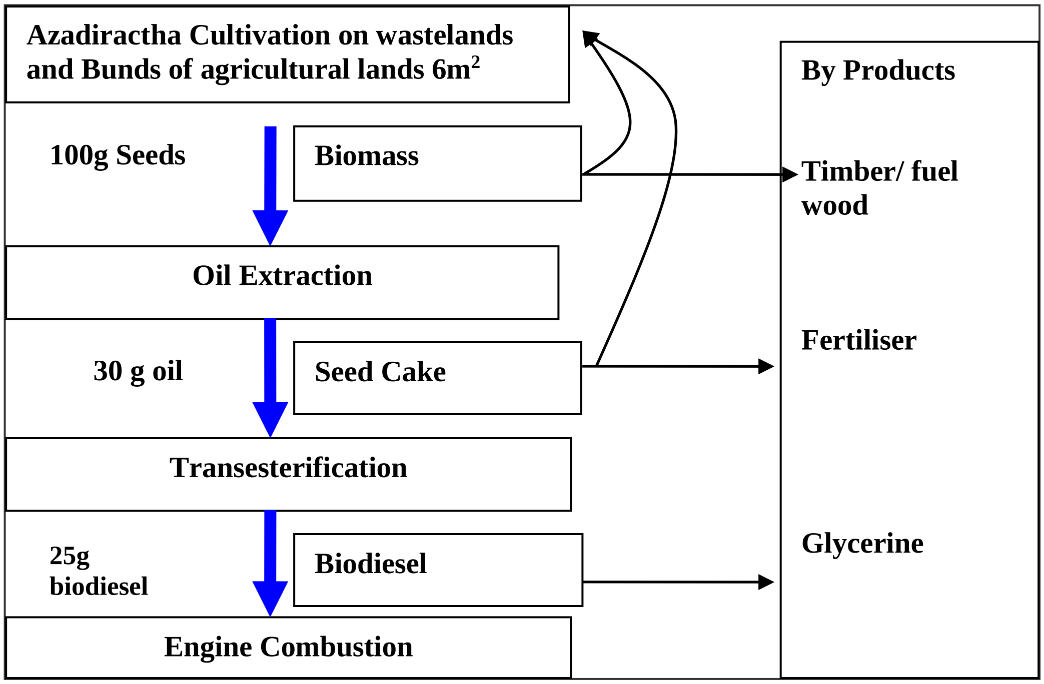


Figure 6.1 System boundary for Azadiractha LCA

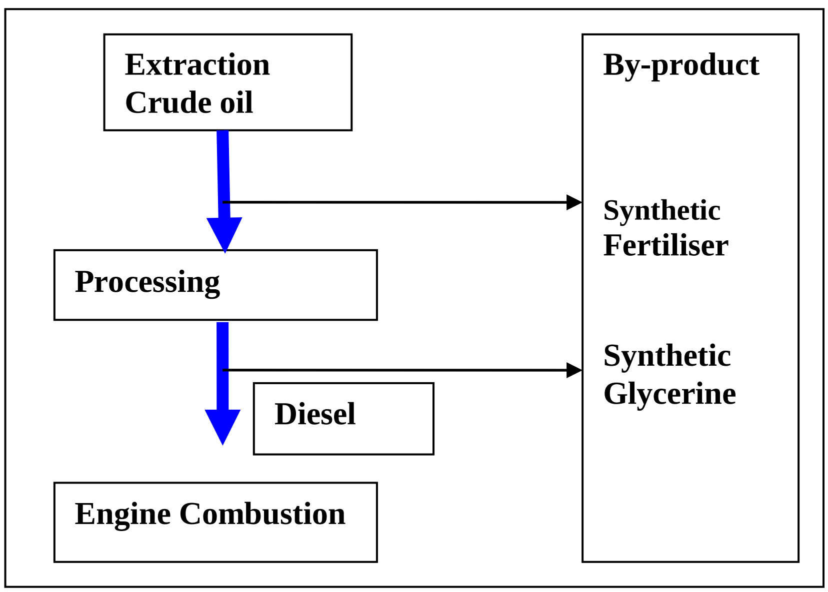


Figure 6. 1 System boundary for reference (Fossil fuel- Diesel)

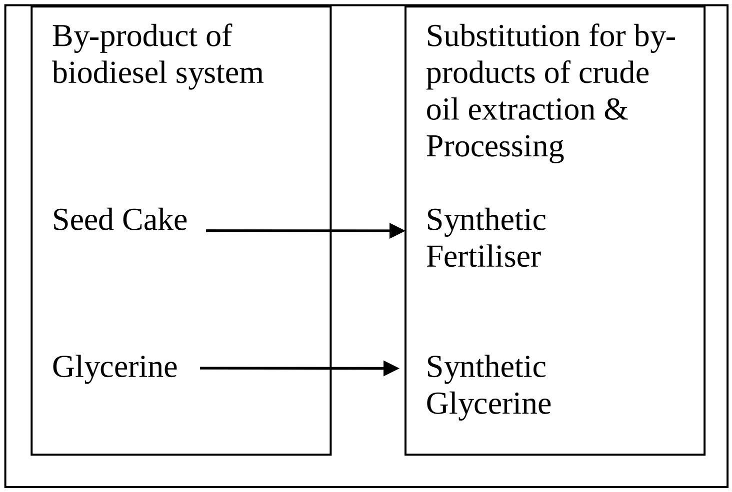


Figure 6. 2 System boundary for substitution

6.3 Data Collection

The data was gathered from Biofuel park offices and interaction with farmers associations called "*Jaivika Indhana Beejagala Belegarara Sangha*" (Biofuel feedstock growers association). The data collected for Azadiractha LCA is in line with data collected for Pongamia and Madhuca LCA studies (Appendix 4 and 5). The factors considered in this study are given in Table 3.1 to 3.5 of Methods Chapter.

6.3.1 Production System

This section depicts the study of production system, based on the data collected from Biofuel Park. Seedlings / saplings are raised in poly bags in the nursery. Seeds are sown in a mixture of soil and local compost and are watered manually. Saplings are transplanted on wastelands and agriculture field bunds. A tree / plant population of 300 /ha is maintained on wasteland / degraded lands. However, number of saplings planted on bunds depends on the type of farming practices. A distance of 10 to 12 m is maintained between each tree, when planted on bunds. Very similar to Pongamia and Madhuca Azadiractha is a very hardy tree it can establish successfully in almost all kind of soil. Hence, no extra inorganic or organic fertilizers application is practiced. However, to support seedling establishment in the initial stage, 2 to 3 kg farmyard manure is applied per pit. The trees establish very well in southern India with the prevailing rainfall, start yielding from 5th year onwards, and yield increases as age of the tree increases. It reaches its peak yield from 10th to 15th years. Life span of Azadiractha tree is considered well above 100 years

The extraction unit consists of an electric motor driven screw press and a filter press. One tonne seeds and yield 400 kg crude Azadiractha oil. Transesterification process of 100 litres (85 kg) oil consumes 20 kg of methanol and 0.80 kg NaOH. The transesterification reaction is carried out in a heated tank (60-80°C) and yields about 15-16 kg glycerine and 85 to 90 litres of biodiesel. (The glycerine, is assumed to be sold in the market)

6.4 Results of Azadiractha LCA

6.4.1 Energy Analysis

Non-renewable energy requirement

Production and use of one FU of Azadiractha biodiesel consumes 0.034 MJ of non-renewable energy (Ref. Table 6.1), which is similar to Pongamia System NRER and forty times less than reference system i.e. approximately 1.25 MJ (Achten etal. 2010).

Table 6. 1 Non-renewable energy requirement in Azadiractha LCA

Non-renewable Energy Requirement in MJ for Azadiractha LCA			
Sl. No	**Cultivation**	**MJ**	**MJ Per FU**
1	Tractor production	NA	
2	Infrastructure: farm shed	NA	
3	Poly bags production	1.06±0.23	
4	Fertilizer production	NA	
	N, P & K		
5	Diesel production and use	7.16±3.24	
6	Electricity production and use	NA	
	Sub Total	**8.22±3.24**	**0.001**
	Oil Extraction		
7	Oil press production	29.08±5.41	
8	Electricity production and use: oil press Filter press	57.74±0.88	
	Sub Total	**86.82±5.4**	**0.014**
	Biodiesel Production		
9	Transesterification unit production	21.09±0.25	
10	Production of methanol	50.25±0.3	
11	Production of catalyst (NaOH)	1.65±0.66	
12	Electricity production and use:-- transesterification unit	35.18±7.52	
	Sub Total	**108.17±7.66**	**0.024**
	Grand Total	**203.21±9.97**	**0.034±0.002**

Energy in put is found to be 0.47 MJ (Ref. Table 6.2) per functional unit i.e. producing 100g of seeds. Input energy is also found to be 20% less compared to Madhuca System (0.58 MJ/FU) and 30% less compared Pongamia system (0.66 MJ/FU).

Table 6. 2 Energy inputs into Azadiractha system

Stage	Energy	Quantity / Yr / ha	Units	Calorific value in MJ	Energy in MJ	Energy in MJ / FU
Cultivation	Man power	11	Man days	10	110±14.4	
	Diesel	22	Litre	37.5	825±98.8	
	FYM	600	kg	0.03	18.18±2.16	
	Poly bags usage	330	Numbers	0.69	229.28±27.3	
				Sub Total	**1182.46±103.81**	**0.20**
Oil Extraction	Man power	6	Man days	10	60±10.7	
	Diesel	11	Liters	37.5	412.5±131.2	
	Electricity used	60	kWh	3.6	216±26.6	
				Sub Total	**688.5±134.68**	**0.11**
Esterification	Man power	4	Man days	10	40±5.7	
	Electricity used	35.29	kWh	3.6	127.05±15.24	
	NaOH	1.5	kg	23.3	34.95±4.3	
	H_2SO_4	0.3	kg	3	0.9±0.12	
	Acetic Acid	0.3	kg	13	3.9±0.52	
	Methanol	37.5	litres	13.23	496.12±60.1	
				Sub Total	**702.93±17.42**	**0.12**
				Total	**2573.89±178.7**	**0.04**
Miscellaneous Energy inputs (Assumption 10 % of Total Energy In puts)					**257.38**	**0.04**
				Grand Total	**2831.28±178.7**	**0.47±0.03**

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

*Therefore input energy required for producing 0.1kg = 0.1kg x 2831.28/600 kg =0.47MJ

Table 6. 3 Energy output from Azadiractha life cycle

Energy Outputs From Azadiractha System @ 6th Year							
Stage	**Energy**	**Quantity / Yr / ha**	**Units**	**Calorific value in MJ ****	**Energy in MJ**	**Energy in MJ / FU**	**** References**
Cultivation	Seed	600	Kg	-NA-	0		
	Fuel Wood	3000	Kg	19.25	57750±6930		Fire wood 2012
				Sub Total	**57750±6930**	**9.63**	
Oil Extraction	Oil	150	Kg	-NA-			
	Seed cake	390	Kg	-NA-			
				Sub Total	**0**	**0.00**	
Esterification	Biodiesel	127.5	Kg	39	4972.5±594.3		Ragit 2009
	Glycerine	22.5	Kg	18.5	416.25±51.2		Kain et al. 2009
				Sub Total	**5388.75±594.62**	**0.90**	
				Grand Total	**63138.75±7139**	**10.52±1.19**	

Table 6. 4 Net energy gain & Net energy ratio

	Biodiesel	Total System
Energy input in MJ / FU	0.12	0.47
Net Energy Gain	0.94	10.05
Net Energy Ratio	7.80	22.38

Energy output per functional unit is found to be high in contrast to Jatropha system analyzed by Achten et al. 2010 and 35 % lower than Pongamia system and 40% lower than Madhuca system. Net energy ratio is also found to be less (22.3), which is 26% less than Madhuca system and 10% less than Pongamia system (Ref. Table 6.3 & 6.4).

Research on use of Azadiractha seed cake for biogas generation is found to be very little since Azadiractha seed cake has anti bacterial effect, which hinders digestion of seed cake for methane generation. The seed cake is used as organic manure, especially in sugarcane, paddy, banana and vegetable crops, since it has insecticidal / nematicide effect apart from providing organic nitrogen to plants (INSEDA-Azadiractha 2008).

6.4.2 Global Warming Potential (GWP)

The Azadiractha biodiesel system showed an emission of 35.17gCO_2-eq / FU (Ref. Table 6.5), which is 8 times less than reference system (i.e. Fossil fuel = approximately 280g CO_2-eq). The biodiesel production phase is the biggest contributor in the system (38%), followed by oil extraction (35%) and cultivation (26%). Azadiractha tree wood is not harvested for fuel hence CO_2 emission at cultivation phase is the least when compared to Pongamia cultivation (Lokesh et al. 2012). Since very little inorganic fertilizer is used in the system the GWP is very less compared to (by six times) Palm oil (Kina et al. 2009) and (by four times) Jatropha system (Achten et al. 2010), which uses a considerable amount of inorganic fertilizer for better yield.

Table 6. 5 Green house gas emissions from Azadiractha life cycle

Stage	Particulars	Quantity	Units	CO_2	Unit	kg CO_2-eq	gCO_2- eq / ha	gCO_2- eq /FU	References
Cultivation	Poly-bags production & discharge	1.65	kg	5.5	kg	9.075	9075±0.66		Lonny Grafman et al. 2012, Juerg n.d.
	Organic Fertilizer application [1 t of FYM has Approx 10 kg N = 0.01 N20 Emission]	6	kg	0.01	kg	0.06	60±0.07		IPCC-ID:417274, TNAU 2012
	Diesel Use	140	km	0.333	kg/km	46.62	46620±5.8		ARAI 2007
					Sub Total	**55.755**	**55755±5.69**	**9.29**	
Oil Extraction	Electricity production and use: - oil press + Filter press						74800±0.07		Achten et al. 2010
					Sub Total		**74800±0.07**	**12.47**	
Biodiesel Production	Methanol production						2992±0.09		Achten et al. 2010
	Electricity production and use: - transesterification unit						74800±0.07		Achten et al. 2010
	Biodiesel Combustion in an Engine (B100)	127.5	kg	20.9	g/kg		2664.75±305.2		Ragit et al. 2009
					Sub Total		**80456.75±299.3**	**13.41**	
					Total		**211011.75±301.9**	**35.17±0.05**	

6.4.3 Acidification and Eutrophication Potential of Azadiractha System

The Azadiractha system showed a drastic decrease in AP of 95% compared to the reference system. The major contribution is made during the diesel combustion for transportation during cultivation phase, which still is very negligible or may be considered nil compared to Jatropha (Achten 2009) and Palm oil (Kian 2010). In view of the fact that acidification potential results are quite negligible and direct application of inorganic fertilizer and pesticides are missing / not used in the system, Eutrophication potential has not been considered (Table 6.6).

As per calculations made from data collected from biofuel park a four to five year old Azadiractha plantation has a sequestration capacity of about 10 t/ ha / year (and fifteen year old plantation has a sequestration capacity of 26 t / ha /yr). The CO_2 emission from Azadiractha system is 0.2 tonnes/ ha (Table 6.5). These 0.2 tonnes of CO_2 can be sequestered by standing biomass of Azadiractha trees on wasteland and can further sequester additional 9 tonnes of CO_2.

Table 6. 6 Total SO_2 equivalent emission from Azadiractha system

Greenhouse Gas Emissions NH_3, NO_X and SO_X emissions to air [SO_2-eq]						
Stage	**Particulars**	**Quantity**	**Unit**	**$gSO_{2\text{-eq}}$/ha**	**gSO_2-eq/FU**	**References**
Cultivation	N volatilization (NH3)	0.31	kg	0.29±0.003		
	Poly bag Production & Discharge- SO_2	330	Numbers	117.81±27		Juerg 2009 & Graffman 2011
	Poly bag Production & Discharge- NO_x	330	Numbers	207.9±26.9		Juerg 2009 & Graffman 2011
	Diesel use- NO_x	210	km	91.14±15.8		ARAI 2007
		Subtotal		**417.14±41.21**	**0.14**	
Oil Extraction	Electricity production and use- Oil press + Filter Press	60	kWh	66.67±5.04		IPCC-ID1622
		Subtotal		**66.67±5.04**	**0.02**	
Biodiesel Production	Electricity production and use- transesterification unit	35.29	kWh	39.22±4.67		IPCC-ID417274
	Biodiesel Combustion	127.5	kg	0.13±0.2		Karmakar et al. 2012
		Subtotal		**39.35±4.4**	**0.01**	
		Grand Total		**523.17±40.70**	**0.17±0.01**	

6.4.4 Land Use Change

The use of land for a given purpose may change its quality in terms of life support or potentiality for other usage (Lindeijer et al. 2002).

As a part of Azadiractha biodiesel LCA, land use change and its ecological impact studies were carried out. The impact percentage of planting Azadiractha on wasteland and agricultural land bunds showed that both LUC and LUO with respect to ecological structural quality and functional quality were very little.

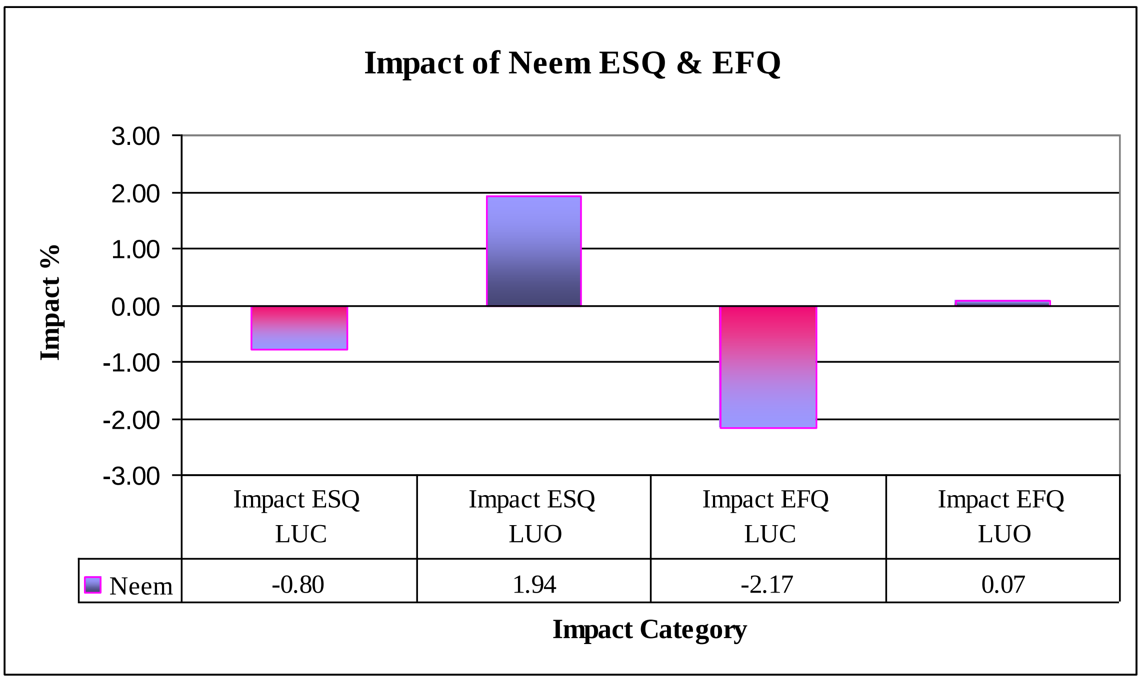


Figure 6. 3 Azadiractha ESQ and EFQ

Figure 6.4 & 6.5 indicates that Azadiractha being a local tree species similar to Pongamia and Madhuca has very little impact on local ecology. Ecological impact calculation per functional unit also reveals that, planting Azadiractha trees on waste land and agricultural land bunds has resulted in improvements in ESQ impact of (-23.98 %) and EFQ impact of (-65.6%) with respect to LUC.

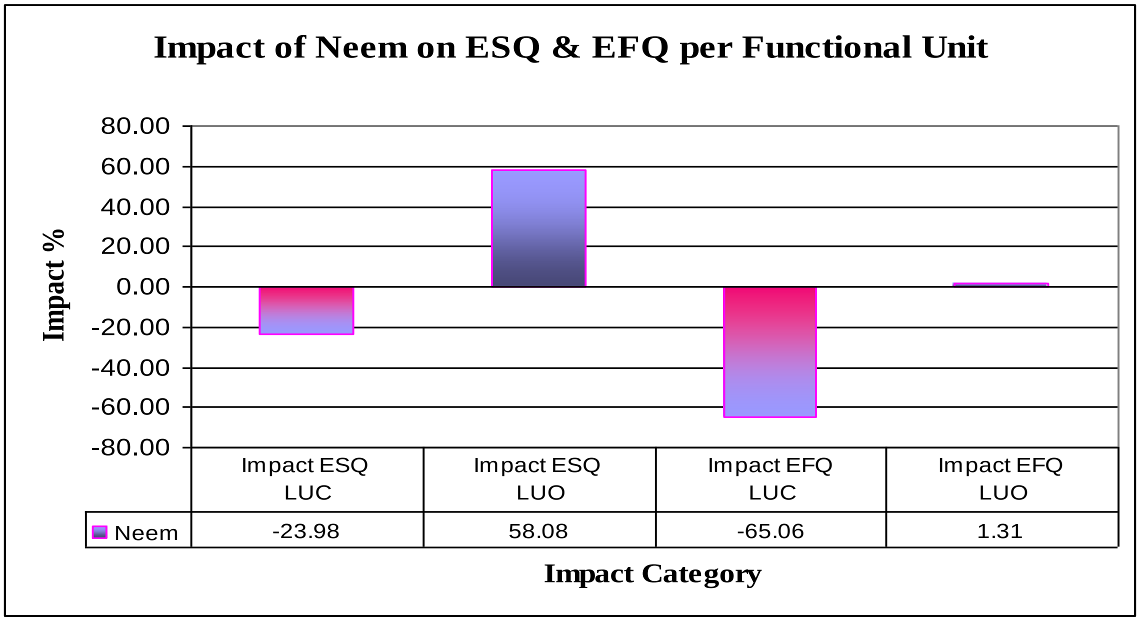


Figure 6. 4 Impact of Azadiractha on ESQ and EFQ per Functional unit

The improvement in ESQ signifies that the Azadiractha plantation has better storage ability in terms of vegetation (biomass), constitution (structure) and biodiversity than the wasteland. The improvement in EFQ (-65.06%) signifies that the Azadiractha plantation has better control over water, organic matter and nutrient movement (absorption) than the wasteland (Achten et al.2009). This is because Azadiractha 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. The roots seem to have an unusual ability to extract nutrients and moisture from highly leached sandy soils, as it has deep tap root system. The optimum pH is 6.2 or above, although Azadiractha will grow well at pH 5.0 bringing surface soils to neutral pH by its leaf litter. (INSEDA- Azadiractha and NOVODB-Azadiractha 2009). The impact of Azadiractha occupying the wasteland shows an ESQ reduction of 58% and an EFQ reduction of 1.31% compared to the potential natural vegetation. These land use impacts apply to 6 m^2 * (5yr) /FU

6.5 Economics of Azadiractha Cultivation

This section addresses the cost of cultivation of Azadiractha followed by cost of production of biodiesel from Azadiractha oil. Cost of cultivation has been carried out for cultivating Azadiractha as a biodiesel feedstock in one hectare of wasteland under rain fed condition. Cost of cultivation is normally calculated till the plantation stabilizes and starts yielding. In the case of Azadiractha, the plantation starts yielding after five years and the input cost is found to be very little after five years, since the tree is self-sustaining. Hence, cost of cultivation has been calculated for first five years of plantation only (Table 6.7).

Table 6. 7 Cost of Azadiractha cultivation in one hectare

Cost of Azadiractha Cultivation in One Hectare									
	Spacing	**5.5 x 5.5 m**							
	No trees/ ha	**330**							
	Survival /ha	**300**							
	Replacement	**50**							
	Average wage / day in Rs	**150**							
SL .No	**Particulars**	**Quantity**	**Cost Rs.**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total in Rs.**
1	Cost of Plants Including Transportation in Rs		3	990					990±36
2	No of man days for digging 330 pits (55 pits/ MD)	6		900					900±72
3	Cost of Plants Including Transportation for replanting		3		150				150±36
4	Digging for replanting	1			150				150±12
5	Staking	2		300					300±36
6	FYM @ 2 kg / pit	600	1	600					600±78
7	Irrigation @ twice/ year	2	250	500	500	500	500	500	2500±72
8	Contingency (10 % for first year and Rs. 150 for next four years			320	150	150	150	150	920±60
9	Grand Total			3520	950	650	650	650	**6510±166.4**

* Irrigation is only life saving measure taken in hot summer months. Approximately 30 to 40 litres of water is used for one irrigation

Income from seed yield /ha

Table 6. 8 Earning from Azadiractha seed from 5th to 10th year

Year	Seed / tree (kg)	No. of trees (Survived)	Qty of seed (kg)	Selling Price / kg	Total Income (Rs.)	Income after deduction of COC in Rs.
5	2	300	600	16	9600	3180±72.4
6	3.5	300	1050	16	16800	10380
7	6	300	1800	16	28800	22380
8	8	300	2400	16	38400	31980
9	10	300	3000	16	48000	41580
10	12	300	3600	16	57600	51180

* Rs 16/- is the selling price as of Jan2012, obtained from oil mills at Tumkur district + http://agmarknet.nic.in/ (Assuming the Selling price will be constant)

Seed yeild / tree data collected from Biofuel Park

Azadiractha plantation normally starts yielding after fifth year and the yield gradually increases and stabilizes after ten or twelve years. Price of seed, oil and oil cake has been collected from oil mills at Tumkur district and Agriculture produce market committee-Market, Bangalore. For calculation of income from selling seed and oil + seed cake the prices of current market rate i.e. January 2012 have been considered. As understood from the above Table 4.12, one can get back the investment made on Azadiractha plantation in the fifth year or the first year of yield and obtain a profit of Rs. 3180/- if seed alone is sold in open market.

