A Life Cycle Assessment on Liquid Biofuel Use in the Transport Sector of Ethiopia

by

Dereje Kebede Abebe

submitted in accordance with the requirements for
the degree of

Master of Science

In the subject

Environmental Management

University of South Africa

Supervisor: Dr. N. Gessese

Co-supervisor: Prof. M. Tekere

June 2013

Student Number: 47203072

I hereby declare that "**A Life Cycle Assessment on Liquid Biofuel Use in the Transport Sector of Ethiopia**" is my own work and that all sources that I have used or quoted have been indicated and acknowledged by means of complete references.

____________________	June 2013
SIGNATURE	DATE

Mr. Dereje Kebede Abebe

Abstract

Seed-oil based biodiesel production particularly biodiesel production from the non-edible oil seed bearing plant - *Jatropha curcas* L. - is a key strategic direction outlined in the biofuels strategy of the Government of Ethiopia. The main objective underlying the strategy include substitution of imported diesel oil used in the road transport sector while at the same time contributing to the local and global greenhouse gasses (GHG) reduction efforts. In this study the environmental benefits and costs of production and use of *Jatropha* biodiesel in the road transport sector of Ethiopia is assessed using a life cycle analysis (LCA) methodology. The analysis focused on determining the potential environmental impacts and net non-renewable energy saving potential of biodiesel from *Jatropha* oil-seeds using the following metrics: (i) Net Greenhouse Gas (GHG) reduction, and (ii) Net Energy Balance (NEB) relative to diesel oil. The study shows that the net GHG emissions reduction potential of *Jatropha* Methyl Ester (JME) is highly influenced by the magnitude of initial carbon loss occurring in the process of conversion of different land uses to *Jatropha* plantation, and less so on other unit processes of JME production system analysed. The NEB of JME relative to use of diesel oil per functional unit of one GJ is less sensitive to impacts of land use change and is generally positive. Where no land use change impacts is considered, or where *Jatropha* is grown on lands with low carbon stock such as grasslands, substitution of diesel oil with JME in Ethiopia can provide GHG emission reduction of about 43%, and for each MJ of JME produced the non-renewable energy requirement will be 0,38 MJ. Production of JME by converting lands with high above ground, below ground and/or soil carbon stocks such as shrub lands or well stocked forest lands will result in net loss of carbon and require ecological carbon payback time of 50 to hundreds of years.

The impact of introducing and use of JME-diesel oil blends by Anbassa City Bus Services Enterprise (ACBSE) bus fleets shows that, displacement of diesel oil with JME that have positive GHG reduction potential, will also contribute to the reduction of air pollutants and improvement of ambient air quality in Addis Ababa. Two key recommendations of this research work are that to ensure environmental sustainability of biodiesel production from *Jatropha* seeds (i) land availability and land suitability assessment for estimating the potential available land for *Jatropha* (and other oil-seed bearing plants) shall be conducted, and