If the seed is used for oil extraction one could get a profit of Rs. 22200/-(Table 6.9 & 6.10)

Income from Azadiractha oil + seed cake is as follows

Table 6. 9 Income from Azadiractha oil and seed cake

Year	Qty of seed (kg)	Oil Yield @30% / kg of seed	Selling price of oil in Rs.	Income from oil 'A' in Rs.	Seed cake yield in kg	Selling Price of seed cake in Rs.	Income from seed cake 'B' in Rs.	A+B	Income after deduction of cost of cultivation *
5	600	180	120	21600±2590	390	18	7020±842	28620±2751	22200
6	1050	315	120	37800	682.5	18	12285	50085	43665
7	1800	540	120	64800	1170	18	21060	85860	79440
8	2400	720	120	86400	1560	18	28080	114480	108060
9	3000	900	120	108000	1950	18	35100	143100	136680
10	3600	1080	120	129600	2340	18	42120	171720	165300

* Income of oil (A+B) – Cost of cultivation **=** Rs. 28620-6420 = **Rs. 22200/-**

Inputs Cost of producing 100 litres of biodiesel from Azadiractha oil is as follows

Table 6. 10 Cost of biodiesel production from Azadiractha oil

Sl.No.	Inputs	Quantity	Unit	Buying price in Rs.	Unit	Total Price in Rs.
1	Seeds	334	kg	16	Per kg	5344±641
2	Electricity for oil Extraction	26.72	kWh	8.5	Per kWh	227.12±26.5
3	Electricity for biodiesel Production 100L	19.09	kWh	8.5	Per kWh	162.23±19.4
4	Methanol	25	litres	35	Per litre	875.00±101.5
5	Sodium hydroxide	1	kg	65	Per kg	65.00±7.8
6	Sulphuric Acid	150	ml	0.2	Per ml	30.00±3.6
7	Acetic Acid	150	ml	0.2	Per ml	30.00±3.6
					Grand Total	**6733.35±670.22**
					Inputs Cost for 1 litre biodiesel	**67.33±6.7**

Income from by product of (100 litres) biodiesel production is found to be Rs.42.07 (table 6.11)

Table 6. 11 Income from by product of (100 litres) biodiesel production

Sl.No	Inputs	Quantity	Unit	Price in Rs.	Unit	Total in Rs.
1	Seed Cake	217.1	kg	18	Per kg	3907.8±460
2	Crude Glycerine	15	kg	20	Per kg	300±34.5
					Total	**4207.8±456.18**
					Income from 1 litre	**42.07±4.51**

Input cost of biodiesel production from Azadiractha oil is Rs.67.33/- (Table 4.14), which is found to be higher by 13% compared to Pongamia; and 24% compared to Madhuca. This is due to lower oil percentage of Azadiractha seed. However income from by products of Azadiractha biodiesel is slightly higher due to higher seed cake price i.e. Rs.18/- (Ref. Table 6.11) as compared to Pongamia (Rs.15/-) and Madhuca (Rs.12/-).

Assuming that biodiesel production unit will be at village level and average requirement of diesel fuel per day would be approximately 200 litres, capital cost has been calculated for a 48000 litre / year capacity (Table 6.12)

Capital cost: is constant for biodiesel production from the same infrastructure (Ref. Table 4.14) when compared to current prevailing diesel prices (Rs.51.20/-) in Karnataka, biodiesel price is found to be lower by Rs.8.20/-. Actual diesel price is higher than the prevailing price due to government subsidy of Rs 8/- per litre as on Oct. 2012 (Ministry of petroleum- GOI). One litre of diesel with out government subsidy shall cost approximately Rs.59.2/- per litre. Hence when compared with unsubsidized diesel, Azadiractha biodiesel is found to be cheaper by Rs.16.2/- (Table 6.12). Since the Azadiractha oil price is found be Rs.120 / kg, farmers may get lured to extract oil and sell in open market rather than produce biodiesel.

Actual cost of one litre biodiesel produced from Azadiractha oil

Table 6. 12 Actual Cost of Azadiractha biodiesel

Sl.No	Particulars	Unit	Cost / Unit	Total in Rs
1	Inputs cost for producing Biodiesel 'A'	48000 L	67.33	3232007.31
2	Income from selling crude glycerine 'B'	7200 kg	20	144000
3	Income from selling seed cake 'C'	102960 kg	18	1853280
4	A- (B+C)			1234727.31
5	Capital Cost Per year			105833.33
6	Labour cost	1+2		348000
7	Maintenance per year			20000
8	Insurance per year			10000
	Total Cost per 48000 liters			1718560.65
	Cost of one liter biodiesel			**36**
	Selling price with 20 % profit			**43**
	Profit @20% Margin			**336000**

As seen from the table 6.9 income from Azadiractha + seed cake (6th year), it is found that a farmer gets an income of Rs. 50085/- for 262 litres of oil from 1050 kg of seeds.

It is to be noted that 315 litre of oil yields 268 litre of biodiesel costing Rs. 36 per litre and Rs. 43 @ 20% profit margin, which is lower than fossil diesel (Earning a profit of Rs. 2197.6 for 268 litres of biodiesel). Moreover, 268 litre of biodiesel yields very little profit compared to selling oil + seed cake (i.e. Rs. 50085/-). It is also a known fact that Azadiractha, apart from yielding oil and cake provides a huge market for medicinal use of chemical compound named Azadirachtin extracted from seeds. Around 5g of Azadirachtin is extracted from 1kg of seeds, which is priced around two$ /g (Rs.120 /g) in international market (Neem foundation 2012).

From the LCA studies carried out it can be inferred that producing biodiesel from Azadiractha oil is not economically viable when compared to its profitability from oil, seed cake and other by products. Very similar to Madhuca, Azadiractha shall also be available as biodiesel feedstock only after the traditional market is saturated. However, trees like Simarouba, which do not have any streamlined market for its oil and seed cake in India seem to be promising feedstock, which has been discussed in the following chapter 7.

Salient Outcomes of Azadiractha LCA

- Gestation period of Azadiractha tree — 5 years
- All the parts of the tree have medicinal value
- Seed cake is used as an organic fertiliser, which also serves as nematicide
- Life expectancy of a Azadiractha tree is above — 100 years
- NRER of Azadiractha Life cycle — 0.034 MJ / FU
- Energy input — 0.47 MJ / FU
- Energy output — 10.52 MJ / FU
- Net Energy Gain — 10.05 MJ /FU
- Net Energy Ratio — 22.38
- CO_2 Emission — 35.17 g CO_2-eq / FU
- SO_2 Emission — 0.17g SO_2-eq / FU
- CO_2 Sequestration (5 year old Plantation) — 10 t / ha / year
- Impact of Azadiractha on ESQ
  - LUC — -119.88 / FU
  - LOU — +290.41 / FU
- Impact of Azadiractha on EFQ
  - LUC — -325.3 / FU
  - LOU — +10.88 / FU
- Economics
  - Cost of Azadiractha cultivation in one hectare — Rs. 7320/-
  - Price of Azadiractha seed — Rs. 16/-
  - Price of Azadiractha oil — Rs. 120/-
  - Price of Azadiractha seed cake — Rs. 18/-
  - Price of Glycerine — Rs. 20/-
  - Cost of Biodiesel produced from Azadiractha Oil — Rs. 36/-
  - Price of Biodiesel with 20 % profit margin — Rs. 43/-
  - Price of Diesel — Rs. 51.20/-
- Credits
  - Glycerine replacing synthetic glycerine — 22.5 kg
  - Seed Cake replacing chemical fertilisers — N=9.75 kg, P=3.9 kg K= 5.85 kg

Conclusion: From the LCA studies carried out it can be inferred that producing biodiesel from Azadiractha oil is not economically viable.

However, producing biodiesel from Azadiractha oil is economically viable provided seed is purchased or harvested from a local plantation and oil extracted at local level. (Section 8.7, Fig. 8.9, 8.10 & 8.11).

CHAPTER 7

LIFE CYCLE ASSESSMENT OF BIODIESEL PRODUCED FROM SIMAROUBA GLAUCA OIL

7.1 LCA of Simarouba Biodiesel Produced and Used in Rural Karnataka

This section portrays an exclusive LCA study Simarouba biodiesel system in rural Karnataka, very similar to Pongamia, Madhuca and Azadiractha LCA, which is being used for reclaiming wasteland and for producing biodiesel for local consumption in transportation / water pumping / electricity generation. The LCA evaluates the performance of the Simarouba system against conventional diesel as reference system. Apart from assessing energy input / output and green house gas emission, this analysis also assess acidification, eutrophication and land use change impact. LCA of Simarouba biodiesel aims at studying the use of Simarouba biodiesel as a source of fuel for transportation / water pumping / electricity generation produced locally.

The LCA of the Simarouba, biodiesel included cultivation, oil extraction, esterification, and associated by-products of each phase (Seed cake, biogas from seed cake and biogas slurry as fertilizer). The data was collected from Biofuel Park located at Madenur in Hassan district of Karnataka State. The system boundary conditions included the usage of biodiesel and associated by-products locally (Ref. Figure 7.1, 7.2 & 7.3). One MJ of energy available in Simarouba biodiesel was considered as the functional unit (FU) for life cycle impact assessment. This study focused on Simarouba plantations on waste lands and village common lands.

7.2 Life Cycle Inventory

This LCA study was carried out at ‘Biofuel Park’, Hassan. This study focused on Simarouba plantations on wastelands, degraded lands and agricultural land bunds. The boundary conditions of LCA studies of Simarouba biodiesel in comparison with fossil fuel has been depicted in figure 7.1, 7.2 and 7.3.

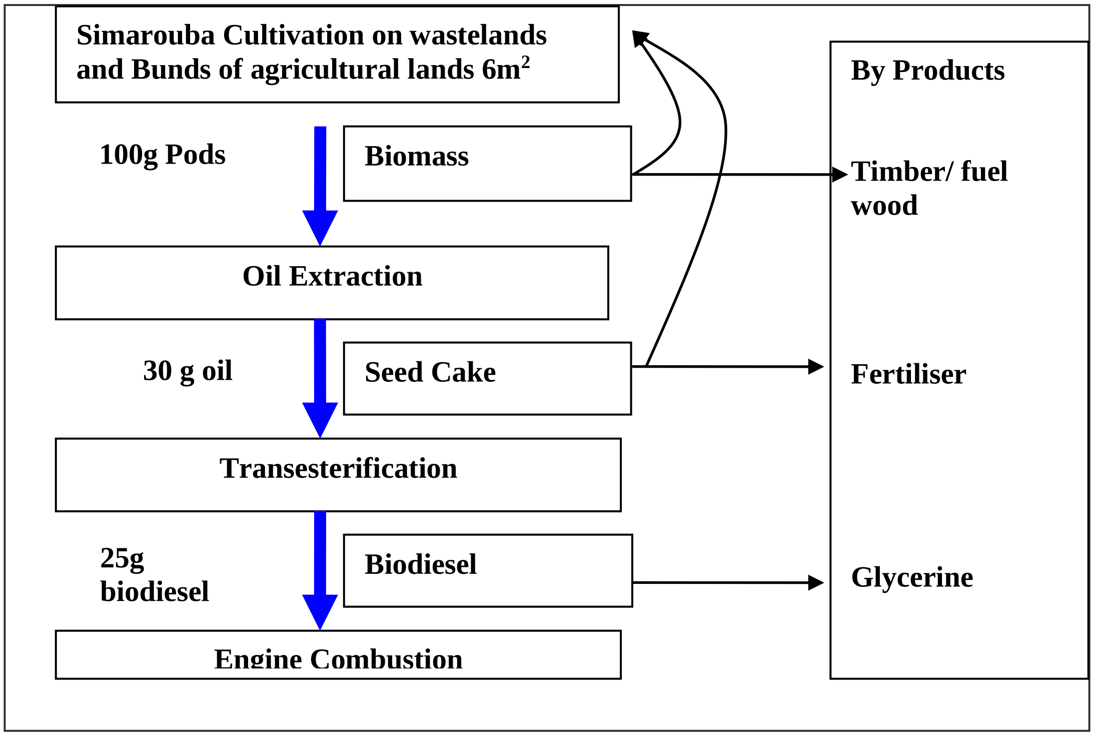


Figure 7. 1 System boundary for Simarouba LCA

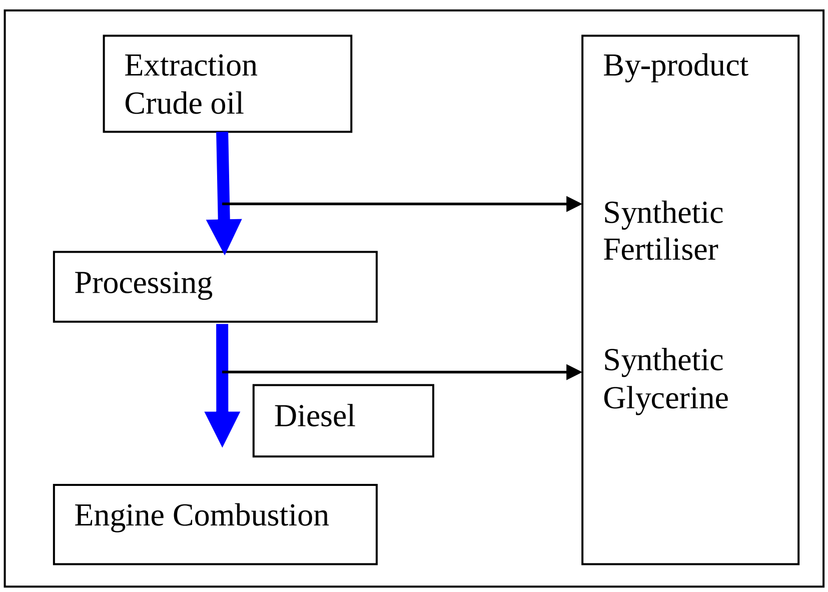


Figure 7. 2 System boundary for Reference (Fossil fuel- Diesel)

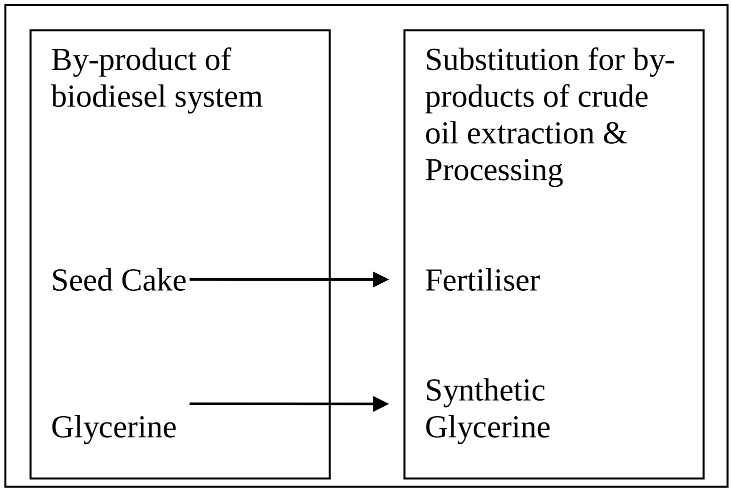


Figure 7. 3 By-product of biodiesel system as substitutes

7.3 Data Collection

The data was collected from Biofuel park offices followed by personal interviews and interaction with farmers associations "*Jaivika Indhana Beejagala Belegarara Sangha*". This data collected, is in line with data collected for Pongamia Madhuca and Azadiractha LCA studies (Appendix 4 & 5). The factors considered in this study are given in Table 2.7 to 2.12.

7.3.1 Production System

This section portrays an exclusive LCA study of Simarouba biodiesel in rural India, which is being used for rejuvenating wasteland and for producing biodiesel for local consumption in transportation / water pumping / electricity generation. The LCA evaluates the performance of the Simarouba system against conventional diesel as reference system. Apart from assessing energy input / output and green house gas emission, this analysis also assess acidification, eutrophication and land use change impact. LCA of Simarouba biodiesel aims at studying the use of Simarouba biodiesel as a source of fuel for transportation / water pumping / electricity generation produced locally. The environmental impacts producing a biogas from Simarouba seed cake has been taken into consideration, in addition to biodiesel production in LCA.

This section depicts the study of production system, based on the data collected from Biofuel Park. Seedlings are raised in poly bags in the nursery. Seeds are sown in a mixture of soil and local compost and are watered manually. Saplings are transplanted on wastelands and agriculture field bunds. Tree population of 500 / ha is maintained on wasteland / degraded lands. However, number of saplings planted on bunds depends on the type of farming practices. A distance of 6 to 8 m is maintained between each tree, when planted on bunds. Simarouba is a very hardy tree and it can establish successfully in almost all kind of soil. Hence, no extra inorganic or organic fertilizers application is practiced. However, to support seedling establishment in the initial stage, 2 to 3 kg farmyard manure is applied per pit. The trees establish very well in southern India with the prevailing rainfall and start yielding from 6^{th} year onwards and reach its peak yield from 10^{th} to 12^{th} years. An average seed yield of about 3 to 4 tons / ha is obtained from a 10 year old plantation. Life span of Simarouba tree is considered way above 80 years.

The extraction unit consists of an electric motor driven screw press and a filter press. One tonne seeds and yield 250 to 300 kg crude Simarouba oil. Transesterification process of 100 litres (85 kg) oil consumes 20 kg of methanol and 0.80 kg NaOH. The transesterification reaction is carried out in a heated tank (60-80°C) and yields about 15-16 kg glycerine and 85 to 90 litres of biodiesel. (The glycerine is assumed to be sold in the market)

7.4 Results of Simarouba LCA

7.4.1 Energy Analysis

Non-renewable energy requirement

Production and use of one FU of Simarouba biodiesel consumes 0.02 MJ/FU of non-renewable energy (Ref. Table 7.1), which is far lower than Pongamia, Madhuca and Azadiractha System NRER and reference system (fossil fuel system) i.e. approximately 1.25 MJ (Achten et al. 2010).

Table 7. 1 Non-renewable energy requirement for Simarouba LCA

Non-renewable Energy Requirement in MJ for Simarouba LCA			
Sl. No	**Cultivation**	**MJ**	**Per FU**
1	Tractor production	NA	
2	Infrastructure: farm shed	NA	
3	Poly bags production	1.76±0.23	
4	Fertilizer production	NA	
	N, P & K		
5	Diesel production and use	7.16±3.24	
6	Electricity production and use	NA	
	Sub Total	**8.92±3.24**	**0.00**
	Oil Extraction		
7	Oil press production	29.08±5.41	
8	Electricity production and use: oil press Filter press	57.74±0.88	
	Sub Total	**86.82±5.43**	**0.01**
	Biodiesel Production		
9	Transesterification unit production	21.09±2.5	
10	Production of methanol	50.25±0.3	
11	Production of catalyst (NaOH)	1.65±0.66	
12	Electricity production and use:- transesterification unit	35.18±7.52	
	Sub Total	**108.17±7.9**	**0.01**
	Grand Total	**203.91±10.38**	**0.02±0.001**

Energy input is found to be 0.23 MJ per functional unit for producing 100g of seeds (Table 7.2). Input energy is found to be 51 % less than Azadiractha (0.47 MJ/FU) 60% less compared to Madhuca (0.58 MJ/FU) and 65% less compared Pongamia (0.66 MJ/FU).

Table 7. 2 Energy inputs into Simarouba System

Energy Inputs into Simarouba System						
Stage	**Energy**	**Quantity / Yr / ha**	**Units**	**Calorific value in MJ**	**Energy in MJ**	**Energy in MJ / FU**
Cultivation	Man power	14	Man days	10	140±14.9	
	Diesel	22	Litres	37.5	825±98.8	
	FYM	1000	kg	0.03	30.3±3.6	
	Poly bags usage	500	Numbers	0.6948	347.4±40.9	
				Sub Total	**1342.7±109.81**	**0.15**
Oil Extraction	Man power	6	Man days	10	60±7	
	Diesel	11	Litres	37.5	412.5±50.1	
	Electricity used	90	kWh	3.6	324±39.1	
				Sub Total	**796.5±63.84**	**0.09**
Esterification	Man power	4	Man days	10	40±5.7	
	Electricity used	63.53	kWh	3.6	228.7±28.3	
	NaOH	2.7	kg	23.3	62.91±7.4	
	H_2SO_4	0.54	kg	3	1.62±0.19	
	Acetic Acid	0.54	kg	13	7.02±0.84	
	Methanol	67.5	Litres	13.23	893.025±108	
				Sub Total	**1233.28±28.82**	**0.14**
				Total	**3372.481±126.21**	**0.03**
Miscellaneous Energy inputs (Assumption 10 % of Total Energy In puts)					**337.2481**	**0.04**
				Grand Total	**3709.729±126.21**	**0.41±0.01**

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

*Therefore input energy required for producing 0.1kg = 0.1kg x 3709.96/900 kg =0.41MJ

Table 7. 3 Energy outputs from Simarouba System

Energy Outputs From Simarouba System at 6th Year							
Stage	**Energy**	**Quantity / Yr / ha**	**Units**	**Calorific value in MJ ****	**Energy in MJ**	**Energy in MJ / FU**	**** References**
Cultivation	Pod Shell	540	kg	15	8100±970		Data assumed to be similar to Pongamia
	Seed	360	kg	-NA-	0		
	Fuel Wood	1350	kg	19.25	86625±3120		IREDA News 2007
				Sub Total	**94725±3383**	**7.45**	
Oil Extraction	Oil	270	kg	-NA-			
	Seed cake	315	kg	14.3	4505.5±539.8		Data assumed to be similar to Pongamia
				Sub Total	**4505.5±539.8**	**1.00**	
Esterification	Biodiesel	229.5	kg	38	8721±1040		Devan & Mahalakshmi 2009
	Glycerine	40.5	kg	18.5	749.25±90.1		Kian et al 2009
				Sub Total	**9470.25±1078**	**2.14**	
				Grand Total	**47522.25±3730**	**0.82**	

Table 7. 4 Net energy gain & Net energy ratio

	Biodiesel	**Total System**
Energy input/ FU	**0.14**	**0.41**
Net Energy Gain	1.97	10.15
Net Energy Ratio	15.36	25.62

Energy input is found to be 0.41MJ/FU (Table 7.2) and energy output per functional unit is found to be 10.56MJ/FU (Ref. Table 7.3 & 7.4), which is high compared to Jatropha system analyzed by Achten et.al (2010). Energy output of Simarouba system is also found to be on par with Azadiractha system, 1.6 times lower than Madhuca system and 1.5 times lower than Pongamia system. Net energy ratio is found to be 25.62, which is on par with Pongamia system (24.74) and Azadiractha system (22.3) and 15% less than Madhuca system (30.5).

Research on use of Simarouba seed cake for biogas generation is found to be very little. The seed cake is used as organic manure. (* Note in energy output calculation calorific value of the seed cake is assumed to be very near to pongamia seed cake)

7.5 Global Warming Potential (GWP)

The Simarouba biodiesel system showed an emission of 39.9 g CO_2-eq / FU (Table 7.8), which is 7.36 times less compared to the reference system (i.e. Fossil fuel = approximately 280g CO_2-eq). The biodiesel production phase is the biggest contributor in the system (40%), followed by oil extraction (33%) and cultivation (27%). Simarouba tree wood is not harvested for fuel but a meagre sum of 3 kg wood / tree has been taken into account for output energy calculation) hence CO_2 emission at cultivation phase is the least when compared to Pongamia cultivation. However, 10 kg fuel wood harvest/ tree has been assumed for energy output calculation. If fuel wood were, harvested Simarouba system would emit 70.7 gCO_2-eq / FU, which is still 4 times less than Fossil fuel System emission. Since no fertilizer is used in the system the GWP is very less compared to (by 23 times) Palm oil (Kina et al. 2009) and (by 17 times) Jatropha system (Achten et al. 2010), which uses a considerable amount of inorganic fertilizer for better yield.

Table 7. 5 Greenhouse gas emissions (CO_2) from Simarouba system

Stage	Particulars		Units	CO_2	Unit	Kg CO_2-eq	gCO_2- eq / ha	gCO_2- eq /FU	References
Cultivation	Poly-bags production& discharge	2.5	kg	5.5	kg	13.75	13750±3.9		Lonny Grafman et al. 2012, Juerg n.d.
	Organic Fertilizer application [1 t of FYM has Approx 10 kg N = 0.01 N20 Emission]	10	kg	0.01	kg	0.1	100±0.11		IPCC-ID:417274, TNAU 2012
	Diesel Use	140	km	0.33	kg/km	46.62	46620±5.5		ARAI 2007
					Sub Total	**60.47**	**60470±6.63**	**11.09**	
Oil Extraction	Electricity production and use: - oil press + Filter press						74800±0.07		Achten et al. 2010
					Sub Total		**74800±0.07**	**13.72**	
Biodiesel Production	Methanol production						2992±0.09		Achten et al. 2010
	Electricity production and use: - transesterification unit						74800±0.07		Achten et al. 2010
	Biodiesel Combustion in and Engine (B100)	229.5	kg	20.9	g/kg		4796.55±575		Data assumed to be similar to Pongamia
					Sub Total		**82588.55±571.24**	**15.15**	
					Total		**217858.55±553.1**	**39.97 ±0.1**	

7.6 Acidification Potential of Simarouba System

The Simarouba system showed a drastic decrease in AP of 95% compared to the reference system (Table 7.6). The biggest contribution is made during the diesel combustion for transportation during cultivation phase, which still is very negligible or may be considered nil compared to Jatropha (Achten 2009), Palm oil (Kian 2010), Soya, rapeseed biodiesel system (Cherubin et al. 2009). Eutrophication potential has not been considered since direct application of inorganic fertilizer and pesticides are missing / not used in the system and in view of the fact that acidification potential results are quite negligible.

As per calculations made from data collected from biofuel park a 4-5 year old Simarouba plantation has a sequestration capacity of about 35 t / ha / year (Appendix- 12). The amount of CO_2 released by Simarouba system is (0.22 tons/ ha) can be sequestered by Simarouba trees of standing biomass of waste land and still can absorb a surplus of 34.7 tonne of CO_2, which is a very encouraging

Table 7. 6 Greenhouse gas emissions (SO_2) from Simarouba system

Greenhouse Gas Emissions NH_3, NO_X and SO_X emissions to air [SO_2-eq]						
Stage	**Particulars**		**Unit**	**gSO_{2-eq}/ha**	**gSO_2-eq/FU**	**References**
Cultivation	N volatilization (NH_3)	1.68	kg	0.44±0.3		ELV 2000
	Poly bag Production & Discharge- SO_2	500	Numbers	178.50±21.42		Juerg 2009 & Graffman 2011
	Poly bag Production & Discharge- NO_x	500	Numbers	315.00±37.8		Juerg 2009 & Graffman 2011
	Diesel use- NO_x	210	km	91.14±10.8		ARAI 2007
			Subtotal	**585.07±43.4**	**0.06**	
Oil Extraction	Electricity production and use- Oil press + Filter Press	90	kWh	100.01±11.6		IPCC-ID1622
			Subtotal	**100.01±11.6**	**0.01**	
Biodiesel Production	Electricity production and use-transesterification unit	63.53	kWh	70.6±8.4		IPCC-ID417274
	Biodiesel Combustion	230	kg	0.23±0.03		
			Subtotal	**70.83±8.99**	**0.007**	
			Grand Total	**755.93±46.03**	**0.08±0.005**	

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7.7 Land Use Change

As a part of Simarouba biodiesel LCA, land use change and its ecological impact studies were carried out. The impact percentage of planting Simarouba on wasteland and agricultural land bunds showed that both LUC and LUO with respect to ecological structural quality and functional quality were very little.

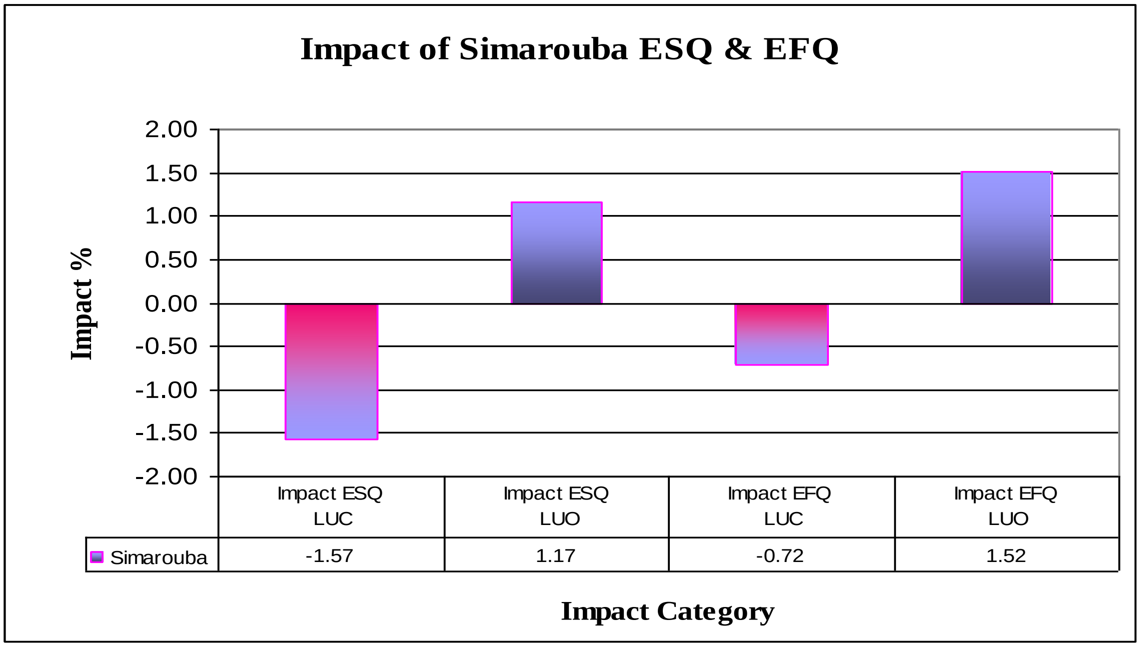


Figure 7. 4 ESQ and EFQ of Simarouba system

Figure 6.4 indicates that although Simarouba is not a native tree, it has adopted itself to local Indian conditions in the past four decades. Hence, Simarouba may be considered as a local tree species similar to Pongamia, Madhuca and Azadiractha. It is also found to have very little impact on local ecology.

Ecological impact calculation per functional unit (Ref. Figure 6.5) also reveals that, planting Simarouba trees on waste land and agricultural land bunds has activated an improvement in ESQ (Impact of -47.09 %) and EFQ (Impact of -21.6%). with respect to LUC. The improvement in ESQ signifies that the Simarouba plantation has better storage ability in terms of vegetation (biomass), constitution (structure) and biodiversity than the wasteland. The improvement in EFQ signifies that the Simarouba plantation has better control over water, organic matter and nutrient movement (absorption) than the wasteland

(Achten et al. 2009) because Simarouba also serves as better soil binder like Pongamia, Madhuca and Azadiractha with well spread root system, which is capable of holding soil intact and promote better water percolation and nutrient uptake.

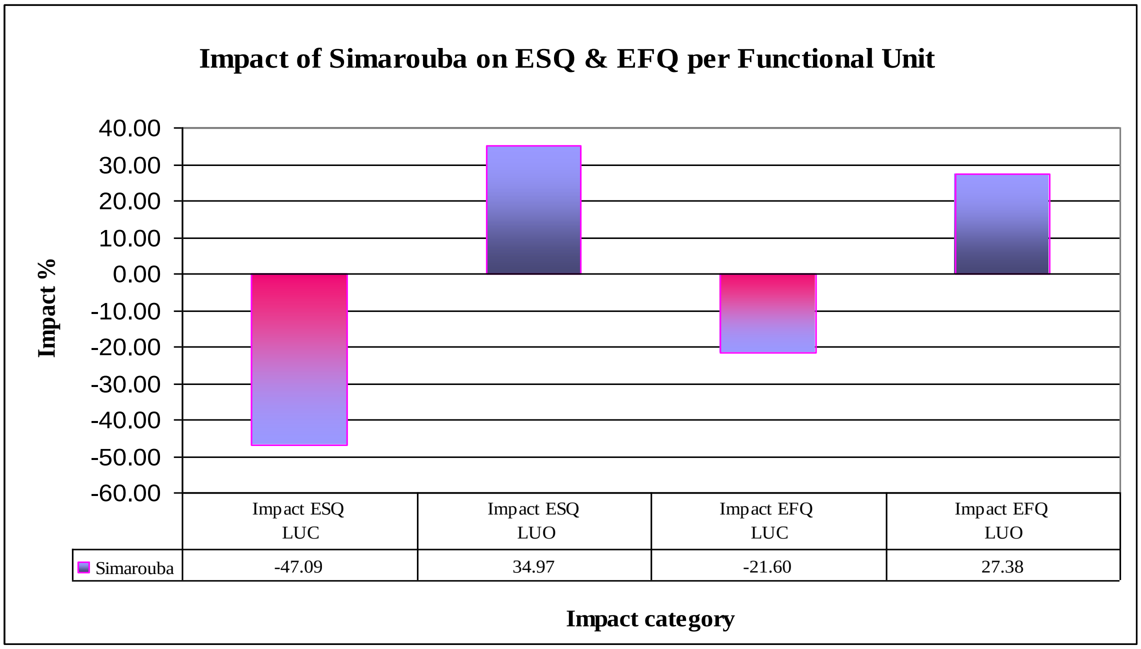


Figure 7. 5 Impact of Simarouba on ESQ and EFQ per functional unit

The roots seem to have a remarkable ability to extract nutrients and moisture from highly degraded soils due to its deep tap root system (Joshi 2000). The LUO impact shows a decrease in ESQ (impact of 34%) and EFQ (impact of 27%) compared to local potential natural vegetation. (These impacts are applicable to 6m^2*yr (5yr) /FU.)

7.8 Economics of Simarouba Cultivation

This section addresses the cost of cultivation of Simarouba followed by cost of production of biodiesel from Simarouba oil.

Cost of cultivation has been carried out for cultivating Simarouba as a biodiesel feedstock in one hectare of wasteland under rain fed condition (Table 5.13).Cost of cultivation is normally calculated until the plantation stabilizes and starts yielding. In the case of Simarouba, the plantation starts yielding from sixth year and the input cost is found to be very little after five years, since the tree is self-sustaining. Hence, cost of cultivation has been calculated for first five years of plantation only. Simarouba plantation normally starts yielding after fifth year and the yield gradually increases and stabilizes after ten or twelve years. Price of seed, oil and oil cake has been collected from oil mills at Tumkur district and Agriculture produce market committee- Market, Bangalore.

For the calculation of income from selling seed and oil + seed cake (Table 5.15) the prices of current market rate i.e. January 2012 have been considered.

Table 7. 7 Cost of Simarouba cultivation in one hectare

Cost of Simarouba Cultivation in One Hectare									
	Spacing	**5 x 4m**							
	No trees/ ha	**500**							
	Survival /ha	**450**	**Replacement 75**			**Average wage / day in Rs.150/-**			
SL .No	**Particulars**	**Quantity**	**Cost in Rs.**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total in Rs.**
1	Cost of Plants Including Transportation		3	1500					1500±36
2	No of man days for digging 500 pits(50 pits/ MD)	9		1350					1350±162
3	Cost of Plants Including Transportation for replanting		3		225				225±36
4	Digging for replanting	2			300				300±24
5	Staking	2		300					300±24
6	FYM @ 2 kg / pit	1000	1	1000					1000±120
7	Irrigation @ twice/ year *	2	250	500	500	500	500	500	2500±72
8	Contingency (10 % for first year and Rs.150 for next four years			465	150	150	150	150	1065±60
9	**Grand Total in Rs**			5115	1175	650	650	650	**8240±182.08**

* Irrigation is only life saving measure taken in hot summer months. Approximately 30 to 40 litres of water is used for one irrigation

Table 7. 8 Earning from Simarouba seed from 6th to 10th year

Income From Seed Yield / ha					
Year	**Seed in kg / Tree**	**No of trees**	**Quantity in Kg**	**Seed price in Rs.**	**Total Income**
6	2	450	900	12	**10800±1301**
7	4	450	1800	12	**21600**
8	8	450	3600	12	**43200**
9	15	450	6750	12	**81000**
10	20	450	9000	12	**108000**
* Assuming the price will be constant					

As understood from calculations (Table 7.9) one can get back the investment made on Simarouba plantation in the sixth year of yield and obtain a profit of Rs.580/- if seed alone is sold in open market. If the seed is used for oil extraction followed by biodiesel production the calculations are as shown in table 5.15.

Table 7. 9 Income from oil and seed cake of Simarouba

Year	**Qty of seed (Kg / tree/ year)**	**Oil Yield @30% / kg of seed**	**Selling price of oil in Rs.**	**Income from oil 'A' in Rs.**	**Seed cake yield in kg**	**Selling Price of seed cake in Rs.**	**Income from seed cake 'B' in Rs.**	**A+B**	**Income after deduction of cost of cultivation ***
6	2	270	40	10800±1300	585	14	8190±982	18990± 1573	**10750**
7	4	540	40	21600	1170	14	16380	37980	**29740**
8	8	1080	40	43200	2340	14	32760	75960	**67720**
9	15	2025	40	81000	4387.5	14	61425	142425	**134185**

* Income of oil (A+B) – Cost of cultivation **=** Rs. 18990- 8240 = **Rs. 10750/-**

India does not have streamlined market for Simarouba oil hence the price used for calculation is only an approximate figure derived after interaction with oil mill owners at Tumkur district and staff at Biofuel Park.

Input Cost of producing 100 litres of biodiesel from Simarouba oil is as shown in table 7.10, which is found to be Rs.5476.34/- (Rs.54.76/ litre). Income from selling the by-product of biodiesel production is found to be Rs.3394/- (Table.7.11). Actual cost of one litre of Biodiesel produced from Simarouba oil is found to be Rs.42/- and selling price Rs.50/- with 20% profit margin (Table 5.18 &5.19).

Table 7. 10 Cost of biodiesel production from Simarouba Oil

Sl.No.	**Inputs**	**Quantity**	**Unit**	**Cost in Rs.**	**Unit**	**Cost in Rs.**
1	Seeds	340	Kg	12	Per kg	4080±490
2	Electricity for oil Extraction	27.2	kWh	8.5	Per kWh	231.20±27.7
3	Electricity for biodiesel Production 100liters	19.43	kWh	8.5	Per kWh	165.14±19.81
4	Methanol	25	litres	35	Per litre	875.00±105
5	Sodium hydroxide	1	kg	65	Per kg	65.00±7.8
6	Sulphuric Acid	150	ml	0.2	Per ml	30.00±3.6
7	Acetic Acid	150	ml	0.2	Per ml	30.00±3.6
					Total	**5476.34±486.94**

Income from by product of (100 litres) biodiesel production

Table 7. 11 Income from by product of biodiesel production from Simarouba oil

Sl.No	**Inputs**	**Quantity**	**Unit**	**Price Rs.**	**Unit**	**Total Rs.**
1	Seed Cake	221	kg	14	Per kg	3094±371
2	Crude Glycerine	15	kg	20	Per kg	300±36
					Total	**3394±365.98**
Income from by product of on litre Simarouba biodiesel						**33.94±3.65**

Capital Cost: is constant for biodiesel production from the same infrastructure (Table 4.14)

Actual Cost of one litre biodiesel

Table 7. 12 Actual cost of one litre biodiesel produced from Simarouba Oil

Actual Cost of One Litre Biodiesel				
Sl.No	**Particulars**	**Unit**	**Cost of BD/100 liters**	**Total in Rs**
1	Inputs cost for producing Biodiesel 'A'	48000	54.76	2628644.57
2	Income from selling crude glycerin 'B'	7200	20	144000
3	Income from selling seed cake 'C'	68952	14	965328
4	A- (B+C)			1519316.57
5	Capital Cost Per year			105833.33
6	Labour cost	1+2		348000
7	Maintenanace per year			20000
8	Insurance per year			10000
	Total Cost per 48000 liters			2003149.9
	Cost of one liter biodiesel			**42**
	Selling price with 20 % profit			**50**

One litre of diesel without government subsidy shall cost approximately Rs.59.2 per litre. Hence when compared with unsubsidized diesel, Simarouba biodiesel is found to be cheaper by Rs.9.20/- (Table 7.12). As seen from the table 5.15 showing income from Simarouba oil + seed cake, a farmer gets an income of Rs. 10750/- for 900 kg of seeds (270 kg of Oil). 270 kg of Simarouba oil yields 230 kg of biodiesel i.e.276 litre of biodiesel, which shall only give profit of Rs.2208/-. This low profit may still push farmers to sell oil in open market if supply chain is streamlined.

From the LCA studies carried out it can be inferred that producing biodiesel from Simarouba oil is both ecologically and economically viable (and the same has been confirmed by the sensitivity analysis carried out in Section 8.7).

A relative analysis of the LCA results from Pongamia, Madhuca, Azadiractha and Simarouba gives a better picture for decision making, which has been discussed in the second part of this thesis in chapter 8.

Salient Outcomes of Simarouba LCA

- Gestation period of Simarouba tree — 4-6 years
- All the parts of the tree have medicinal value
- Seed cake is used as an organic fertiliser
- Life expectancy of a Simarouba tree is above — 80 years
- NRER of Simarouba Life cycle — 0.02 MJ / FU
- Energy input — 0.41 MJ / FU
- Energy output — 10.56 MJ / FU
- Net Energy Gain — 10.15 MJ /FU
- Net Energy Ratio — 25.62
- CO_2 Emission — 40 g CO_2-eq / FU
- SO_2 Emission — 0.08 g SO_2-eq / FU
- CO_2 Sequestration (5 year old Plantation) — 35 t / ha / year
- Impact of Azadiractha on ESQ
  - LUC — -47.09 / FU
  - LOU — +34.97 / FU
- Impact of Azadiractha on EFQ
  - LUC — -21.60 / FU
  - LOU — +27.38 / FU
- Economics
  - Cost of Simarouba cultivation in one hectare — Rs. 10,520/-
  - Price of Simarouba seed — Rs. 12/-
  - Price of Simarouba oil — Rs. 40/-
  - Price of Simarouba seed cake — Rs. 14/-
  - Price of Glycerine — Rs. 20/-
  - Cost of Biodiesel produced from Simarouba Oil — Rs. 42/-
  - Price of Biodiesel with 20 % profit margin — Rs. 50/-
  - Price of Diesel — Rs. 51.20/-
- Credits
  - Glycerine replacing synthetic glycerine — 40.5kg
  - Seed Cake replcing chemical fertilisers N= 25kg, P=3.3kg andK=3.9kg

Conclusion: From the LCA studies carried out it can be inferred that producing biodiesel from Simarouba oil is both ecologically and economically viable

PART 2

CHAPTER 8

RESULTS AND DISCUSSION

This chapter portrays the comparative analysis and discussion of results from LCA studies of Pongamia, Madhuca, Azadiractha and Simarouba biodiesel system. The results have been discussed under following headings.

1. Non Renewable Energy Requirement
2. Energy Input and Output
3. Global Warming Potential
4. Acidification Potential
5. Land Use Change (ESQ & EFQ)
6. Economics

8.1 Non Renewable Energy Requirement (NRER)

NRER consumed for producing one functional unit of biodiesel from Pongamia oil was found to be highest among all the four chosen tree species (i.e.0.05MJ/FU), followed by Madhuca (0.04MJ/FU), Azadiractha (0.03MJ/FU) and Simarouba (0.02MJ/FU) (Ref. Figure 6.1). When compared with Jatropha i.e.0.22MJ/FU (Achten et al. 2010), NRER of Pongamia, Madhuca, Azadiractha and Simarouba system is found to be 4.4, 5.5, 7.3 and 11 times less respectively. Similarly Pongamia, Madhuca, Azadiractha and Simarouba system is found to consume 25, 31, 42 and 62 times less NRER compared to Diesel -1.25MJ/FU (Achten et al. 2010) respectively. This low NRER may be attributed to non-usage of inorganic fertilisers, pesticides and other cultivation practices as followed in Jatropha system (Krishan et al. 2011 and Achten et al. 2010). NRER was found to be highest in transesterification phase followed by oil extraction phase in all the four researched tree species

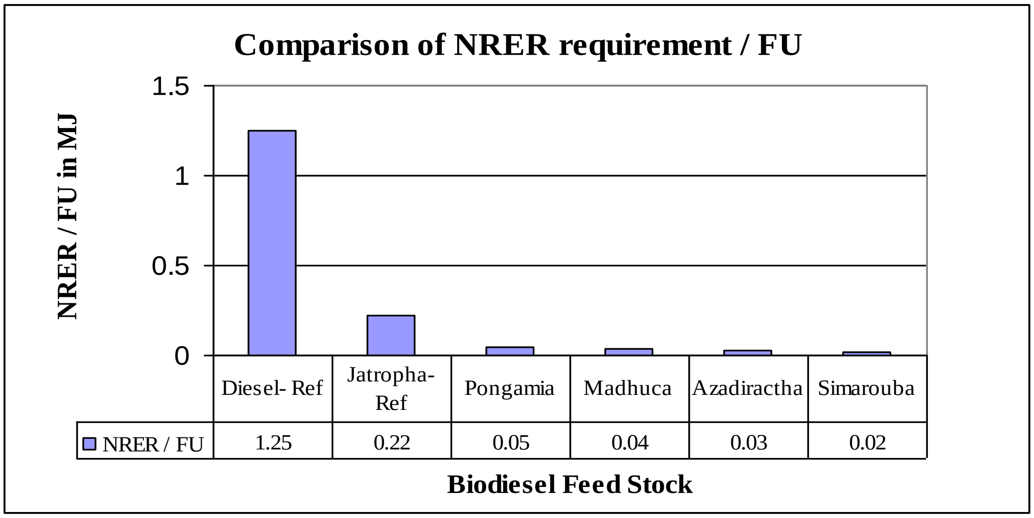


Figure 8. 1 Comparison of NRER requirement /FU

*NRER = Non renewable energy resources

8.2 Energy Input and Output

The energy input into the four TBO biodiesel systems is found to be higher by 2-3 times than energy inputs for Jatropha (0.22MJ/FU) and twice lower than Diesel (1.06MJ/FU) i.e. (Figure 8.2 & Table 8.1). However, the energy output / energy ratio has been found to be highest in Madhuca (17.75), Followed by Pongamia (16.21) Azadiractha (10.52) and Simarouba (10.56) which is far higher than the energy output from Jatropha Diesel.

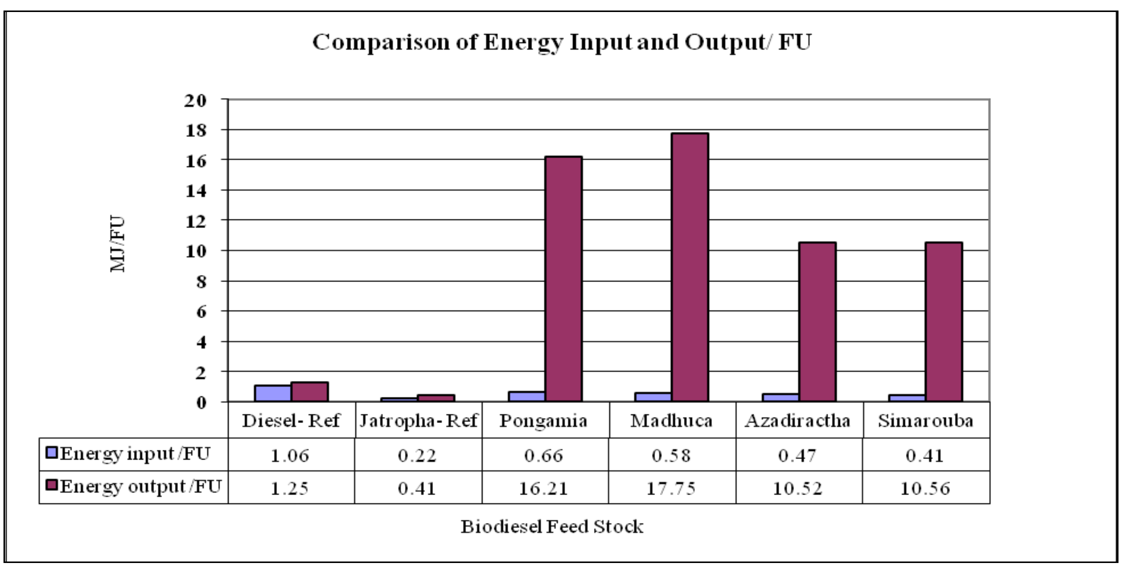


Figure 8. 2 Comparison of energy input and output /FU

Table 8. 1 Comparison energy gain and energy ratio

Tree Species	Pongamia	Madhuca	Azadiractha	Simarouba	Jatropha	Diesel
Energy Gain MJ/ FU	15.55	17.17	10.05	10.15	0.19	0.18
Energy Ratio / FU	24.56	30.60	22.38	25.56	1.86	0.85

8.3 Global Warming Potential

Among the four TBO species, CO_2 emission from Pongamia is found to be highest (304g-eq/FU) (Figure 6.3). This is due to production of biogas from seed cake followed by combustion in an engine. However it is also found that CO_2 emission from Pongamia (46g-eq/FU) with out biogas production and combustion is on par with CO_2 emission of Madhuca system (38.4g-eq/FU), Azadiractha (35.1g-eq/FU) and Simarouba (39.9g-eq/FU), which are 4 times lower than Jatropha system(120g-eq/FU) and 7 times lower than fossil diesel system(280g-eq/FU). The majority of the emissions from the four LCA systems were found to be from biodiesel production and combustion, followed by oil extraction and the cultivation phase. On the other hand, the bulk of the emissions come from the cultivation phase of the Jatropha system, due to usage of inorganic fertiliser and pesticides.

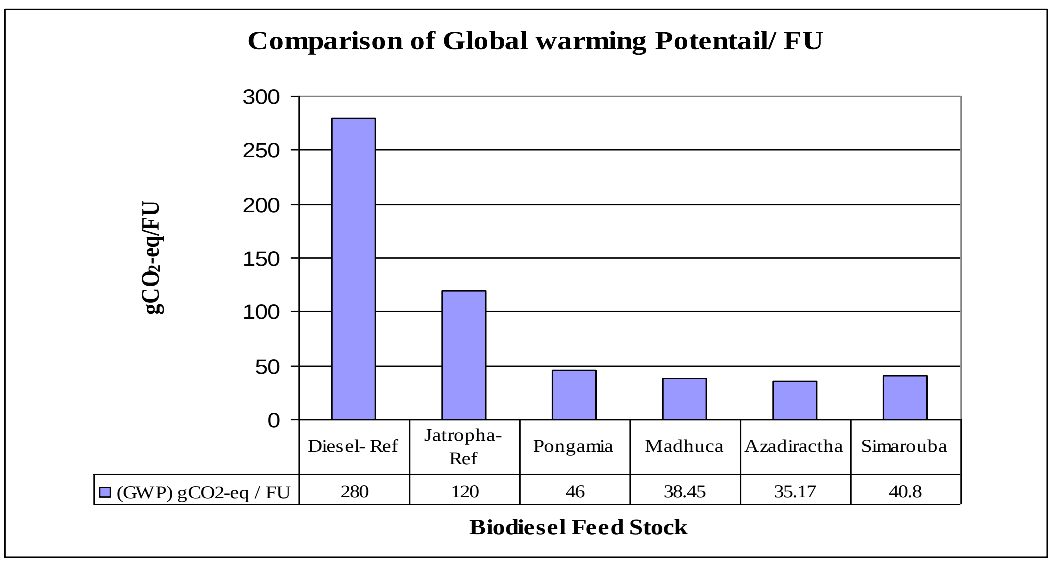


Figure 8. 3 Comparison of global warming potential /FU

8.4 Acidification Potential (AP)

The acidification potential of Pongamia is found to be 3.65gSO_2-eq/FU with biogas production and combustion. However, it is found to be 0.27gSO_2-eq/FU with only biodiesel production, which is 137 times less compared to Jatropha system (135gSO_2-eq/FU). In contrast, Pongamia system's AP is higher compared to Azadiractha (0.17g-eq/FU), Madhuca (0.09gSO_2-eq/FU) and Simarouba (0.13gSO_2-eq/FU). When compared to Jatropha system all the four tree species have very less SO_2 emission, which can be considered nil (Ref. Figure 8.4).

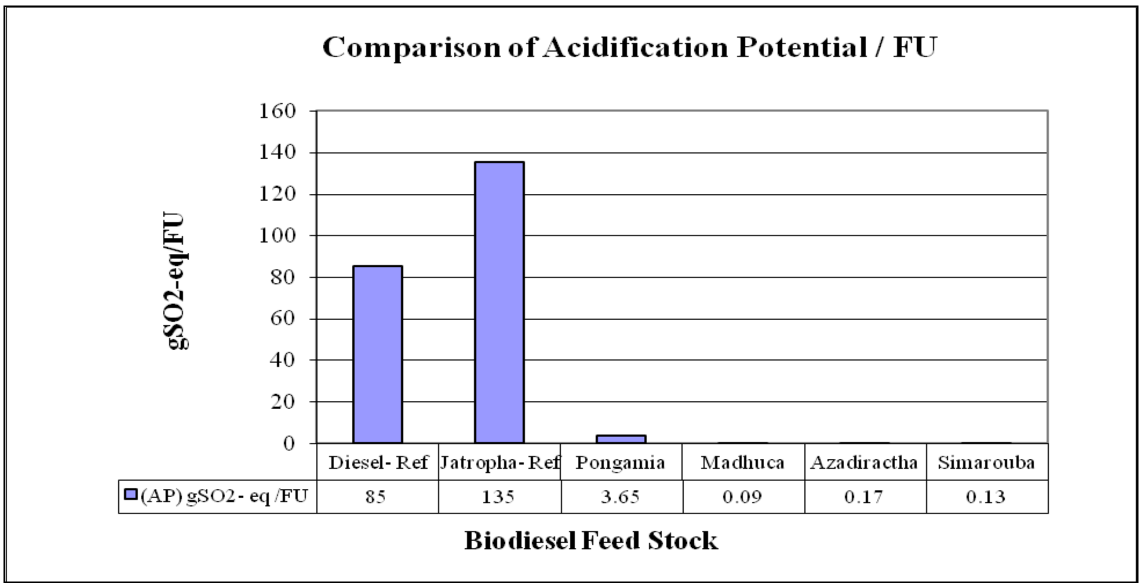
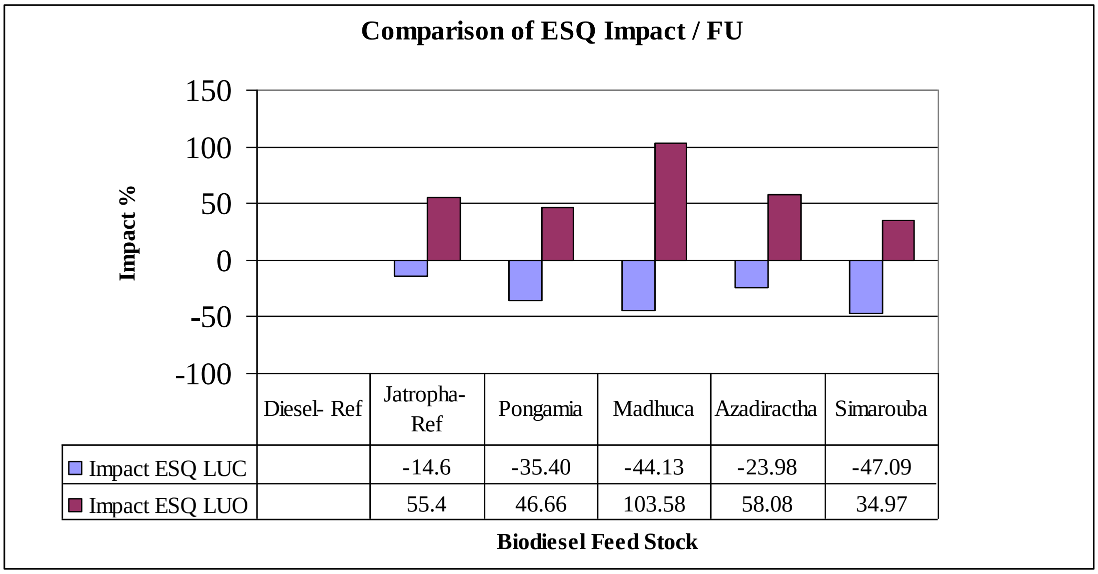


Figure 8. 4 Comparison of acidification potential / FU

8.5 Land Use Change

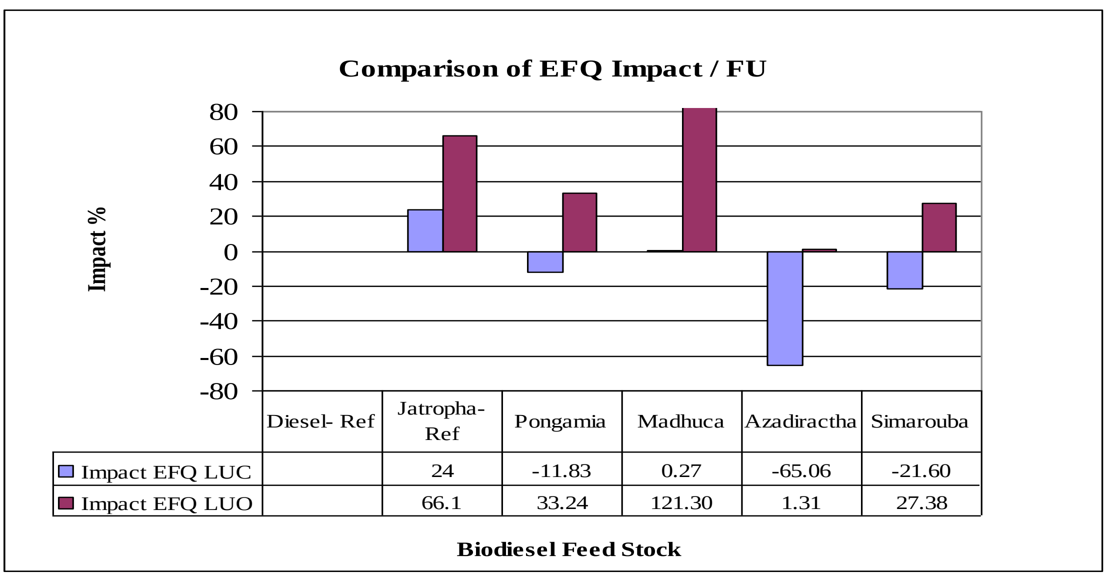
The impact of the land use change from wasteland to Pongamia plantation further indicates an improvement in Ecosystem Structural Quality (ESQ)* and Ecosystem Functional Quality (EFQ)*, which means that the ecosystem has higher potential to provide environmental benefits. Expanding Pongamia plantation will bring an improvement in structural quality (ESQ) and functional quality (EFQ) because no extra agro practices are employed after transplanting. The trees or the plantation shall remain in the local ecology very similar to Local Potential Natural Vegetation (LPNV) i.e. Jackfruit tree. However, research studies conducted by Achten et al. 2010 on Jatropha have shown a decrease in EFQ due to constant agricultural practices, which lowers land capacity (EFQ) to increase its quality to the state of LPNV. (Jatropha may achieve an increase in EFQ or move towards re-naturalization provided it is planted and left alone without management in the same way as Pongamia and other TBO species.)

*[*"Impact on the Ecosystem Structural Quality (ESQ) indicates how does the human land use intervention influence the amount of living and dead biomass, the species composition and the complex ecosystem network structure?"(Achten et al. 2010)]l*



	Diesel- Ref	Jatropha-Ref	Pongamia	Madhuca	Azadiractha	Simarouba
Impact ESQ LUC		-14.6	-35.40	-44.13	-23.98	-47.09
Impact ESQ LUO		55.4	46.66	103.58	58.08	34.97

Figure 8. 5 Comparison of ESQ impact / FU



	Diesel- Ref	Jatropha-Ref	Pongamia	Madhuca	Azadiractha	Simarouba
Impact EFQ LUC		24	-11.83	0.27	-65.06	-21.60
Impact EFQ LUO		66.1	33.24	121.30	1.31	27.38

Figure 8. 6 Comparison of EFQ / FU

Since all the trees are from the same ecosystem, their impact results show that they have minimal difference in impact on local ecosystem in contrast to Jatropha.

["Impact on the Ecosystem Functional Quality (EFQ) indicates how does the human land use interventions influence the capacity of the land to keep control over solar energy, water, sediment and nutrients, to maintain and restore ESQ, and to buffer future disturbances" (Achten et al. 2010)]*

8.6 Economics

Actual diesel price in India is higher than the current pricing due to government subsidy i.e. Rs.8/- per litre as on Oct. 2012 (Ministry of petroleum- GOI). One litre of diesel without government subsidy shall cost approximately Rs.59.2/- per litre and Rs.51.20/- with subsidy. From the figure 8.7 it is evident that price of biodiesel produced from Pongamia oil (Rs.48/-) Simarouba oil (Rs.50/-) and Madhuca (Rs.49/-) are on par with each other, However, price of biodiesel produced from Azadiractha oil is comparatively less (Rs.43/-). This is due to the fact that Azadiractha seed cake fetches a better price in market (Rs.18/-), which in turn reduces production cost of Azadiractha biodiesel by 11% compared to other three biodiesel feedstock (Fig 8.7).

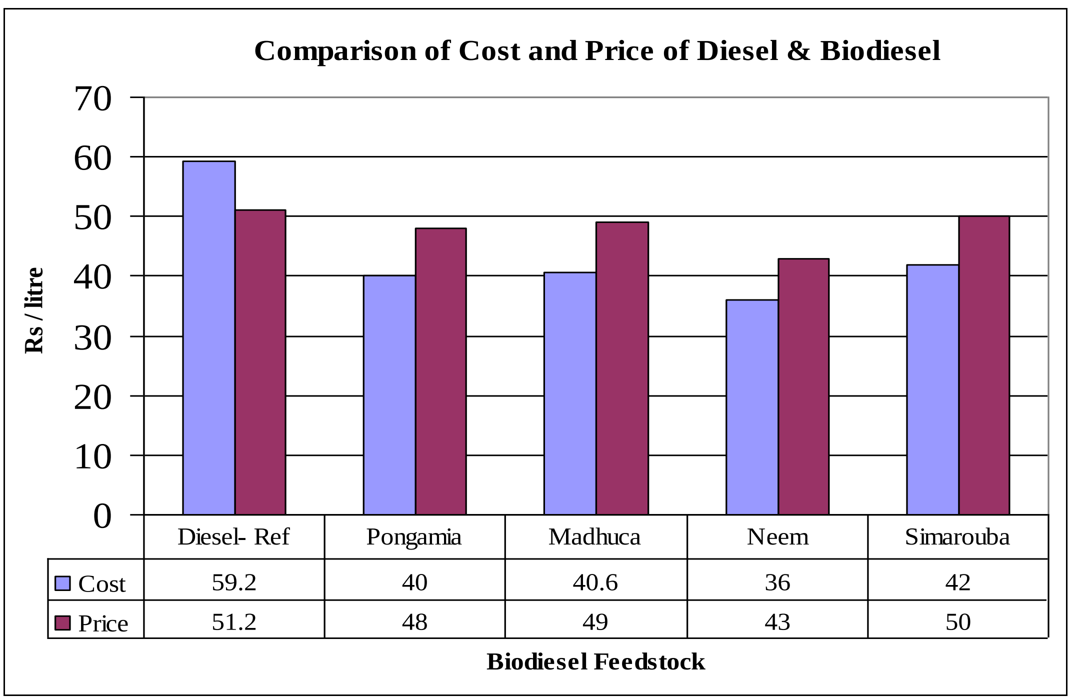


Figure 8. 7 Comparison of cost and price of diesel and biodiesel

Although calculations show a promising sign of Azadiractha being a better crop among the four chosen feedstock, it may be noted that producing biodiesel form Azadiractha would not be economically viable because farmers earn 3 times more (Rs.120/-) from oil alone. The same argument stands good for Madhuca as well, because Madhuca oil is priced around Rs.85/- in open market. However, Azadiractha and Madhuca shall be available for biofuels, once the production starts increasing and their traditional markets get saturated.

Inference

- Four Tree Borne Oil (TBO) biodiesel system studied show low Non Renewable Energy Requirement compared to Jatropha reference system
- Net Energy Gain of all the four TBO species biodiesel system was found to be 80 to 53 % higher than Jatropha reference system
- Producing biogas from Pongamia seed cake enhances the energy efficiency with out altering other impact factors
- Framing sustainable strategies to minimise biomass displacement will result in minimal energy loss in the form of nutrients through biomass displacement. However, leguminous trees like Pongamia have been reported to enrich the soil by forming a symbiosis with Rhizobium bacteria in their root (Ref. Figure 6.8), which fix atmospheric nitrogen. In the long run it may be necessary to provide some trace elements or micro nutrients to maintain the tree species for better yield
- Major portion of the emissions from the four biodiesel system are found to be from biodiesel production (transesterification) and combustion, when compared to Jatropha, which comes from cultivation phase
- The LCA studies suggest that biomass fuels could play a significant role in minimizing net emission of CO_2 to the environment. The most favourable strategy would be different for different places and determined by the land quality, its present usage and energy demand.
- Since all the trees are from the same ecosystem, their impact results show minimal difference in local ecosystem in contrast to Jatropha
- Price of all the four TBO Biodiesel was found to less than conventional diesel, which is very promising for economic sustainability of biodiesel production

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Figure 8. 8 Root nodules on the root hairs of Pongamia (Paul 2008)

In crops like Jatropha, usage of inorganic fertilisers, pesticides and other cultivation practices are inevitable, which are important contributing factors in most of the impact categories resulting in negative environmental performance and sustainability (Achten et al 2010). However, local TBO species like Pongamia, Madhuca, Azadiractha and Simarouba do not call for any irrigation, fertiliser application and agronomical practices, which results in complete sustainability.

8.7 Sensitivity Analysis

Generally, the rationale of a sensitivity analyses is to determine input parameters, which have major impact on model results. This information gives scope to eliminate unimportant parameters and provide a direction for further research in order to reduce uncertainties and improve the accuracy of the model.

Adhering to rigid sensitivity rankings is not as crucial as the identification of the top parameters to which the model is most sensitive. Although some sensitivity analysis methods are mathematical and extensive, they cannot be used effectively since their results, in many cases, are on par with those attained from simpler techniques.

The most preferred of the sensitivity techniques is the direct method. It involves calculating derivatives of single variable of the model with regard to each input factor. The method is only suitable for small variability in parameter values and the derivatives of single variable must be recalculated for every modification in the base-case scenario (e.g. all parameters set to their mean value). As discussed above one-at-a-time sensitivity analyses method, is theoretically the simplest method or with little complexity (Hamby 1994).

When working with complex models a subjective analysis, not considering unimportant variables, may be needed to trim down the number of factors to a right size. (Hamby 1994)

Sensitivity analysis in this research has been carried out for:

1. Energy input to output
2. Global warming potential
3. Cost of biodiesel

8.7.1 Sensitivity Analysis for Energy Input to Output

In view of the frame work proposed (Sustainability at local level), all the parameter accept for the change in distance / diesel consumed as one of the energy input has been considered for sensitivity analysis for energy input to output and global warming potential

Parameters considered for carrying out sensitivity analysis for energy input to output

- Fixed Parameters
  - Manpower
  - FYM
  - Poly bags
  - Electricity
  - Methanol
  - Sulphuric acid
  - Acetic acid
  - Sodium hydroxide
- Variable parameter
  - Travel distance leading to diesel consumed

Sensitivity analysis of energy input output with respect to diesel consumed has been carried out for range of 210 km to 10000 km. It has been observed (Table8.2), as the travel distance increases from the source of production, the net energy gain (NEG) and net energy ratio (NER) is found to decrease. With an increase in the travel distance by 40 km i.e. from 210 to 250 km NER decreased by 25% for Pongamia, 27% for Madhuca, 27% for Azadiractha and 19.4 for 22% for Madhuca. Increasing the travel distance from 250 to 500 km (Fig.8.9), showed a drop in NER to 11.34, 13.55, 8.89 and 13.08 for Pongamia (46%), Madhuca (46%) Azadiractha (41%) and Simarouba (47%) respectively. Further increase in travel distance from 500 to 1000 and 2000

Table 8. 2 Net energy ratio of biodiesel system with change in travel distance / functional unit

Distance in km	Pongamia	Madhuca	Azadiractha	Simarouba
210	24.56	29.60	21.59	24.90
250	18.21	21.76	15.79	19.74
500	11.34	13.43	9.80	13.08
750	8.19	9.57	7.15	9.78
1000	4.78	7.33	5.60	7.81
1250	3.20	5.88	4.60	6.50
1500	2.71	4.86	3.92	5.56
1750	2.34	4.09	3.40	4.87
2000	2.06	3.30	3.01	4.32
2250	1.84	3.02	2.70	3.89
2500	1.66	2.64	2.45	3.52
2750	1.52	2.34	2.24	3.23
3000	1.39	2.07	2.06	2.98
3250	1.29	1.85	1.91	2.77
3500	1.20	1.66	1.78	2.59
3750	1.12	1.49	1.67	2.43
4000	1.05	1.34	1.57	2.28
4250	0.99	1.21	1.48	2.16
4500	0.94	1.10	1.40	2.04
4750	0.89	1.04	1.33	1.94
5000	0.85	0.89	1.26	1.87
5250	0.81	0.81	1.21	1.79
5500	0.77	0.73	1.15	1.68
5750	0.74	0.65	1.10	1.61
6000	0.71	0.59	1.06	1.55

(Fig. 8.9) showed a drastic decrease in NER by 75 % and 90% respectively for all the four TBOs. The observations indicate that there is a strong negative correlation between distance and NER. Relevant range for analysis can be confined to the practical limits of 2000 km. (Higher range of 6000 km has been considered due to the fact that major portion (>80%) of the crude oil is imported in India and the distance travelled by conventional diesel, is found to be >5000 km)

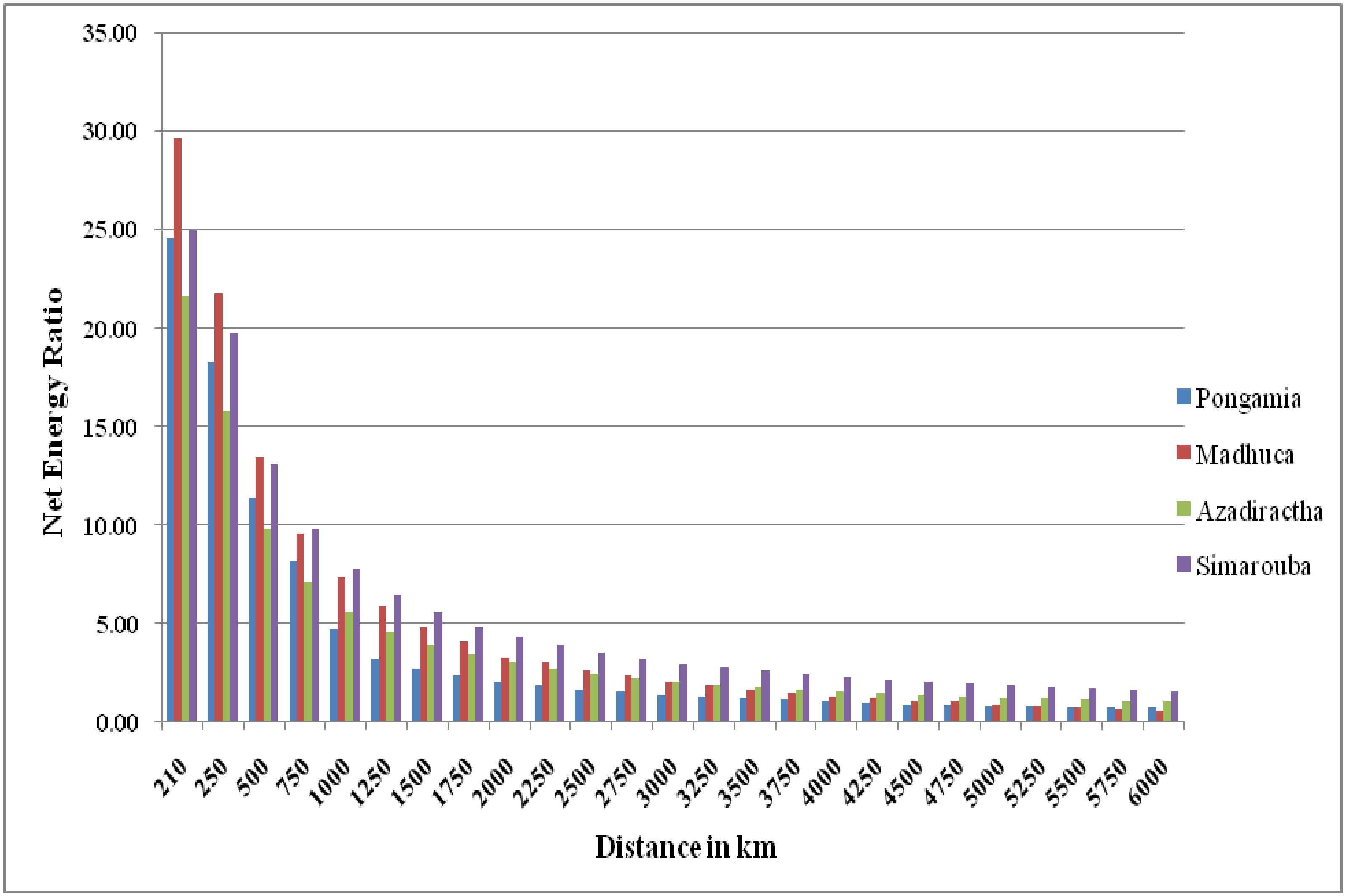


Figure 8. 9 Comparative analysis of net energy ratio of biodiesel system with increase in travel distance

8.7.2 Sensitivity Analysis of Global Warming Potential of Biodiesel System

Parameters considered for carrying out sensitivity analysis for global warming potential are:

- Fixed Parameters
  - Poly-bags production & discharge
  - Organic Manure
  - Methanol production
  - Electricity
  - Biodiesel combustion
- Variable Parameters
  - Travel distance leading to diesel consumed

Sensitivity analysis of GWP / g of CO_2-eq has been carried out for range of 210 km to 6000 km (Table 8.3). As observed from the figure 8.10, except for Pongamia biodiesel life cycle, Madhuca biodiesel emission starts exceeding the CO_2 emission mark of fossil diesel (280g) after 2000 km. However, Madhuca and Azadiractha biodiesel life cycle emission surpass the fossil diesel life cycle emission mark at 5000 km. Based on these observations it can be inferred that as the distance increases from the source of production and use, CO_2 emission also increases. The observations indicate that there is a strong positive correlation between distance and CO_2 emission.

Table 8. 3 Change of GWP of Biodiesel System with Change in Travel Distance / Functional Unit

Distance	Pongamia	Madhuca	Azadiractha	Simarouba	Diesel
210	343	185	35	40	290
250	351	192	41	47	290
500	370	207	55	62	290
750	388	223	69	77	290
1000	407	238	83	93	290
1250	425	253	97	108	290
1500	444	269	111	123	290
1750	462	284	125	138	290
2000	481	300	138	154	290
2250	499	315	152	169	290
2500	518	331	166	184	290
2750	536	346	180	199	290
3000	555	362	194	215	290
3250	573	377	208	230	290
3500	592	392	222	245	290
3750	610	408	236	261	290
4000	629	423	250	276	290
4250	647	439	263	291	290
4500	666	454	277	306	290
4750	684	469	291	322	290
5000	703	485	305	337	290
5250	721	500	319	352	290
5500	740	516	333	367	290
5750	758	531	347	383	290
6000	777	547	361	389	290

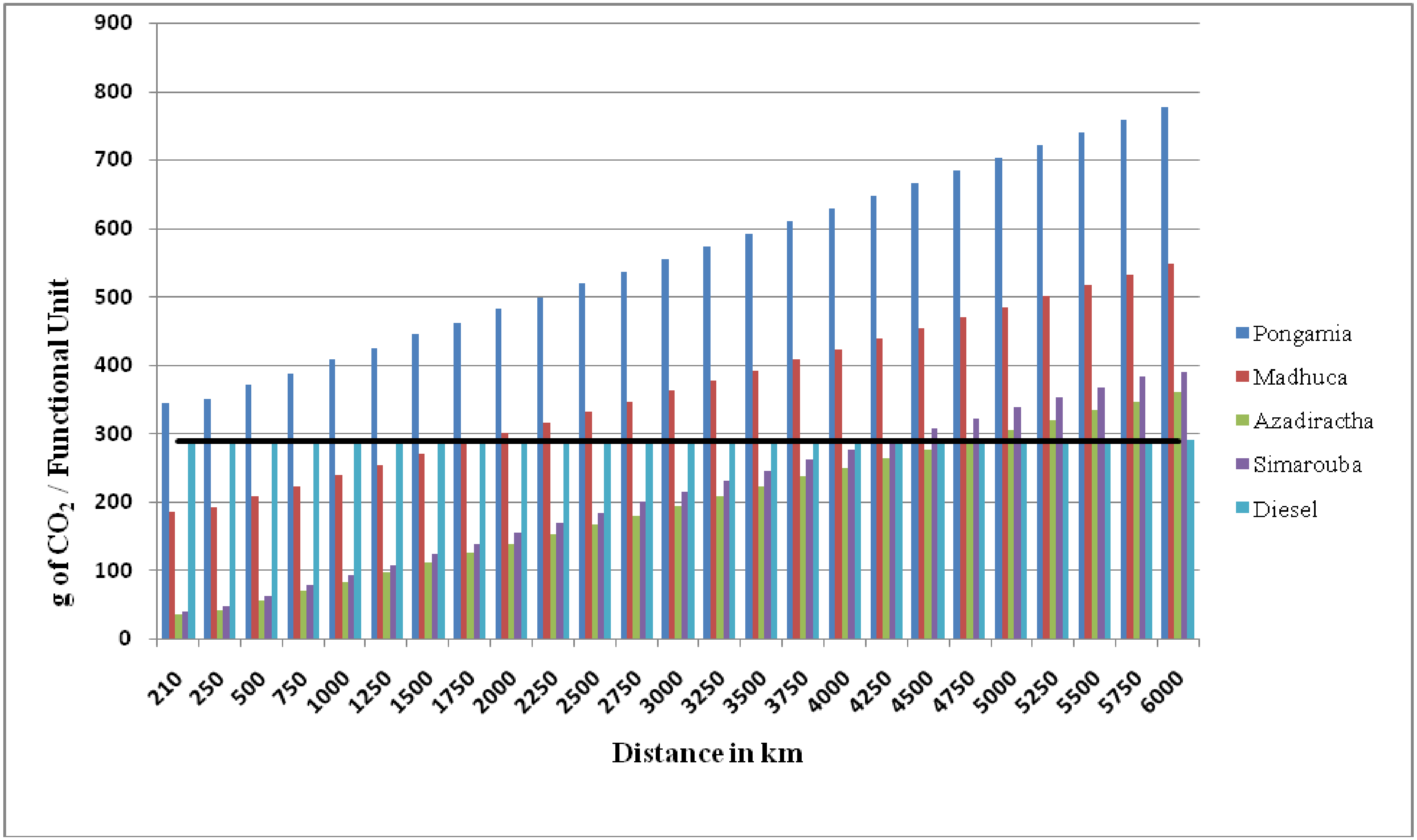


Figure 8. 10 Comparative analysis of GWP of biodiesel system with increase in travel distance

8.7.3 Sensitivity Analysis of Cost of Biodiesel Price

Cost of biodiesel plays a very important role in framing Biofuel polices for sustainability. Hence, history of the variable factors have been collected to foresee the trend and carry out the sensitivity analysis by varying the price of each variable factor.

1. Price of Electricity: According to *Center for Study of Science, Technology and Policy*'s report titled "Karnataka Power Sector Roadmap for 2021-22"; Karnataka state electricity demand would increase by 9% from 2013 to 2022. Hence, an approximate increase of tariff at the rate of 9 % has been assumed for sensitivity analysis.

2. Based on the price details collected from Biofuel Park, average annual price increase between 2011 to 2014 of Methanol, Sulphuric acid, Acetic acid and Sodium Hydroxide have been arrived at by calculating the regression coefficients and forecasting the same for respective trends, which has been used for sensitivity analysis (Aappendix 16).

Parameters considered for carrying out sensitivity analysis for cost of biodiesel are

- Capital cost (Fixed parameter)
- Price of Seed (Variable parameter)
- Variable cost (Variable parameter)
    - Price of Electricity
    - Price of Methanol
    - Price of Sulphuric acid
    - Price of Acetic acid
    - Price of Sodium hydroxide

Biodiesel prices were calculated by varying the variable cost parameters for each year (from 2012 to 2020- refer Table.8.4) and the trend lines were plotted based on the regression analysis, which have been compared in the following graph (Figure 8.11). Comparing the diesel and biodiesel prices (table 8.4) it can be observed that diesel shows an annual average price rise of Rs. 5 /- per year where as Pongamia, Madhuca, Azadiractha, and Simarouba biodiesel show an annual average price rise of Rs. 3.75/-, Rs.3.12/-, Rs. 3.75/- and Rs. 2.37/- respectively. From this analysis, it is observed that biodiesel averge price rise shall remain 25 to 47 % less than average diesel price rise and thus remain economically vailabe.

Table 8. 4 Diesel and Biodiesel Prices from 2012 to 2020

Year	Diesel Price in Rs	Pongamia Biodiesel Price in Rs	Madhuca Biodiesel Price in Rs	Azadiractha Biodiesel Price in Rs	Simarouba Biodiesel Price in Rs
2012	48	40	41	36	42
2013	55	42	42	40	47
2014	61	49	52	46	47
2015	62	49	52	50	50
2016	67	57	55	52	51
2017	73	60	58	56	55
2018	78	64	60	60	58
2019	83	66	63	62	58
2020	88	70	66	66	61
Average annual price difference in Rs	5	3.75	3.12	3.75	2.37

The results of the sensitivity analysis of NER and CO_2 emission with respect to travel distance discussed above help in deciding optimum radius (in km) for complete value chain of the TBOs based biodiesel (i.e production and use). It can be inferred that the shorter the value chain (Distance from production and use) higher the sustainability of the biodiesel system. These findings correlate with the out come of a study on Soya biodiesel in Chicago area by *National Renewable Energy Laboratory* in United States (John et al 1998), which inferred that, deciding on the optimum distance between place of production and use of soya biodiesel helped in higher chances of sustainability. Hence, this sensitivity analysis results strongly support the outcome of the strategies proposed for local production of biodiesel at village level, rather than hub and spoke method of value chain .

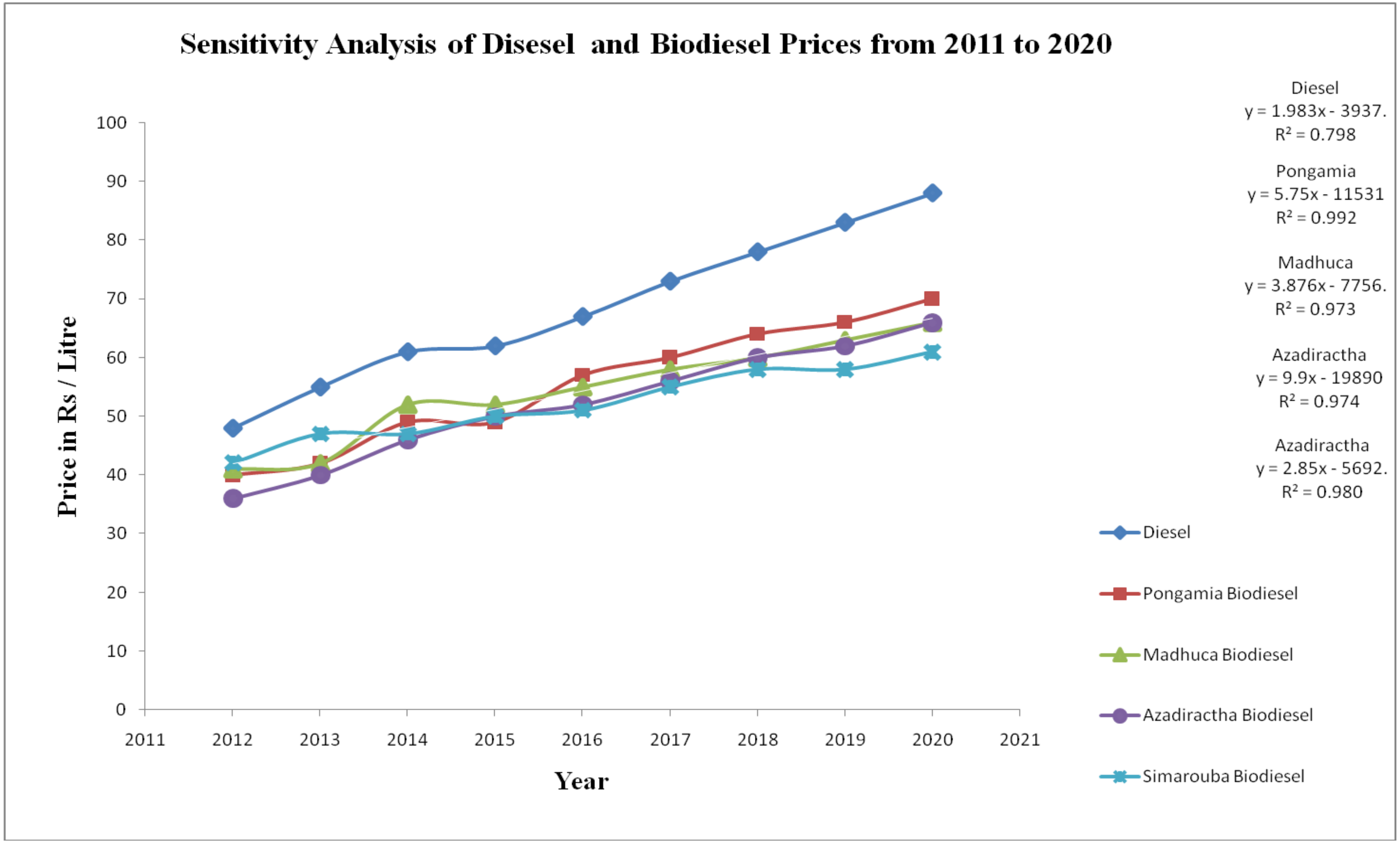


Figure 8. 11 Sensitivity analysis of diesel and biodiesel prices from 2011 to 2020

As per the vision of Government of India, substituting 20 % of diesel with biodiesel by 2017 can be achieved, provided a strong supply chain is established for the feedstock. It is a known fact that as demand increases, price also increases depending on the supply and stock available. Formulation of feasible strategy for assured supply of biodiesel feedstock and availability of appropriate infrastructure is important. The limitation on gestation and yield of the feedstock is to be kept in view while formulating such strategies. Using the LCA results of the four TBO species, an attempt has been made to relook at the current biodiesel production strategy of Biofuel Park, Hassan and formulate a sustainable biodiesel production strategy at village level. The same has been discussed in the following chapter-9.

PART 3

CHAPTER 9

BIODIESEL PRODUCTION STRATEGY A REVIEW

The University of Agricultural Sciences, Bangalore, set up the Biofuel Park at Madenur in 2006 for providing technology for production of biofuel and for motivating farmers to cultivate TBO species, to produce biodiesel from TBO. So far, over 13.4 x 10^5 seedlings of Pongamia (4.27 x 10^5), Madhuca (1.4 x 10^5), Azadiractha(1.6 x 10^5), Simarouba(1.95 x 10^5), Jatropha(4.16 x 10^5) and Amoora (394), have been planted in Hassan district, covering 17558 acres (The Hindu Aug 10 2012). Biofuel Park has also actively supported Karnataka state forest department by supplying 62000 saplings covering around 1000 acres. Approximately 15,000 to 20,000 tonnes of seed are produced every year, resulting in additional income for the farming community. The park purchases seeds from farmers as any private enterprises do. The park has the capacity to produce over 250 litres of biodiesel a day (The Hindu Aug 10, 2012 and Biofuel Park 2012).

The actual cost of producing one litre of biodiesel from Pongamia oil at Biofuel Park is Rs.53/- *it supplies biodiesel to government vehicles at the same price as that of conventional diesel (This initiative has been taken to popularise use of biofuels). The Karnataka State government through the Biofuel Development Board funds Biofuel Park (Biofuel Park 2012).

Following the model of the milk producers union (Biofuel Park 2012), the Biofuel Park has involved large number of farmers in its activities. Similar to milk producers' unions, 465 associations of oilseeds growers have been formed in the district. The governing body of each association includes women (The Hindu Aug 10, 2012). At present Biofuel Park has been collecting Pongamia seeds predominantly from its famer association and processing it to produce biodiesel. A brief statistics of the biofuel park model is given in following table 9.1.

**Cost of the biodiesel at Biofuel park (i.e. Rs53/-) is due to its experimental expenses in popularizing the concepts of biofuel.*

Table 9. 1 A brief statistics of biofuel park model

Current Biofuel Park Model			
Sl. No.	**Particulars**		**Unit**
1	Number of farmers association	465	
2	Average wt of seeds collected / year from 465 associations	465000	kg
3	Pongamia seeds collected from farmers at price of	15	Rs./kg
4	Biodiesel produced / year from Pongamia oil	139500	litres
5	Biodiesel sold locally & for farming community	53	Rs./ litre
6	Pongamia seed cake produced / year	302250	kg
7	Pongamia seed cake sold back to farmers at	17	Rs./ kg
8	Average distance of 465 farmers association from Biofuel Park	25-35	km
9	Total distance travelled for seed collection, seed cake and Bio Diesel delivery (Covering approximately 6 villages per trip)	5812	km

The amount of emission from a goods carrier vehicle travelling 5812 km amounts to 2332 kg of CO_2, 22 kg of CO and 12kg of NOx.

9.1 SWOT Analysis of the Current Biofuel Park Model

Strength

- Popularising small volume bio-diesel production
- Very good network of farming community (465 associations of oilseeds growers, similar to milk producers' unions)
- Over 14 x 10^5 seedlings of Pongamia, Madhuca, Azadiractha, Simarouba, Jatropha and Amoora have been planted in Hassan district, covering 17,558 acres
- The promoted tree species have relatively low energy input and very high-energy output
- The tree species promoted are perennial with a life expectancy of > 80 years
- Lower capital investment and maintenance
- Seed Cake serves as good source of organic manure.

Weakness

- Methanol used in transesterification process is toxic & derived from fossil fuel
- Pongamia glycerol has a specific odour, which fetches lower price, as it has to be refined before processing and it does not have streamlined / established market
- Cost of biodiesel Rs.53/- at biofuel park is found to be higher than the conventional diesel
- A 14 % Value Added Tax on biodiesel

Opportunities

- Re-use of glycerol / glycerine
- Methanol recovery using waste heat
- Potential for using bio-ethanol (rather than methanol)
- Strengthening bio-fuel network
- Framing strategies to reduce biodiesel production cost
- Constant raise in crude oil price
- Employment generation in villages
- Enhanced use of fallow and waste land
- Carbon credit value (Kyoto protocol)
- TBO seeds required in large quantities to sustain the huge demand
- Employing biotechnology for evolving better yielding tree species

Threats

- Cost escalation of feedstock, methanol and catalyst
- Use of methanol (Improper handling / storage/ security/ may lead to hooch disasters at village level)
- Use of catalyst like NaOH /KOH (Improper handling and availability)
- Use of milk run system/ hub and spoke method of seed collection, biodiesel and seed cake distribution results in biomass displacement, deprive the usage of biodiesel and seed cake at local / village level. (Maximum amount of seed cake sold back is brought by farmers from other parts of state and biodiesel sold to State transport department resulting in biomass displacement)

From the SWOT analysis of the current strategy, it is quite evident that biomass displacement and cost of biodiesel is a major concern. This issue calls for a robust strategy for biodiesel production and usage at local level. In the present research, a case study at village named Kinnarahalli was carried out for production and usage of biodiesel at local / village level to evaluate alternative strategies.

9.2 Alternative Strategies

9.2.1 Strategy –A

Kinnarahalli is a small village with 80 houses and is situated at distance of 20 km from the Biofuel Park. The village has a very active farmers association for biofuel feedstock seed collection. At present, the village has around 60 Pongamia trees yielding around 1.8 tons of seeds, which is collected by biofuel park personnel on the lines of milk collection logistics system.

Table 9. 2 Electricity usage and cost at Kinnarahalli

Kinnarahalli Scenario					
No. of House holds	80	Average Electricity Usage / Month (kWh)		Tariff In Rs./ kWh	Total Cost in Rs
Small	10	18	180	2.2	396±21.6
Medium	30	30	900	2.2	1980±237
High	40	45	1800	3.2	5760±216
Average kWh / Month			2880	Cost / Month	8136±247.9
Average kWh / Year			34560	Cost / Year	97632
Average kWh / day			**94.68**	Cost / Day	**267.5 = 270**

* Number of household data collected from Panchayat office of the village
*Averge electricity usage data collected form state electricity board office

Kinnarahalli village is supplied with electricity by the state electricity board. It receives single phase electricity from 6pm in the evening to 6am in the morning for domestic use. It also receives three phase electricity for farm irrigation purpose between 2pm to 6pm. The electricity usage at Kinnarahalli village is as shown in table 9.2. On an average, the whole village consumes 95 kWh /day (Table 9.2).

If the farmer's association were encouraged to generate their own electricity for at least 3 hours in a day using biodiesel, the village would require approximately 122kWh electricity per day. (Table No. 9.3). The kWh required per day was estimated, after interacting with people of Kinnarahalli to understand the kind of appliances and number of hours used by them. Based on this requirement (122 kWh / Day), diesle generator set and the fuel required was estimated (Table 9.4).

Note: The cost of electricity from national grid on an average is Rs 5-6 / kWh (GOI-Ministry of Power 2014) and Electricity generated using biodiesel would cost approximately Rs 14 / kWh. The alternative strategies discussed in section 9.2 are due to inadequate grid power supply in rural India.

If the raw material cost were considered nil, because it is produced and used locally, the cost of electricity produced using biodiesel would be very near to the cost of electricity from grid. This argument is debatable and may not be convincing as per general accounting practices. Hence, Rs 14 / kWh may stand good.

Table 9. 3 Electricity load calculations / house hold at Kinnarahalli

No of houses @ Kinnarahalli Village = 80					
	Appliance	Load in watts(W)	No of Appliance	Applicane usage in h/ Day	Watts (W) /Day
Lighting	Lamps	100	1	3	300
	Fluorescent lamp	40	1	3	120
Cooling	Fan	100	1	3	300
Other	TV	200	1	3	600
	Mixer Grinder	200	1	1	200
				Total Watts	1520
				kW	1.52
				Total kWh required for 80 houses per day (3 hours)	**122**
				Total kWh required / h	**41**

To generate 41kWh electricity per hour a 50kVA-75 bhp diesel engine generator would be required. The amount of fuel required for this generator has been tabulated (Table no 9.4).

Table 9. 4 Fuel requirement for electricity generation at Kinnarahalli

50kVA-75 bhp DG Set - SFC	Fuel Required for electricity generation / h in kg (41 kWh)	Fuel For 3 h in kg (122kWh)
SFC- Diesel* = 155g/bhp-h	11.63	46.50
SFC-Biodiesel *= 180g/bhp-h	13.50	54.00
SFC- Straight Vegetable Oil * = 190g/bhp-h	14.25	57.00

** Reference* *SFC- Diesel (Kirloskar Republic Series DG Sets)*
SFC Biodiesel (Varun Rao 2007, Suersh et al)
SFC SVO (Varun Rao 2007)

From the calculation shown in Table No.9.4 it is clear, to generate 122kWh electricity in a span of 3 hours, it would require around 54 kg of biodiesel or 57 kg of SVO. Further, it is estimated that Kinnarahalli would require approximately 8 hectares of fifteen-year-old Pongamia plantation (Table No.9.5) to produce 3 hours of electricity daily.

Table 9. 5 Pongamia trees required for generating electricity for a year at Kinnarahalli

Fuel For 123kWh units in kg	**kg Seeds Required / day**	**kg Seeds Required / year**	**No of trees Yielding 30 kg seeds / tree (15 yr old tree)**	**No of Hectare required**	**Seed cake available in kg/ yr**	**Income if Seed cake Sold as Manure @ Rs. 15/-**
Biodiesel-54.00	190	69350	2312	7.0	45078	676170
SVO- 57.00	200	73000	2433	7.4	47450	711750

Similarly, number of trees or acreage of plantation required for Madhuca, Azadiractha and Simarouba tree have been estimated and tabulated in table No.9.6, 9.7 & 9.8

Table 9. 6 Madhuca trees required for generating electricity for a year at Kinnarahalli

Fuel in kg	**kg Seeds / day**	**kg Seeds / year**	**No of trees Yielding 30 kg seeds / tree (15 yr old tree)**	**No of Hectares required**	**Seed Cake available in kg / yr**	**Income if Seed Cake Sold as Manure @Rs.12**
Biodiesel-54.00	162	59130	1971	9.66	35478	425736
SVO- 57.00	171	62415	2081	10.22	37449	449388

Table 9. 7 Azadiractha trees required for generating electricity for a year at Kinnarahalli

Fuel in kg	**kg Seeds / day**	**kg Seeds / year**	**No of trees Yielding 30 kg seeds / tree (15 yr old tree)**	**No of Hectares required**	**Seed Cake available in kg / yr**	**Income if Seed Cake Sold as Manure@ Rs.18/-**
Biodiesel-54.00	216	78840	2628	7.96	51246	922428
SVO- 57.00	228	83220	2774	8.41	54093	973674

Considering the four tree species selected, Simarouba plantation requires around 5 hectares land, which is 35, 42 and 47% less compared to Pongamia, Azadiractha, and Madhuca plantation respectively.

Table 9. 8 Simarouba trees required for generating electricity for a year at Kinnarahalli

Fuel in kg	**kg Seeds / day**	**kg Seeds / year**	**No of trees Yielding 30 kg seeds / tree (15 yr old tree)**	**No of Hectares required**	**Seed Cake available in kg / yr**	**Income if Seed Cake Sold as Manure @ Rs. 14/-**
Biodiesel-54.00	189	68985	2300	4.60	24834.6	347684.4
SVO- 57.00	200	73000	2433	4.87	26280	367920

If 8 to 9 hectares of land is available for biofuel feedstock plantation, planting Simarouba can significantly increase the electricity generation from 3 hours to 5-6 hours per day.

Table 9. 9 Highlights of strategy-A

If planted with 2312 Pongamia trees, land required	7 ha
Seed cake available from 2312 trees	45084 kg
Income from seed cake **(a)**	Rs. 676260/-
Income for Glycerin @ Rs. 20/kg (0.15 / litre of BD * 21224 litres of BD) = 3183.6 kg **(b)**	Rs. 63673/-
Biodiesel conversion cost of 21224 litres @ Rs.20/- **(c)**	Rs. 424480/-
Savings = **(a + b)-c**	Rs. 315453/-

9.2.2 Strategy-B

If electricity is generated from both; biodiesel and biogas, 7.7 ha Pongamia block plantation or 2312 Pongamia trees collectively can suffice to generate electricity for 365 days from Biodiesel and another 83 days extra from biogas. This strategy-B results in a savings of Rs.53060 (Table 9.8).

Table 9. 10 Highlights of Strategy- B

If planted with 2312 Pongamia trees, land required	7 ha
Seed cake available from 2312 trees	45084 kg
Biodiesel conversion cost of 21224 litres @ Rs. 20/-	Rs. 424480/-
Seed cake required for compensating for biodiesel conversion cost @Rs15/kg	23583 kg
Surplus seed cake	21502 kg
Biogas from 21502 kg seed cake	5160.5 m^3
kWh produced from 5160.5 m^3 of biogas	10321 kWh
Number of days electricity supplied from biogas 10321 kWh/123kWh/day	83.9days
Total number of days electricity produced from Biodiesel + Biogas	365 + 83.9 = 449 days
Savings = Income from Glycerin @ Rs 20 / kg (0.15 / litre of BD * 17687 litres of BD) = 2653 kg = 2653*20 = 53060	Rs.53060 /-

9.2.3 Strategy-C

Strategy – C has been formulated for scenarios with shortage of land. This strategy is similar to strategy-B except for use of fossil diesel in lieu of biogas for generating electricity for a year (365 days). The money required for purchase of conventional / fossil diesel shall be raised by selling seed cake to local farmers. This strategy shall require 5.8 hectares of Pongamia block plantation or 1920 Pongamia tree collectively. The savings from this strategy is approximately Rs 7540/- (Table 9.11).

Table 9. 11 Highlights of strategy- C

If planted with 1920 Pongamia trees, land required	5.8 ha
No of days biodiesel would last from 1920 trees	272 days
Income, if seed cake is sold to local farmers (a)	Rs. 561600/-
Income from selling glycerine @Rs 20/ kg (0.15 * 17422 litres of biodiesel) = 2613 kg (b)	Rs. 52326
a + b = c	Rs. 613926
Cost of Conventional diesel for 93 days i.e. 5038 liter (d)	Rs. 257945/-
Cost of Biodiesel conversion @ Rs 20 / litre (e)	Rs 348440/-
Savings c- (d + e)	Rs. 7540/-

Strategy-A& B address an alternative solution with appropriate calculation for tiding over biomass displacement issue. The second most important issue is cost of biodiesel. Cost of biodiesel is divided into two parts namely (1) Cost of inputs excluding raw material (seeds) and (2) Cost of conversion (Ref Table 9.11).

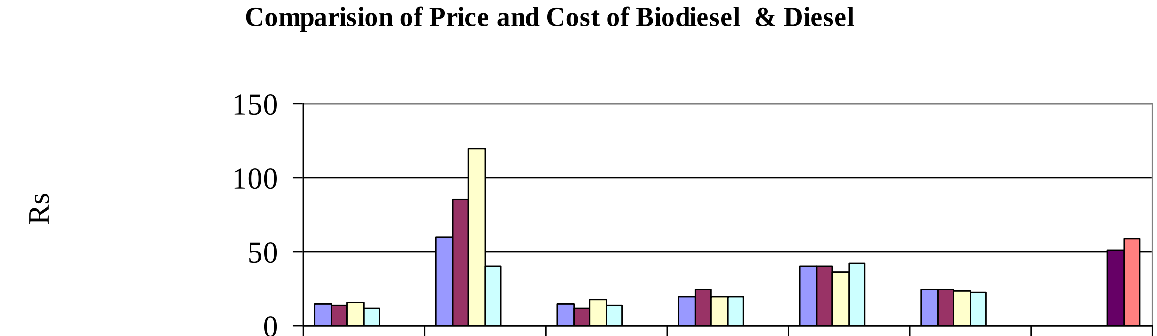
Table 9. 12 Comparison of CO_2 Emission from alternative Strategy

CO_2 Emission from Strategy-A (Biodiesel alone)	
CO_2 from Biodiesel alone / year	**36 tonne**
CO_2 emission / day	**98.6kg**
CO_2 Emission from Strategy-B (Biodiesel + Biogas)	
CO_2 from Biodiesel (36) + Biogas (7.2)	**43.2 tonne**
CO_2 emission / day (43.2 / 449 days)	**96.21 kg**
CO_2 Emission from Strategy-C (Biodiesel + Diesel)	
CO_2 from Biodiesel (29) + CO_2 from fossil diesel(9)	**38 tonne**
CO_2 emission / day	**104 kg**

From the table No.9.14 it is apparent that, the conversion cost of biodiesel is around Rs. 22 / litre of biodiesel. Capital cost and labour cost contribute a significant share in the conversion cost. If these are reduced, the conversion cost will be further reduced.

(* Conversion Cost in calculation has been rounded off to Rs.20 / litre)

Cost of raw material plays a very vital role in determining the final product cost. It is understood from general principles of economics the 'price increases with increase in demand and availability of stock'. Hence, price of seed and oil in open market directly dictates the cost of biodiesel. Prices of Pongamia, Madhuca, and Azadiractha seeds are in the range of Rs.15-16/- except for Simarouba, which is Rs.12/- (Figure 9.1). From comparison of price and cost of biodiesel produced from four TBOs feedstock, it is evident that the price of oil in the open market fetches a better price. This sounds economical to the farmer to sell oil and buy fossil diesel.



	Price of Seed in Rs /kg	Price of Oil in Rs /kg	Price of Seed Cake in Rs /kg	Price of Crude Glycerine /kg	Cost of Biodiesel in Rs / l	Biodiesel Conversion Cost in Rs / l	
Pongamia	15	60	15	20	40	24.14	
Madhuca	14	85	12	25	40.64	24.74	
Neem	16	120	18	20	36	23.93	
Simarouba	12	40	14	20	42	22.06	
Diesel Price with subsidy in Rs							51.2
Diesel Price without subsidy in Rs							59.2

Figure 9. 1 Comparison of price and cost of biodiesel produced from four TBOs

Hence, couple of brain storming sessions with farmers association along with Biofuel park personnel was carriedout to lay a road map for implementing any of the above-discussed strategies. The road map proposed after brainstorming deliberations are as follows.

1. Replace the stationary biodiesel production unit (Located at Biofuel Park) with mobile biodiesel processing unit. (Biodiesel on Wheels)
2. Mobile processing unit needs to be designed and fabricated using value engineering and value analysis concepts to reduce cost without compromising the functionality.
3. Appoint only two staff members per mobile unit, which reduces the overheads.
4. This mobile unit may be allocated to ten villages and scheduled to visit each village every ten days and produce biodiesel.
5. To make up for the conversion cost, the farmers association may be encouraged to part with seed cake (23579 kg) and glycerine (2653 kg) worth the cost of biodiesel conversion (Table.9.8)

Note: More than 50 people, who are Gram Panchayat Members and reprsentatives of Biofuel Seeds Growers Associations were involved in the discussion. Fifity percent of the members were women.

6. By doing so, monetary transaction may be avoided and the association shall still have half of the seed cake with them.
7. Further, remaining seed cake may be returned to farmer members for usage as organic manure or used by the farmers association to produce biogas and use the same for electricity generation.
8. Biogas plant sludge may be sold or given to farmer members for usage as organic manure in their field. This will help in reducing biomass displacement and enable farming community produce biofuel with little cost for power generation or other farming purposes.
9. The seed cake collected from villages as biodiesel conversion cost may be pooled at Biofuel Park and sold in open market or to interested farmers. The money generated from this shall help in paying the mobile unit staff, take care of its maintenance and even repay the cost of mobile unit itself.

Table 9. 13 Capital cost for biodiesel production

Sl. No.	**Particulars**	**Cost**	**Life in Years**	**Cost for one year in Rs.**
1	Trailer including electrification and Water storage*	100000	20	5000±600
2	Oil Extraction Machine**	50000	15	3333±400
3	Filter Press**	20000	10	2000±240
4	Esterification unit**	200000	15	13333±1600
5	Fuel testing equipment**	10000	5	2000±240
			Total	25666±1762

** It is an estimation made after discussion with Biofuel park personnel*

** Data collected from actual price lists of the equipment and rounded off (A 12 % standard deviation has be taken into consideration to take care of inflation)

Note: Calculations for justifying the proposed road map are as shown in table 9.11 & 9.12. The Esterification capacity is estimated to be 48000 litres / year hence capital cost per litre of biodiesel produced shall be Rs.1.8/. Work force required, has been estimated to appoint one trained personal with a salary of approximately Rs.15000/- month + 1 associate with a salary of Rs.7000/ month, which results in labour cost of Rs.5.5/ litre (Table 9.11).

Table 9. 14 Conversion cost of biodiesel

Sl.No.	Particulars	Cost / litre in Rs.
1	Electricity for oil extraction	2.38
2	Electricity for biodiesel production	1.7
3	Methanol	8.75
4	Sodium Hydroxide	0.65
5	Sulphuric Acid	0.3
6	Acetic Acid	0.3
7	Capital Cost Per year/ litre	1.8
8	Labour cost / litre	5.5
9	Maintenance per year/ litre	0.42
10	Insurance per year/litre	0.21
	Total Cost	22

* Data collected from esterification plant at Biofuel Park

9.3 Horizontal Deployment of Alternative Strategy

The project cost of Biofuel Park is Rs.60 Million. If this concept is established in 29 districts of Karnataka (Table 9.15), it would cost Rs.1.74 Billion, to the Government of Karnataka. However if the concept of processing on wheels is adopted at Gram/ village Panchayath* level in Karnataka State at the rate of one mobile biodiesel processing unit per two village Panchayaths, it would cost around Rs.1.69 billion, which is equal to the cost of biofuel project planned for the 29 districts. (Table 9.13)

A **Gram Panchayath is a local self government at village level*

Table 9. 15 Karnataka state geography

Longitude	11º30´ to 18º23´N
Latitude	74º 05´ to 78º 35´E
Geographical Area (km2)	191791
No of Districts	29
No. of Taluks **	176
No. of Hoblies *	745
No. of villages	29406
No. of Towns	270
No. of Gram-Panchayaths (2003-04)	5653
Current Biofuel park project cost is Rs. 60 million if replicated in 29 districts = Rs 1.74 billion + Conversion cost	
If one processing on wheels / 2 grampanchayths = Rs. 1.69 billion + Conversion cost for five years + Extension cost	

A **hobli, is defined as a cluster of adjoining villages (30 to 60) administered together for tax and land tenure purposes in the states of Karnataka, India*

*** A **Taluk** is defined as a cluster of Hoblis with a town as its head quarters*

**** A **District** is cluster of Taluks with many towns and one major city as its head quarters*

This strategy would, help in sustainability of villages with respect to local energy needs and would generate more employment for farming community and mobile biodiesel processing unit staff. It would also minimise GHG emission drastically compared to Biofuel park model, regarding; too and fro transportation of feedstock, chemicals, biodiesel, by product and minimise biomass displacement

9.4 Inference

From table 9.12 it can be inferred that all the strategies have marginal difference in their CO_2 emission. Among the three strategies, Strategy–B has least CO_2 emission (96 kg/Day) followed by Strategy-A (98.6 kg/Day) and Strategy-C (104 kg/Day). However, comparison of revenues show that Strategy–A has highest revenue (Rs.315453) followed by Strategy-B (Rs.53060) and Strategy-C (Rs.7540). As seen from Table 9.16, sequestration capacities of the four tree species, far exceeds the emission from life cycle of biodiesel production and use. Hence, any of the four TBOs or in combination can be chosen for establishing energy plantations.

Choosing Strategy-A may be found to be beneficial both economically and ecologically. However, if the land availability is a constraint for monoculture of TBO species / combination of TBO species, the strategies proposed may be implemented successfully provided the planned numbers of trees (2312 trees) are planted on accessible places like agricultural bunds, on the side of roads and bunds of water bodies. The seeds may be harvested and collected at a common place / designated place for oil extraction and esterification for producing biodiesel and further use.

Table 9. 16 Comparison of CO_2 sequestration

TBOs	CO_2 sequestration in t / ha/ year
Pongamia	22.2
Azadiractha	16.5
Madhuca	21.3
Simarouba	40.5

In the present study, both economic and ecological impacts have been considered in the LCA and the strategies formulated address sustainability. Proposed strategies may be successful, provided the local government supports *(By procuring seedlings / saplings,* *planting, maintenance of the seedlings in summer months & build necessary infrastructure for oil extraction and esterification)* biodiesel production for first ten years before the village level farmers associations become self reliant (Lokesh and Mahesh 2009)

Table 9. 17 Seed yield, biodiesel production and electricity generation for first 10 years from 2312 trees of Pongamia

Particulars	5th yr	6th yr	7th yr	8th yr	9th yr	10th yr
Seed Yield *	4623	6935	11558	16181	23116	27740
BD Produced	982	1473	2456	3438	4912	5894
No of days electricity generated from BD	18	27	45	63	90	109
No of days electricity generated from diesel purchased by selling seed cake	24	36	60	84	120	144
Total no of days electricity generated	42	63	105	147	210	253

- Seed yield data collected from Biofuel Park and has been discussed in Chapter 4

Table no 9.15 indicates the gestation period for the proposed strategies, which is found to be approximately 10 years. Handholding by the government during this gestation period shall help villages in achieving sustainability with respect to energy. All the four TBO species selected have been considered (assumed) to produce 30 kg seeds annually after 10 to 12 years; however, it has been observed that as the age increases the yield also increases. Hence the strategy proposed may appear clinical at the outset however may start becoming sustainable even before the estimated gestation period (10 Years).

Harnessing other sources of non-renewable energy like Solar and wind, based on the geographic location of the village would strengthen the strategies for energy sustainability at village level. Savings from proposed strategy- ‘A’ could help in implementing solar and wind energy system.

The strategies discussed, explore the economic and ecological potential of Pongamia, Madhuca, Azadiractha and Simarouba biodiesel production from the perspective of sustainability at village level. Although the estimates are made based on certain assumptions, it offers valuable findings, which can help in framing policies for biodiesel production from the feedstock suggested.

9.5 Sustainability –Perspective

The above discussion, on the sustainability of biodiesel production form tree borne oils at rural / village level is feasible. This is justified by the following:

- Growing local TBOs at village level, which has been successfully proved by Biofuel Park (Section 2.2)
- Availability of low cost technology for oil extraction (Figure.3.4 & 3.4) and biodiesel production using locally available technology (Figure 3.5and 3.8)
- Proof of using 100% biodiesel produced from Pongamia oil in a 16 year old vehicle –'TATA Sumo', a MUV manufactured by TATA motors In India (Ref. Figure 3.6) gives ample scope to believe that 100% biodiesel can serve as fuel for engines used in agriculture operations at village level.
- The biomass generated i.e., seed cake (Table 2.2, 2.4, 2.9 & 4.13) and leaf litter form the TBOs biodiesel life cycle serves as organic manure, which is encouraged to be used at village level, thus giving back a considerable amount of nutrients back to the soil.
- Opportunity to generate biogas using seed cake and use it locally for cooking and heating. It also provides an opportunity for bottling the biogas and sell it as a substitute for LPG (Liquefied Petroleum Gas). The biogas sludge serves as very good organic manure, which is readily absorbed by plants, compared to seed cake (Section.4.3).

From the points discussed, it is quite evident that strategy proposed in this research shall help in minimising the biomass displacement and promote sustainability with respect to meeting energy needs of farming community.

Based on the results of the LCA of the four TBO species and case study of biodiesel production strategy, conclusions have been drawn, with suggestions for future work in the following chapter.

* A review paper on Biofuel strategy has been published and the reference of the same has been cited in appendix 17.

CHAPTER 10

CONCLUSIONS

This chapter highlights the important results, contributions and limitations of this research, followed by author's perspective and suggestions for further research.

In the year, 2008 Government of India had estimated that by 2017, 20% of diesel consumption must be replaced by biodiesel. To satisfy this requirement, it was estimated that more than 20 million hectares of biodiesel feedstock plantation would be required. According to government of India's biofuel policy, only non-edible oils need to be used for biodiesel production. Hence, Jatropha has been promoted as a suitable feedstock for biodiesel production and has been planned to grow this TBO species on wastelands / marginal lands across India (Lokesh & Mahesh 2009) / (Section 1.5).

However, among the total waste land available, only three categories (comprising about 17 million hectares) of land is considered to have the potential for cultivation with crops like Jatropha (Section 1.5).

Studies carried out by Tamil Nadu Agriculture University reveal that Jatropha is capable of producing estimated yields only in irrigated land (2500 plants / ha= 3 t seeds / ha) than rain fed (1600 plants /ha= 1t seeds /ha) with average oil percentage of 25 % (Section 1.5).

Jatropha was depicted as the wonder shrub that could produce biodiesel, reclaim wasteland and enhance rural development without compromising food production or ecosystem services (Section 1.5.1). Wasteland available in India is rain fed and if Jatropha alone is planted in the 17 million hectare of land, one can obtain an average yield of 17 MMT of seeds yielding 3.8 MMT of biodiesel, which will only suffice for one fourth of biodiesel requirement (Section1.5.1)

A major portion of the wasteland available around villages is grassland and community forests, which provide commodities like fodder, fuel wood, timber and thatching material for landless and small farmers. All these commodities cannot be obtained from one variety of shrub / tree i.e. Jatropha. The promotion of Jatropha will surely have a negative impact on villages depending on the output of community forests (Section1.5.1). In this research study, an attempt has been made to develop sustainable biodiesel production strategies based on comprehensive approach (LCA).

The outcome of this dissertation presents a broad view on the use of oil from local trees as feedstock for biodiesel production and use for electricity generation and other farming operations.

Inbrief the study addresses environmental and socio-economic sustainability, for biodiesel production at rural level, with the following outcomes:

10.1 Environmental and Socio-economic Sustainability

- Assessment of environmental and socio-economic sustainability aspects confirm that Pongamia, Madhuca, Azadiractha and Simarouba biodiesel systems require less energy input and emit less greenhouse gases in comparison to the conventional fossil fuel based reference system and Jatropha biodiesel system (Section.8.1).
- It is also observed that energy output from Pongamia, Madhuca, Azadiractha and Simarouba is 16 - 20 times higher than Jatropha system (Ref Section.8.2).
- Furthermore, Pongamia, Madhuca, Azadiractha and Simarouba biodiesel system showed less impact on ecosystem quality than Jatropha (and oil palm).
- It was observed that bulk of the emission comes from biodiesel production and combustion followed by oil extraction and cultivation phase. On the contrary, majority of the emission from Jatropha system comes from cultivation phase, due to usage of fertiliser and other agro practices (Section.8.3 & 8.4).
- It was observed that CO_2 emission from Pongamia, Madhuca, Azadiractha and Simarouba are three 3-4 times lower than Jatropha system and 7-8 times lower than fossil diesel system (Section.8.3).
- Pongamia, Madhuca, Azadiractha and Simarouba tree plantations have very high CO_2 sequestration capacity, far exceeding the GHG emission from biodiesel life cycle of each crop. This is due to its perennial nature with life expectancy beyond 80 to 100 years (Section.8.3).

- Acidification potential of Pongamia, Madhuca, Azadiractha and Simarouba biodiesel system was also found to be nil when compared to Jatropha system, due to very little usage of inorganic fertiliser and pesticides. This indicates that Pongamia, Madhuca, Azadiractha and Simarouba biodiesel systems require less inputs compared to Jatropha System (Section 8.4).
- Planting the wasteland with Pongamia, Madhuca, Azadiractha and Simarouba plantation triggers an improvement of ESQ, resulting in higher storage capacity in terms of biomass, structure and biodiversity than the wasteland. ESQ impact of all the four tree species has been found to be 2-4 times better than Jatropha (Section 8.5).
- EFQ impact is found to improve for changing the unused land to Pongamia, Madhuca and Simarouba plantation since all four-tree species chosen are from local ecology and any improvement in ESQ should result in improvement of EFQ (Section 8.5).

Biofuels, are becoming an inevitable choice owing to increasing fuel prices and associated global warming, caused by fossil fuel GHG emissions. The Government of India has made a clear policy of exploiting non-edible oils for biodiesel production and the use of wasteland or marginal lands for biofuel feedstock production. Lack of knowledge and uncertainties associated with promoted crops like Jatropha may result in an unsustainable strategy. Moreover, hype given for Jathropha provides ample scope for opportunists / investors to encroach fertile land (Section 1.1.1 & 1.5.1). States like Chhattisgarh and Uttar Pradesh have promoted growth of Jatropha in vast area of wasteland claiming to generate employment and rural development. On the contrary, it seems like a quick decision, without looking into drawbacks of monoculture with respect to yield, pest and diseases infestation, economic viability and requirements of local people.

It is a known fact that availability of agriculture land per capita has declined from 0.48 hectare in 1951 to 0.14 hectares in 2000 in India. In addition to the human population, more than 500 million cattle and other domestic animals are dependent on the biomass from the land (Bali 2000).

Hence, relevant strategies, as discussed in chapter 9 are necessary to promote growth of appropriate biofuel feedstock without raising food–fuel conflict. The strategies developed need to be framed to suit local ecology and economics of Indian context in view of the increasing fossil fuel requirement (Section 8.7 Fig 8.11).

It has become evident from the LCA studies carried out in this research that oil yielding local tree species are better suited as biodiesel feedstock with respect to ecology and economic perspective (Section 8.5 8.6 and 8.7) They are also found to out-perform Jatropha both economically and ecologically.

As of September 2012, India's diesel consumption was 65 MMT. Agriculture alone consumes 12 % i.e. 8 MMT (Mukesh 2012 and Paradeep 2012). It is a fact that Jathropa alone cannot the meet the target of substituting 20% of diesel with biodiesel by 2017. With crude oil consumption, increasing annually at an average rate of 5%, the diesel substitution also increases accordingly. Hence, it would be judicious to frame strategies for growing TBOs as biodiesel feed stock at village level to meet the local requirement at the outset and sell the surplus if any for blending with diesel. This strategy may help in meeting the diesel fuel requirement of Agriculturae sector In India (12% of total consumption i.e. 8 to 10 MMT), thus sparing the fossil diesel for other sectors.

The current global political issues and Indian scenario of constant price rise in fossil fuel, raise a natural thought for alternative fuel. The present situation is appropriate for promoting and educating the farming community about the importance of sustainability pertaining to energy. The success factor in promoting sustainability may be very high during this period. The present economic crisis due to raise in the prices of fossil fuel in the international market and global warming concern around the world may be harnessed for promoting grid free electricity generation using biofuels or a combination of renewable sources. By practicing this system, communities using fossil fuel can reduce their dependence on them. Remote communities without access to fossil fuel may nurture biofuel feedstock plantation as a sustainable asset for the betterment of their livelihood. As seen in the case study of Powerguda, a small hamlet near Hyderabad- (Wani 2006)

The approach of village level biofuel feedstock production use has additional benefits

- Local tree and plant species gel with the farming community and local ecology seamlessly
- Since the tree species have been promoted to be grown on waste land and bunds, they serve as soil binder, shade and source of organic mulch
- Nitrogen fixing capabilities of trees like Pongamia further enhances the soil fertility and being perennial in nature they serve more than one generation of farming community
- Locally organised oil extraction will help in using the seed cake as soil amendment / organic fertiliser / biogas generation
- Adopting scientific silvicultural practices may also help in reaping quality timber and fire wood if necessary without affecting the oil yield
- Investment will be less due to the hardy nature of the crop, which calls for little care and nourishment
- Community based approach has control over community lands for growing biofuel feedstock without compromising the local needs
- It promotes a sense of security and opens up vistas for self employment for individuals and self help groups (especially rural women self help groups)

On the other hand, local village level organisations need to be educated about the following for the success of sustainability.

- Harvesting methods and post harvest handling of the seeds.
- Oil Extraction and filtering methods
- Esterification procedures and safety precautions to handle chemicals like caustic soda, sulphuric acid, acetic acid and in particular methanol (to avoid hooch tragedies)
- Maintenance of esterification and power generation equipment
- Promoting use of de-gummed straight vegetable oil in static engines for power generation shall shorten the value chain and reduce the cost of biofuels. (Which has been a very successfully practiced model by Prof U. Shrinivasa in programme named SuTRA at Indian Institute of Science Bangalore)

With all the pros and cons discussed, author is of the strong opinion that sustainability at village level shall only be successful if appropriate strategies addressing employment generation be promoted in parallel to energy generation. This is a lesson to be learnt from AMUL or KMF strategy, which showed that constant income generation models are well received and nurtured by rural society. One such proposal may be encouraging self help groups / cooperatives at villages to install biogas-bottling plants, bottle excess methane and sell the same to urban population, thus reducing pressure on LPG supply and promoting better livelihood at village level.

10.2 Novel Outcome

The novel outcome of this research has been the framework evolved as the methodology for studying / analysing the sustainability of biodiesel production from any given feedstock. The framework is as follows: (Chapter 3 for detailed explanation)

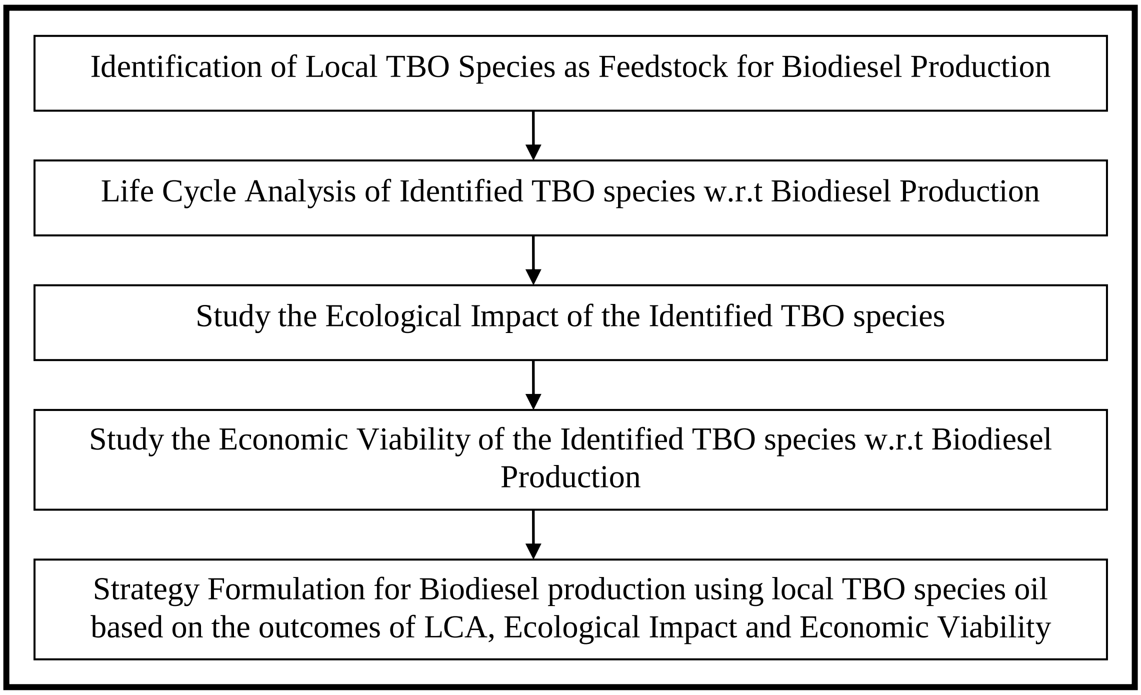


Figure 10. 1 Frame Work for Analysing the Sustainability of Biodiesel Production**The**

unique feature of this frame work is, it involves both ecological impacts and economic viability analysis. The outcome from using this framework shall help in policy decision making. It is evident from the LCA results of Azadiractha and Madhuca that they are ecologically viable but economically unviable, which helps in decision making for choosing or recommending any given TBOs as biodiesel feed stock.

10.3 Suggestion for Further Research

Acceptable methodologies for assessing land use change and land occupation involving both flora and fauna is still in the wanting. Other issues of LCA studies are related to allocation of land use change impacts over time, life cycle inventory methods, availability of data, characterisation factors and life cycle impact assessment models and regionalisation of models (as applied in this research) is needed for better decision making.

Further research on the impact of global warming, ecosystem quality, water requirement and biodiversity would add value for better assessment of impacts in LCA studies. Integration of geographical information systems in LCA studies could help in developing new life cycle inventory methods. This will help in improving data access for deriving useful policy indicators.

Cultivation aspects addressed in the four LCA studies reveal that there exists a wide scope for research in the field of agronomy and genetics of all the four tree species i.e. Pongamia, Madhuca, Azadiractha and Simarouba. Research to reduce the gestation period of these crops would be of prime importance. Application of genetics research is necessary towards increasing the yield, stabilising the yield, increasing the oil content and resistance to pests and diseases.

Biodiesel production process / esterification process itself hosts scope for innovative research: (1) reduction of the process time. (2) use of natural / organic and locally available substitutes as catalyst (3) the most wanting research would be elimination / substituting of methanol (4) refining crude glycerine for better usage in soap making or even pyrolysis for energy generation

Scope for further research also lies in detoxification of seed cake for usage as animal feed and extraction of active ingredient useful in pharmaceutics or in herbicides, anti microbial chemicals and insecticides. Such high value co-products might give way for system improvement activities. Potential research on cost effective technological requirements in the field of mechanical harvesting, seed processing, decortications and oil extraction is necessary as well.

Immediate scope for further research would lie in studying the sustainability of biodiesel production from other TBO species in the remaining nine-agro climatic zones of Karnataka. This would help in generating data for policy formulation and decision making with respect to sustainable biodiesel production in Karnataka State.

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Appendix -1

List of TBO Species

Sl. No	Scientific Name	Oil %
1	Anacardium occidentale	40-60
2	Antidesma Menasu	15-20
3	Aphanamixis polyctachya	10-20
4	Aporosa lindleyana	15-25
5	Azadirachta indica	35-42
6	Baccaurea courtallensis	20-35
7	Bauhinia malabarica	10-25
8	Bauhinia phoenicea	10-20
9	Bauhinia purpurea	10-20
10	Bauhinia racemosa	10-20
11	Bauhinia variegata	20-30
12	Bischofia javanica	15-20
13	Bridelia montana	15-20
14	Buchanania axillaris	20-35
15	Bridelia stipularis	20-35
16	Buchanania lanzan	15-28
17	Butea monosperma	15-20
18	Butea superba	20-30
19	Caryota urens	15-20
20	Cassia fistula	15-20
21	Cassia montana	15-20
22	Cassia siamia	15-20
23	Chloroxylon swietenia	30-40
24	Chukrasia tabularis	20-28
25	Chrysophyllum lanceolatum	10-20
26	Cipadessa baccifers	15-25
27	Corypha umbraculifera	10-20
28	Daphniphyllum neilgherrense	15-25
29	Derris scandens	15-20
30	Dysoxylum binentariferum	15-20
31	Emblica officinalis	15-25
32	Erythrina stricta	15-25
33	Erythrina suberosa	20-25
34	Euphorbia antiquorum	15-20
35	Fahrenheltia zeylanlca	15-20
36	Givotia rottleriformis	15
37	Glochidion Zeylanicum	25-35
38	Holigarna grahamii	25-35
39	Jatropha curcas	30-35
40	Kinglodendron pinnatum	15-20
41	Kirganelia reticulata	15
42	Kriganelia reticulata	15

Appendix -1 Continued

43	Lannea coromandelica	10-15
44	Lansium anamalayanum	10-20
45	Macaranga indica	10-15
46	Macaranga peltata	10-20
47	Madhuca indica	10-15
48	Madhuca longifolia	25-35
49	Madhuca neriifolia	20-30
50	Mallotus philippensis	10-20
51	Mallotus tetracoccus	10-20
52	Mangifera indica	10-15
53	Melia dubia	15-25
54	Mimusops elengi	25-30
55	Moullava spicata	15-20
56	Nothopegia beddomei	15-20
57	Ougenia ougensis	10-15
58	Pterygota alata	30-40
59	Palaquium ellipticum	25-30
60	Phoenix dactylifera	10-15
61	Phoenix humilis	10-20
62	Phoenix sylvestris	10-15
63	Pongamia pinnata	20-35
64	Pterocarpus marsupium	15-25
65	Pterospermum acerifolium	10-15
66	Pterospermum diversifolium	10-15
67	Pterospermum heyneanum	15-20
68	Ricinus communis	45-50
69	Scleropyrum pentandrum	40-50
70	Saraca asoca	50-60
71	Securinega leucopyrus	15-20
72	Semecarpus anacardium	30-35
73	Simarouba glauca	60-70
74	Soymida febrifuga	15-20
75	Spondias pinnata	25-30
76	Sterculia guttata	30-45
77	Sterculia urens	30-40
78	Sterculia villosa	25-30
79	Swietenia mahogony	15
80	Tamarindus indica	10-15
81	Toona ciliata	10-20
82	Trewia nudiflora	10-15
83	Trichilia connaroides	15-25
84	Trewia nudiflora	10-15
85	Xantolis tomentosa	20-30
86	Xylia xylocarpa	10-15

Source: Department of Forestry and Environmental sciences, UAS, Bangalore

Appendix -2

List of Biofule Feed Stock Growers Association Selected for LCA Studies

Sl.No.	Name of the Association	Village	Distance in km from Biofuel Park
1	Sri Chikkagiri Ranganatha Swamy Biofuel growers and seed collectors association	Thirupathihalli	38
2	Sri Ajeneya Biofuel growers and seed collectors association	Kirkadlu	38
3	Sri Vedavathi Biofuel growers and seed collectors association	Vedavathi	40
4	Nayakarahalli Biofuel growers and seed collectors association	Nayakarahalli	61
5	Sri Lakshmi devi Biofuel growers and seed collectors association	Doddagaddavalli	37
6	Sri Lakshmi devi Biofuel growers and seed collectors association	Sakalenahalli	29
7	Anjuneya Swami Biofuel growers and seed collectors association	Chikkagadduvalli	38
8	Male Malleshwara Biofuel growers and seed collectors association	Sigeguddada Kaval	34
9	Anjuneya Swami Biofuel growers and seed collectors association	Kattehalli	64
10	Anjuneya Swami Biofuel growers and seed collectors association	Mayasamudra	21
11	Basthihalli Biofuel growers and seed collectors association	Basthihalli	61
12	Doddabeekanahalli Biofuel growers and seed collectors association	Doddabeekanahalli	38
13	Kurubarahalli Biofuel growers and seed collectors association	Kurubarahalli	31
14	Sri Gowramma Biofuel growers and seed collectors association	Bylahalli	36
15	Sri Anjaneya Biofuel growers and seed collectors association	Madapura	76
16	Sri Malekallu Siddeshwara Biofuel growers and seed collectors association	Chathranahalli	38
17	Sri Rajarajeshwari Biofuel growers and seed collectors association	Kalenahalli	30
18	Sri Byraveshwara Biofuel growers and seed collectors association	H. Dyavalapura	15
19	Sri Byraveshwara Biofuel growers and seed collectors association	Chikkanayakanahalli	51
20	Sri Muniyamma Biofuel growers and seed collectors association	Doddabagenahalli	45
21	Sri Rama Biofuel growers and seed collectors association	Padumanahalli	37
22	Sri Vigneshwara Biofuel growers and seed collectors association	Anjaneyapura	35
23	Sri Renukadevi Biofuel growers and seed collectors association	Sannenahalli	43
24	Sri Rama Biofuel growers and seed collectors association	Hosur	22
25	Sri Lakshmidevi Biofuel growers and seed collectors association	Cheeranahalli	22
26	Sri Subramanyaswamy Biofuel growers and seed collectors association	Hulihalli	30

Appendix -2 Continued

27	Sri Deviramma Biofuel growers and seed collectors association	Kodaramanahalli	36
28	Sri Udusalamma Biofuel growers and seed collectors association	Somanahalli	28
29	Sri Anjaneyaswamy Biofuel growers and seed collectors association	Chikkabagenahalli	31
30	Sri Lakshmidevi Biofuel growers and seed collectors association	Javenahalli	28
31	Sri Bollamma kali Biofuel growers and seed collectors association	Mahadevanahalli	29
32	Sri Deviramma Biofuel growers and seed collectors association	Ballekere	33
33	Sri Maruthi Biofuel growers and seed collectors association	Mudanahalli	20
34	Sri Male Malleshwara Biofuel growers and seed collectors association	Kadadharavalli colony	35
35	Sri Anjuneya Biofuel growers and seed collectors association	Ibdani	32
36	Sri Chowdeshwari Biofuel growers and seed collectors association	Beekanahalli	38
37	Sri Mariayamma Biofuel growers and seed collectors association	Kallahalli	48
38	Sri Manjunatha Biofuel growers and seed collectors association	Rahuthanahalli	36
39	Sri Chowdeshwari Biofuel growers and seed collectors association	Jinnenahalli	33
40	Sri Rajeshwari Biofuel growers and seed collectors association	Jinnenahalli	33
41	Sri Kalikamba Biofuel growers and seed collectors association	Mallenahalli	21
42	Sri AnjaneyaBiofuel growers and seed collectors association	Parasanahalli	9
43	Sri Durgadevi Biofuel growers and seed collectors association	Doranahosahalli	36
44	Sri Mylaralingeshwara Biofuel growers and seed collectors association	Hulihalli koppal	30
		Average Distance in km	36
		Standard Deviation	±12.6

Appendix - 3

Data Collected from Biofule Feed Stock Growers Associations for Pongamia and Madhuca - Cultivation Phase of LCA

Sl.No	Parameters	Pongamia	Madhuca
1	Soil type	Red to Sandy Loam	Red to Sandy Loam
2	Seed Collection Kg/ Day/Person	160 ± 15.5	187 ± 11.49
3	Irrigation	Rainfed	Rainfed
4	Number of Labour required for transplanting / ha	6 ± 3.9	3 ± 0.47
5	FYM / ha in kg	597 ± 12.75	507 ± 36.7
6	N + P + K/ pit in kg	Not Applied	Not Applied
7	Herbicide & Pesticide & Quantity	Not Applied	Not Applied
8	Labour required for Weeding /ha	2 ± 0.52	2±0.46
9	Inter cultivation if any	Not Practiced on Community Land	Not Practiced on Community Land
10	Yield / ha From a 10 yr old Plantation in Quintals	28 ± 2.23	9.52 ± 0.51
11	Labour required for Harvesting / ha	5 ± 0.5	2 ± 0.47
12	Labour Required for drying	2 ± 0.37	4 ± 0.57
13	Transportation	Mini truck-86% Bullock Cart -7% Tractor - 7 %	Mini truck-86% Bullock Cart -7% Tractor - 7 %
14	Seed Storage	Heaping	Heaping
15	N- Fixing	Yes	Yes
16	Beneficial to nature and mankind	Supports Apiculture Leaves Puddleded in Paddy Field - Serves as soil Conditioner and Organic Manure Seed Cake used Organic Manure	Supports Apiculture Seed Cake used as Organic Manure in Lawns & to smoke out rats
17	Medicinal value	Ayurvedic Medicine Preperation	Ayurvedic Medicine Preperation
18	Religious value	Nil	Yes Worshipped
19	Timber and other usage	Agriculture Implements & Fire Wood	Fire wood

Appendix – 4

Data Collected from Biofule Feed Stock Growers Associations for Azadiractha and Simarouba Cultivation Phase of LCA

Sl.No	Parameters	Azadiractha	Simarouba
1	Soil type	Red to Sandy Loam	Red to Sandy Loam
2	Seed Collection Kg/ Day/Person	205 ± 15.7	198 ±1 0.47
3	Irrigation	Rainfed	Rainfed
4	Number of Labour required for transplanting / ha	3 ± 0.5	4 ± 0.45
5	FYM / ha in kg	588 ± 14.78	997 ± 12.75
6	N + P + K/ pit in kg	Not Applied	Not Applied
7	Herbicide & Pesticide & Quantity	Not applied	Not applied
8	Labour required for Weeding /ha	2 ± 0.58	2 ± 0.4
9	Inter cultivation if any	Not Practiced on Community land	Not Practiced on Community land
10	Yield / ha From a 10 yr old Plantation in Quintals	6 ± 0.53	30 ± 3.95
11	Labour required for Harvesting /ha	2 ± 0.42	4 ± 0.47
12	Labour Required for drying	4 ± 0.48	4 ± 0.57
13	Transportation	Mini truck-86% Bullock Cart -7% Tractor - 7 %	Mini truck-86% Bullock Cart -7% Tractor - 7 %
14	Seed Storage	Heaping	Heaping
15	N- Fixing	Nil	Nil
16	Beneficial to nature and mankind	Supports Apiculture Seed Cake used as Organic Manure in Paddy & Horticulutural Crops. It works as a good nemeticide	Supports Apiculture Seed Cake Used as Organic Fertiliser & Also serves a cattle feed
17	Medicinal value	Ayurvedic Medince Preperationa & Folk Medicne	Anti cancer
18	Religious value	Yes- Worshipped	Nil
19	Timber and other usage	Timber, good substitute for Alstonia Spp wood, which is used in Toy manufacturing	Timber, good substitute for Alstonia Spp wood, which is used in Toy manufacturing

Appendix – 5

Data Collected from Biofule Park for Oil Extractiona and Transestrification Phase of LCA

Data Collected for Oil Extraction Phase

Sl.No	Parameters	Pongamia	Madhuca	Azadiractha	Simarouba
1	Oil Extraction Machine capacity	50 kg seed / h			
2	Electricity consumed for oil extraction	60	60	60	90
3	Oil yield in kg	141	162	150	270
4	Man Power Required	6	6	6	6
6	Seed cake yield in kg	227	351	390	221
7	Price of Seed in Rs / kg	15	14	16	12
8	Price of Oil Rs / kg	60	85	120	40
9	Price of Seed Cake Rs / kg	15	12	18	15

Data Collected for Transesterification Phase

Sl.No	Parameters	Pongamia	Madhuca	Azadiractha	Simarouba
1	Oil in kg	141	162	150	270
2	Sodium Hydroxide in kg	1.7	1.6	1.5	2.7
3	Sulphuric in kg	0.34	0.32	0.3	0.54
4	Acetic Acid in kg	0.34	0.32	0.3	0.54
5	Methanol in liters	42.5	40.5	37.5	67.5
6	Electricity Consumed in kWh	34	35.2	35.29	63
7	Man power Required	4	4	4	4
8	Biodiesel Yield	85 to 90 %	85 to 90 %	85 to 90 %	85 to 90 %
9	Glycerin Yield	21.1	24.3	22.5	40.5
10	Biodiesel Specific Gravity	0.87±4	0.85± 2.9	0.86±2.6	0.86±3.5
11	Biodiesel Viscocity	5.6± 2.3	3.8- 4.6	4.6± 2.8	4.5 -5.2
12	Biodiesel Flash Point	161±5.1	160 ± 3.01	159±3.05	161± 3.44
13	Biodiesel Fire Point	173 ± 4.7	173 ± 2.9	172 ± 3.5	173± 3.9
14	Biodiesel Calorific Value	36 ± 0.45	37 ± 0.4	37.5± 0.39	35±0.6

Appendix - 6

Esterification Procedure and Biodiesel Properties

Biodiesel can be produced from any SVO or animal fat. The main ingredient of SVO is 'triglyceride', which is a long-chain hydrocarbon. Esterification of this triglyceride using alcohol in the presence of a catalyst (NaOH / KOH) yields biodiesel and glycerine as by-product

Methodology

Titration Testing

The free fatty acids (FFA) present in vegetable oils need to be neutralized. The amount of FFA varies based on the type of oil.

- Dissolve 1g NaOH in one litre of distilled water.
- Dissolve 1g of the SVO in 10 ml of anhydrous isopropyl alcohol in a conical flask.
- Add few drops of phenolphthalein indicator.
- Titrate against NaOH solution taken in a burette until the colour becomes pale pink.
- The volume of NaOH required to neutralize free fatty acid (A) is noted.
- Suppose 3.5 g of NaOH is required per litre of oil, then the total catalyst required is [3.5+ A] g per litre.

Depending on the FFA content of any given oil, transesterification can be carried out using the following methods

1. **Single Base Method**
2. **Two step Acid-Base Method**

Method 1: Single Base Method or Alkaline Transesterification

Alkaline transesterification process is carried out for the oil with less than 2% FFA

- Add one litre oil into a three neck fitted with condenser, thermometer and methanol dozer
- Heat the vegetable oil to about 60° C.
- Prepare Sodium methoxide by dissolving required amount of NaOH (as per titration test) in 250 ml methanol
- Add Sodium methoxide to the preheated oil and constantly mix the contents for 1.5 hrs using mechanical stirrer.

- Allow the mixture to settle for about 1-2 hrs in a separating funnel.
- Drain out glycerine that settles at the bottom as a viscous liquid.
- The clear liquid that remains on top of the glycerine is the biodiesel.

Method 2: Two step Method (Acid & Base-catalyst esterification)

It is a two-stage process involving an acid esterification followed by alkaline (base) esterification in the second-stage. (Two-stage process is followed when FFA content is more than 2%)

First stage (Acid catalyst Esterification)

- Add 1 ml of H_2SO_4 to 100 ml of methanol
- Carefully add this acid methanol mixture to one litre of pre heated oil.
- Stir the contents continuously at 55° C for an hour
- Allow the contents to settle down in a separating funnel for 1 to 2 hrs.
- The contents separate out to form two layers
- The top layer is rich in excess FFA and methanol. The bottom layer (Oil) is used for transesterification process using Alkaline as catalyst.
- Carry out titration test to find NaOH required
- Measure 120 ml of methanol for each litre of oil and weigh NaOH required per litre of oil based on the titration test. Dissolve NaOH into the methanol to form sodium methoxide.

Second Stage (Alkaline Transesterification)

- Add one litre oil into a three neck flast, fitted with condenser thermometer and methanol dozer
- Heat the SVO to about 60° C.
- Add Sodium methoxide to the preheated oil and constantly mix the contents for 1.0-1.5 hrs using mechanical stirrer.
- Allow the mixture to settle for about 1-2 hrs in a separating funnel.
- Drain out glycerin that settles at the bottom of separating funnel
- The clear liquid that remains on top of the glycerine is the biodiesel.

Washing Biodiesel

Washing of Biodiesel is necessary to remove the soluble components using hot water. Hot water is sprayed on the biodiesel and allowed to settle down and the wastewater is drained off. The washing is carried out three-four times to get pure biodiesel.

Drying Biodiesel

Drying of the freshly washed biodiesel is achieved by heating the biodiesel to 110°C. This heating process will remove traces of moisture and alcohol as well. Once the biodiesel cools down, it can be used in engines as fuel or stored.

Appendix -7

Analytical Results of the Soil Sample

For assessing the impact of Land use change, soil samples were collected from Biofuel Park. Thirty soil samples were collected from each TBOs plot randomly by walking across the block plantaion. The collected samples of each TBOs plot was mixed thoroughly and the sample size reduced to approximately 1 kg by quartering technique.

Soil smaples were analysed at soil chemistry lab of University of agricultural sciences, Bangalore.

UNIVERSITY OF AGRICULTURAL SCIENCES,
GKVK Campus, Bengaluru - 560 065

SS&AC./ 64/2 /11-12

31st May.,2012

To,
Mr.Lohith A.C.,
No.517/1, 2nd 'B'Cross,
Gokula, 1st Stage, 1st Phase,
Bangalore-560 054

Through Director of Research, UAS, Bengaluru.

Sir,

Sub: Analytical results of nine soil samples reg.....
Ref: DR/TT-31/2012-13, dt 04/05/2012

Please find herewith the analytical results of nine soil samples sent by you for analysis in the Dept. of Soil Science and Agricultural Chemistry, College of Agriculture, GKVK, Bengaluru -65.

Parameters	Soil samples 1	2	3	4	5	6	7	8	9
Organic carbon (%)	1.01	1.48	1.09	2.49	0.85	0.80	1.83	2.22	1.32
Organic matter (%)	1.74	2.55	1.87	4.29	1.46	1.37	3.15	3.82	2.27
CEC (cmol(p+)kg^{-1})	16.50	22.77	18.81	37.29	17.16	13.53	16.83	27.39	15.84

The result should not be utilized for legal / commercial purposes without prior consent of the Director of Research.

COUNTERSIGNED

Forwarded
Director of Research
DIRECTOR OF RESEARCH
University of Agricultural Sciences
GKVK, BANGALORE - 560 065

Yours faithfully,
Professor & Head
Dept. of Soil Science & Agricultural Chemistry
31/5/2012
Professor and Head
Dept. of Soil Science & Agril. Chemistry
College of Agriculture, U.A.S. G.K.V.K.
Bangalore - 560 065

Appendix -7 Continued

Nine soil samples were collected from nine different plots of biodiesel feedstock. The following table illustrates the sample description.

Sample No	**Crop**	**Place**	*******	**OC**	**OM**	**CEC**	**Total Area in acres**	**Area Under Research in acres**
Sample 1	Simarouba	Biofuel Park	Current	1.01	1.74	16.5	50	2.5
Sample 2	Vacant land	Hasaganur	FLU	1.48	2.55	22.77	14	1
Sample 3	Pongamia	Biofuel Park	Current	1.09	1.87	18.81	50	2.5
Sample 4	Fig Tree	Hasaganur	LPNV	2.49	4.29	37.29	14	1
Sample 5	Madhuca	Biofuel Park	Current	0.85	1.46	17.16	50	2.5
Sample 6	Vacant land	Biofuel Park	FLU	0.8	1.37	13.53	50	2.5
Sample 7	Azadiractha	Biofuel Park	Current	1.83	3.15	16.83	50	2.5
Sample 8	Pongamia	Hasaganur	Current	2.22	3.82	27.39	14	1
Sample 9	Jack	Biofuel park	LPNV	1.32	2.27	15.84	50	2.5

***

Current: Represents samples collected from plots currently hosting the biodiesel feedstock

FLU: Represents former land use

LPNV: Represents local potential natural vegetation

OC= *Soil Organic Carbon is the main source of energy for soil microorganisms* *(Unit %)*

OM = *Soil Organic Matter is a heterogeneous, dynamic substance that varies in particle size, carbon content, decomposition rate and turnover time. SOM contains approximately 58% C; therefore, **a factor of 1.72** is be used to convert OC to SOM. Example OC of Simarouba* =1.01 OM = 1.01 x 1.72 = 1.74 ref above table *(Unit %)*

CEC = *Cation exchange capacity is the total capacity of a soil to hold exchangeable cations. CEC influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification. Soils with a higher clay fraction and organic matter tend to have a higher CEC. (Unit-cmol(P^+)/ kg)*

Appendix- 8

Total Above Ground Biomass of Pongamia

TAB of Pongamia							
Sl.No	**Factor**	**Age**	**D**	**H in Ft**	**W – Green Weight Above Ground**	**Green Wt roots included**	**Dry Wt**
1	0.25	5	8	12	192.00	230.40	167.04
2	0.25	5	10	11	275.00	330.00	239.25
3	0.15	5	12	12	259.20	311.04	225.50
4	0.25	5	9	11	222.75	267.30	193.79
5	0.15	5	13	12	304.20	365.04	264.65
6	0.25	5	8	11	176.00	211.20	153.12
7	0.25	5	8	13	208.00	249.60	180.96
8	0.25	5	9	12	243.00	291.60	211.41
9	0.25	5	10	11	275.00	330.00	239.25
10	0.15	5	12	11	237.60	285.12	206.71
11	0.15	5	14	12	352.80	423.36	306.94
12	0.25	5	11	13	393.25	471.90	342.13
13	0.25	5	8	13	208.00	249.60	180.96
14	0.25	5	9	12	243.00	291.60	211.41
15	0.25	5	10	11	275.00	330.00	239.25
16	0.25	5	10	10	250.00	300.00	217.50
17	0.25	5	11	12	363.00	435.60	315.81
18	0.25	5	10	13	325.00	390.00	282.75
19	0.25	5	9	10	202.50	243.00	176.18
20	0.25	5	8.5	10	180.63	216.75	157.14
21	0.15	5	12	10	216.00	259.20	187.92
22	0.25	5	11	8	242.00	290.40	210.54
23	0.25	5	11	9	272.25	326.70	236.86
24	0.25	5	10	8	200.00	240.00	174.00
25	0.15	5	12	11	237.60	285.12	206.71
26	0.25	5	11	12	363.00	435.60	315.81
27	0.25	5	10	14	350.00	420.00	304.50
28	0.25	5	11	9	272.25	326.70	236.86
29	0.15	5	12	10	216.00	259.2	187.92
30	0.15	5	12	10	216.00	259.20	187.92
					Average Dry wt in pounds		**225.36**
					Average Dry wt in kg		**102.44**

Appendix - 9

Total Above Ground Biomass of Madhuca

TAB of Madhuca							
Sl.No	**Factor**	**Age**	**D**	**H in Ft**	**W – Green Weight Above Ground**	**Green Wt roots included**	**Dry Wt**
1	0.25	5.00	8	10	160.00	192.00	139.20
2	0.25	5.00	9	11	222.75	267.30	193.79
3	0.25	5.00	9	10	202.50	243.00	176.18
4	0.25	5.00	8	11	176.00	211.20	153.12
5	0.15	5.00	8	12	115.20	138.24	100.22
6	0.15	5.00	9	12	145.80	174.96	126.85
7	0.25	5.00	7	11	134.75	161.70	117.23
8	0.15	5.00	8	12	115.20	138.24	100.22
9	0.15	5.00	8	12	115.20	138.24	100.22
10	0.25	5.00	9.5	11	248.19	297.83	215.92
11	0.15	5.00	10	12	180.00	216.00	156.60
12	0.25	5.00	9	10	202.50	243.00	176.18
13	0.25	5.00	8	11	176.00	211.20	153.12
14	0.15	5.00	10	12	180.00	216.00	156.60
15	0.25	5.00	9	11	222.75	267.30	193.79
16	0.25	5.00	10.5	10	275.63	330.75	239.79
17	0.15	5.00	11	12	217.80	261.36	189.49
18	0.25	5.00	9	11	222.75	267.30	193.79
19	0.25	5.00	8	11	176.00	211.20	153.12
20	0.25	5.00	9	11	222.75	267.30	193.79
21	0.15	5.00	10	12	180.00	216.00	156.60
22	0.25	5.00	11	11	332.75	399.30	289.49
23	0.15	5.00	10	12	180.00	216.00	156.60
24	0.15	5.00	9	12	145.80	174.96	126.85
25	0.25	5.00	9	11	222.75	267.30	193.79
26	0.15	5.00	10	12	180.00	216.00	156.60
27	0.15	5.00	9	12	145.80	174.96	126.85
28	0.25	5.00	10	11	275.00	330.00	239.25
29	0.25	5.00	9	11	222.75	267.30	193.79
30	0.15	5.00	10	12	180.00	216.00	156.60
					Average Dry wt in pounds		**167.52**
					Average Dry wt in kg		**76.15**

Appendix -10

Total Above Ground Biomass of Azadiractha

TAB of Azadiractha							
Sl.No	Factor	Age	D	H in Ft	W – Green Weight Above Ground	Green Wt roots included	Dry Wt
1	0.15	5.00	8.0	12.00	192.00	230.40	167.04
2	0.15	5.00	10.0	12.00	300.00	360.00	261.00
3	0.15	5.00	9.00	13.00	263.25	315.90	229.03
4	0.15	5.00	8.00	12.00	192.00	230.40	167.04
5	0.15	5.00	8.50	12.00	216.75	260.10	188.57
6	0.15	5.00	8.00	12.00	192.00	230.40	167.04
7	0.15	5.00	9.00	13.00	263.25	315.90	229.03
8	0.15	5.00	9.50	14.00	315.88	379.05	274.81
9	0.15	5.00	8.00	11.00	176.00	211.20	153.12
10	0.15	5.00	8.50	10.00	180.63	216.75	157.14
11	0.15	5.00	9.50	10.00	225.63	270.75	196.29
12	0.15	5.00	8.00	11.00	176.00	211.20	153.12
13	0.15	5.00	10.00	12.00	300.00	360.00	261.00
14	0.15	5.00	11.00	10.00	302.50	363.00	263.18
15	0.15	5.00	8.50	11.00	198.69	238.43	172.86
16	0.15	5.00	9.00	12.00	243.00	291.60	211.41
17	0.15	5.00	9.50	13.00	293.31	351.98	255.18
18	0.15	5.00	9.00	11.00	222.75	267.30	193.79
19	0.15	5.00	8.50	10.00	180.63	216.75	157.14
20	0.15	5.00	9.00	11.00	222.75	267.30	193.79
21	0.15	5.00	10.00	12.00	300.00	360.00	261.00
22	0.15	5.00	12.00	13.00	280.80	336.96	244.30
23	0.15	5.00	11.00	14.00	423.50	508.20	368.45
24	0.15	5.00	9.00	13.00	263.25	315.90	229.03
25	0.15	5.00	9.00	11.00	222.75	267.30	193.79
26	0.15	5.00	8.50	12.00	216.75	260.10	188.57
27	0.15	5.00	8.50	13.00	234.81	281.78	204.29
28	0.15	5.00	9.50	12.00	270.75	324.90	235.55
29	0.15	5.00	10.00	12.00	300.00	360.00	261.00
30	0.15	5.00	11.50	14.00	277.73	333.27	241.62
					Average Dry wt in pounds		**215.97**
					Average Dry wt in kg		**98.17**

Appendix -11

Total Above Ground Biomass of Simarouba

TAB of Simarouba							
Sl.No	Factor	Age	D	H in Ft	W – Green Weight Above Ground	Green Wt roots included	Dry Wt
1	0.15	5.00	14.00	14.00	411.60	493.92	358.09
2	0.15	5.00	15	12	405.00	486.00	352.35
3	0.15	5.00	15	13	438.75	526.50	381.71
4	0.15	5.00	16	12	460.80	552.96	400.90
5	0.15	5.00	15	14	472.50	567.00	411.08
6	0.15	5.00	17	14	606.90	728.28	528.00
7	0.15	5.00	15	14	472.50	567.00	411.08
8	0.15	5.00	14	13	382.20	458.64	332.51
9	0.15	5.00	15	14	472.50	567.00	411.08
10	0.15	5.00	15	14	472.50	567.00	411.08
11	0.15	5.00	16	13	499.20	599.04	434.30
12	0.15	5.00	17	14	606.90	728.28	528.00
13	0.15	5.00	15	12	405.00	486.00	352.35
14	0.15	5.00	15	10	337.50	405.00	293.63
15	0.15	5.00	15	11	371.25	445.50	322.99
16	0.15	5.00	15	12	405.00	486.00	352.35
17	0.15	5.00	16	12	460.80	552.96	400.90
18	0.15	5.00	15	13	438.75	526.50	381.71
19	0.15	5.00	16	15	576.00	691.20	501.12
20	0.15	5.00	15	16	540.00	648.00	469.80
21	0.15	5.00	16	14	537.60	645.12	467.71
22	0.15	5.00	15	13	438.75	526.50	381.71
23	0.15	5.00	15	14	472.50	567.00	411.08
24	0.15	5.00	16	12	460.80	552.96	400.90
25	0.15	5.00	17	14	606.90	728.28	528.00
26	0.15	5.00	15	13	438.75	526.50	381.71
27	0.15	5.00	16	12	460.80	552.96	400.90
28	0.15	5.00	15	14	472.50	567.00	411.08
29	0.15	5.00	16	13	499.20	599.04	434.30
30	0.15	5.00	16	14	537.60	645.12	467.71
					Average Dry wt in pounds		**410.67**
					Average Dry wt in kg		**186.67**

Appendix -12

Total Above Ground Biomass of LPNV and CO_2 Sequestered / ha by TBOs

Jack fruit Tree (LPNV- Plain land / Biofuel Park)							
Sl. No	**Factor**	**Age**	**D**	**H in Ft**	**W – Green Weight Above Ground**	**Green Weight roots included**	**Dry weight in pounds**
1	0.15	10	20	16	960.00	1152.00	**835.20**
						Dry weight in kg	**379.64**

Feedstock	**Dry weight in lbs**	**CO_2 Sequestered**	**CO_2 Sequestered / yr in lbs**	**CO_2 Sequestered / yr in kg**	**CO_2 Sequestered / ha in Kg**	**CO_2 Sequestered / ha in ton**
Pongamia	225.36	824.82	164.96	74.23	22270.05	22.27
Azadiractha	215.97	790.46	158.09	71.14	21342.43	21.34
Madhuca	167.52	613.13	122.63	55.18	16554.5	16.55
Simarouba	410.67	1503.05	300.61	135.27	40582.45	40.58

Appendix -13

Emission Report – Conventional Diesel

COMPUTERISED POLLUTION UNDER CHECK CENTERS

(Rule 231(B)(8) of KMV Rules 1989)

Licence No : 47/1993-94

Center Name : Sri Balaji Emission Testing Center

Center Address : No.16, 2nd Block, Juganahalli, Rajaji Nagar, Bangalore-560010

Customer Name : Bala Krishna

Customer Mobile : 9448506060

Pucc No : D027101034

Vehicle No : KA04N7372

Year of Regn : 05-06-1997

Type of Vehicle : CAR

Make : Tata Motors

Model : SUMO

Test Date : 05-06-2011

Time : 14:17

Valid UpTo : 04-12-2011

Photo of Vehicle

Hologram Sticker

Test Data

Flushing Cycle			
Avg	RPM Min	RPM Max	Temp
	760	2590	79

Srno	RPM Min	RPM Max	Km	HSU%	Temp
1	0760	2580	0.04	4.5	0079
2	0760	2570	0.03	5.7	0079
3	0760	2620	0.01	5.7	0079
4	0760	2550	0.05	5.1	0079
5	0760	2620	0.37	4.5	0079
Mean			0.12	5.25	

Pres Limit for Diesel vehicle	K(Light Absorption Co-efficient)	Harridge Units %
Free Acceleration	2.45	65

This Vehicle meets Emission Standards Prescribed by Rule 115(2) of CMVR 1989. Accordingly the Certificate is valid for Six Months

Seal of Testing Station	Testing Station Code	Authorised Signatory
	D027	

Note : Rate of Diesel Testing :

1) Three Wheelers Rs 100.00

2) Four wheelers Rs 100.00

This Certificate is not acceptable without Hologram Sticker & Get Renewed the Certificate within the Expiry Date.

Appendix -14

Emission Report – B20

COMPUTERISED POLLUTION UNDER CHECK CENTERS

(Rule 231(B)(8) of KMV Rules 1989)

Licence No : 47/1993-94

Center Name : Sri Balaji Emission Testing Center

Center Address : No.16, 2nd Block, Juganahalli, Rajaji Nagar, Bangalore-560010

Customer Name : Balakrishna

Customer Mobile : 9448506060

Pucc No : D027101035

Vehicle No : KA04N7372

Year of Regn : 05-06-1997

Type of Vehicle : CAR

Make : Tata Motors

Model : SUMO

Test Date : 05-06-2011

Time : 14:44

Valid UpTo : 04-12-2011

Photo of Vehicle

Hol er

Test Data

Flushing Cycle			
Avg	RPM Min	RPM Max	Temp
	767	2550	89

Srno	RPM Min	RPM Max	Km	HSU%	Temp
1	0767	2530	0.06	4.5	0089
2	0767	2500	0.25	4.5	0089
3	0767	2560	0.05	4.5	0089
4	0767	2550	0.08	4.5	0089
5	0767	2500	0.61	4.0	0089
6	0767	2590	0.43	4.5	0089
Mean			0.29	4.38	

Pres Limit for Diesel vehicle	K(Light Absorption Co-efficient)	Harridge Units %
Free Acceleration	2.45	65

This Vehicle meets Emission Standards Prescribed by Rule 115(2) of CMVR 1989. Accordingly the Certificate is valid for Six Months

Seal of Testing Station	Testing Station Code	Authorised Signatory
	D027	

Note :Rate of Diesel Testing:-

1) Three Wheelers Rs 100.00

2) Four wheelers Rs 100.00

This Certificate is not acceptable without Hologram Sticker & Get Renewed the Certificate within the Expiry Date.

Appendix -15

Emission Report – B 100

COMPUTERISED POLLUTION UNDER CHECK CENTERS (Rule 231(B)(8) of KMV Rules 1989)

This Vehicle meets Emission Standards Prescribed by Rule 115(2) of CMVR 1989. Accordingly the Certificate is valid for Six Months

Licence No : 47/1993-94

Center Name : Sri Balaji Emission Testing Center

Center Address : No.16, 2nd Block, Juganahalli, Rajaji Nagar, Bangalore-560010

Customer Name : MMM

Customer Mobile : 9448506060

Pucc No : D027101641

Vehicle No : KA04N7372

Year of Regn : 20-08-1997

Type of Vehicle : CAR

Make : Tata Motors

Model : SUMO

Photo of Vehicle

Pres Limit for Diesel vehicle	K(Light Absorption Co-efficient)	Harridge Units %
Free Acceleration	2.45	65

Srno			Km		
1	0766	2808	0.28	2.5	0081
2	0766	2934	0.47	2.5	0081
3	0766	2931	0.34	2.5	0081
4	0766	2934	0.53	2.5	0081
	0766	2861	0.01	2.5	
	0766	2992	0.08	3.5	0081
	0766	2973	0.51	2.5	0081
	0766	3079	0.63	2.5	0081
9	0766	2957	0.70	2.5	0081
Mean			0.48	2.75	

Flushing Cycle & Test Data			
Avg	RPM Min	RPM Max	Temp
	766	3000	81

Test Date : 04-07-2011 Time : 17:11

VALID DATE : 03-01-2012

This Certificate is not acceptable without Hologram Sticker & Get Renewed the Certificate within the Expiry Date.

Authorised Signatory	Testing Station Code	Seal of Testing Station
	D027	

Print

Appendix -16

Data for Identifying the Trend for Sensitivity Analysis

Year	Methanol Price / Litre	Sodium Hydroxide Price / kg	Sulphuric Acid / Litre	Acetic Acid / Litre
2011	30	62	335	265
2012	35	65	342	272
2013	40	66	355	314
2014	46	66	362	324
r	= - 10629 + 5.30 (Year)	= - 2552 + 1.30 (Year)	= - 18569 + 9.40 (Year)	= - 43780 + 21.9 (Year)

Diesel Price From 2010 to 2014	
Dates	Diesel Price in Rs/ l
02-11-2010	42.34
25-06-2011	46.06
01-07-2011	46.21
25-07-2012	44.98
01-08-2012	45.11
14-09-2012	51.24
27-10-2012	51.41
18-01-2013	52.09
16-02-2013	52.64
23-03-2013	53.02
11-05-2013	54.21
01-06-2013	54.82
02-07-2013	55.39
01-08-2013	55.49
01-10-2013	56.10
01-10-2013	57.08
01-11-2013	57.69
01-12-2013	58.30
21-12-2013	58.40
04-01-2014	59.01
01-02-2014	59.38
01-03-2014	60.00
13-05-2014	61.33
01-06-2014	61.94
01-07-2014	62.85
01-08-2014	63.46
31-08-2014	64.07
19-10-2014	60.43
01-11-2014	57.94
r	= - 10436 + 5.21 (Year)

Ref:http://www.mypetrolprice.com/6/Diesel-price-in-Bengaluru?FuelType=1&LocationId=6

Appendix -16 Continued

Price of biodiesel feed stock -seed, oil and seed cake for identifying the trend and carry out sensitivyt analysis for biodiesel price in comparision toconventional diesel

	Pongamia Seed Price / kg	**Pongamia Oil Price / kg**	**Pongamia Seed Cake- Price / kg**
2011	13	55	12
2012	15	60	15
2013	16	65	16
2014	18	68	17
r	=-3205+1.60(Year)	=-8793+4.4(Year)	=-3205+1.60(Year)
	Madhuca Seed Price / kg	**Madhuca Oil Price / kg**	**Madhuca Seed Cake Price / kg**
2011	14	75	10
2012	14	85	12
2013	15	85	12
2014	17	88	13
r	=-1998+1(Year)	=-7766+3.9(Year)	=-1800+0.9(Year)
	Azadiractha Seed Price / kg	**Azadiractha Oil Price / kg**	**Azadiractha Seed Cake Price / kg**
2011	15	112	16
2012	16	120	18
2013	18	130	20
2014	20	142	21
r	=-3404+1.7(Year)	=-19999+10(Year)	=-3403+1.7(Year)
	Simarouba Seed Price / kg	**Simarouba Oil Price / kg**	**Simarouba Seed Cake price / kg**
2011	11	37	12
2012	12	40	14
2013	13	42	14
2014	13	42	15
r	= -1397 + 0.7(Year)	= -3381 +1.70 (Year)	- 1798 + 0.9 (Year)

Appendix-17

Research Paper Published

1. Lokesh A. C. and N. S. Mahesh. (2009) 'Strategies for the Sustainability of Bio Diesel Production from Feed Stock in India: A Review'. *Agricultural Engineering International: CIGRE Journal*, 11,1-10 [online] avaiable from www.cigrjournal.org/index.php/Ejounral/article/view/1312/1235

2. Lokesh, A. C., Mahesh, N.S., Gowda Balakrishna, Hall William. (2012). 'Life cycle assessment of biodiesel production from pongamia oil in rural Karnataka'. *Agricultural Engineering Inernational CIGRE Journal*, 14, (3), 67-77 [online] available from http://www.cigrjournal.org/index.php/Ejounral /issue/view/34>

3. Lokesh A. C., N. S. Mahesh, Balakrishna Gowda and Peter White. (2014). 'Study on Sustainabilty of Madhuca Biodiesel'. *SAS TECH Journal*, 13(1), 2014, pp 103 – 114 [online] available from <_msruas.ac.in/pdf_files/Publications/SEG%20Publications%202014.pdf>

4. Lokesh A. C., N. S. Mahesh, Balakrishna Gowda and Peter White. (2014). 'Sustainable biofuel strategy in karnataka state a review' (Conference paper). *Proceedings of the International Conference "Sustainable Energy Use and Management",* Academica Brancusi Publishing House, Târgu-Jiu, Romania, ISBN: 978-973-144-647-9

5. Lokesh A. C., N. S. Mahesh, Balakrishna Gowda and Peter White. (2015). 'Sustainable biofuel strategy in Karnataka state a review' (Extended Paper). *Management of Environmental Quality: An International Journal*, Print Published on 6th March 2015, 26 (2) [online] available from <https://mc. manuscriptcentral.com/meq#refX>

6. Lokesh A.C., N. S. Mahesh, BalakrishnaGowda, Rajesh Kumar K and Peter White. (2015). 'Neem Biodiesel- A Sustainability Study'. Avestia Publishing, *Journal of Biomass to Biofuel.* 2,1-10 [online] available from <http://jbb. avestia.com/2015/001.html>

Appendix-18

Low Risk Research Ethics Approval

UARC Ethics Low Risk Projects 08-09.doc Revision 1.05

Low Risk Research Ethics Approval Checklist

Applicant Details

Name Lokesh. A. C	E-mail lokesh@msrsas.org
Department	Date 14-5-11
Course Ph.D.	Title of Project Studies on Biodiesel Production from Local Tree Species oil and Consequent Ecological Impact in Rural Karnataka

Project Details

Summary of the project in jargon-free language and in not more than 120 words:

- Research Objectives
- Research Design (e.g. Experimental, Desk-based, Theoretical etc)
- Methods of Data Collection

Participants in your research

1. Will the project involve human participants?	Yes	No ✓

If you answered **Yes** to this questions, this may **not** be a low risk project.

- If you are a student, please discuss your project with your Supervisor.
- If you are a member of staff, please discuss your project with your Faculty Research Ethics Leader or use the Medium to High Risk Ethical Approval or NHS or Medical Approval Routes.

Risk to Participants

2. Will the project involve human patients/clients, health professionals, and/or patient (client) data and/or health professional data?	Yes	No ✓
3. Will any invasive physical procedure, including collecting tissue or other samples, be used in the research?	Yes	No ✓
4. Is there a risk of physical discomfort to those taking part?	Yes	No ✓
5. Is there a risk of psychological or emotional distress to those taking part?	Yes	No ✓
6. Is there a risk of challenging the deeply held beliefs of those taking part?	Yes	No ✓
7. Is there a risk that previous, current or proposed criminal or illegal acts will be revealed by those taking part?	Yes	No ✓
8. Will the project involve giving any form of professional, medical or legal advice, either directly or indirectly to those taking part?	Yes	No ✓

If you answered **Yes** to **any** of these questions, this may **not** be a low risk project.

- If you are a student, please discuss your project with your Supervisor.
- If you are a member of staff, please discuss your project with your Faculty Research Ethics Leader or use the Medium to High Risk Ethical Approval or NHS or Medical Approval Routes.

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Risk to Researcher

9. Will this project put you or others at risk of physical harm, injury or death?	Yes	No ✓
10. Will project put you or others at risk of abduction, physical, mental or sexual abuse?	Yes	No ✓
11. Will this project involve participating in acts that may cause psychological or emotional distress to you or to others?	Yes	No ✓
12. Will this project involve observing acts which may cause psychological or emotional distress to you or to others?	Yes	No ✓
13. Will this project involve reading about, listening to or viewing materials that may cause psychological or emotional distress to you or to others?	Yes	No ✓
14. Will this project involve you disclosing personal data to the participants other than your name and the University as your contact and e-mail address?	Yes	No ✓
15. Will this project involve you in unsupervised private discussion with people who are not already known to you?	Yes	No ✓
16. Will this project potentially place you in the situation where you may receive unwelcome media attention?	Yes	No ✓
17. Could the topic or results of this project be seen as illegal or attract the attention of the security services or other agencies?	Yes	No ✓
18. Could the topic or results of this project be viewed as controversial by anyone?	Yes	No ✓

If you answered **Yes** to **any** of these questions, this is **not** a low risk project. Please:

- If you are a student, discuss your project with your Supervisor.
- If you are a member of staff, discuss your project with your Faculty Research Ethics Leader or use the Medium to High Risk Ethical Approval route.

Informed Consent of the Participant

19. Are any of the participants under the age of 18?	Yes	No ✓
20. Are any of the participants unable mentally or physically to give consent?	Yes	No ✓
21. Do you intend to observe the activities of individuals or groups without their knowledge and/or informed consent from each participant (or from his or her parent or guardian)?	Yes	No ✓

If you answered **Yes** to **any** of these questions, this may **not** be a low risk project. Please:

- If you are a student, discuss your project with your Supervisor.
- If you are a member of staff, discuss your project with your Faculty Research Ethics Leader or use the Medium to High Risk Ethical Approval route.

Participant Confidentiality and Data Protection

22. Will the project involve collecting data and information from human participants who will be identifiable in the final report?	Yes	No ✓
23. Will information not already in the public domain about specific individuals or institutions be identifiable through data published or otherwise made available?	Yes	No ✓
24. Do you intend to record, photograph or film individuals or groups without their knowledge or informed consent?	Yes	No ✓
25. Do you intend to use the confidential information, knowledge or trade secrets gathered for any purpose other than this research project?	Yes	No ✓

If you answered **Yes** to **any** of these questions, this may **not** be a low risk project:

- If you are a student, discuss your project with your Supervisor.
- If you are a member of staff, discuss your project with your Faculty Research Ethics Leader or use the Medium to High Risk Ethical Approval or NHS or Medical Approval routes.

Gatekeeper Risk

26. Will this project involve collecting data outside University buildings?	Yes ✓	No
27. Do you intend to collect data in shopping centres or other public places?	Yes	No ✓
28. Do you intend to gather data within nurseries, schools or colleges?	Yes	No ✓
29. Do you intend to gather data within National Health Service premises?	Yes	No ✓

If you answered **Yes** to **any** of these questions, this is **not** a low risk project. Please:

- If you are a student, discuss your project with your Supervisor.
- If you are a member of staff, discuss your project with your Faculty Research Ethics Leader or use the Medium to High Risk Ethical Approval or NHS or Medical Approval routes.

Other Ethical Issues

30. Is there any other risk or issue not covered above that may pose a risk to you or any of the participants?	Yes	No ✓
31. Will any activity associated with this project put you or the participants at an ethical, moral or legal risk?	Yes	No ✓

If you answered **Yes** to these questions, this may **not** be a low risk project. Please:

- If you are a student, discuss your project with your Supervisor.
- If you are a member of staff, discuss your project with your Faculty Research Ethics Leader.

Principal Investigator Certification

If you answered **No** to **all** of the above questions, then you have described a low risk project. Please complete the following declaration to certify your project and keep a copy for your record as you may be asked for this at any time.

Agreed restrictions to project to allow Principal Investigator Certification

Please identify any restrictions to the project, agreed with your Supervisor or Faculty Research Ethics Leader to allow you to sign the Principal Investigator Certification declaration.

Participant Information Leaflet attached. Informed Consent Forms attached.

Principal Investigator's Declaration

Please ensure that you:

- Tick all the boxes below and sign this checklist.
- Students must get their Supervisor to countersign this declaration.

I believe that this project **does not require research ethics approval**. I have completed the checklist and kept a copy for my own records. I realise I may be asked to provide a copy of this checklist at any time.	✓
I confirm that I have answered all relevant questions in this checklist honestly.	✓
I confirm that I will carry out the project in the ways described in this checklist. I will immediately suspend research and request a new ethical approval if the project subsequently changes the information I have given in this checklist.	✓

Signatures

If you submit this checklist and any attachments by e-mail, you should type your name in the signature space. An email attachment sent from your University inbox will be assumed to have been signed electronically.

Principal Investigator

Signed .... (~~Principal Investigator~~ or Student)

Date ....14-5-11..

Students storing this checklist electronically must append to it an email from your Supervisor confirming that they are prepared to make the declaration above and to countersign this checklist. This-email will be taken as an electronic countersignature.

Student's Supervisor

Countersigned .... (Supervisor)

Date ....22/5/11..

I have read this checklist and confirm that it covers all the ethical issues raised by this project fully and frankly. I also confirm that these issues have been discussed with the student and will continue to be reviewed in the course of supervision.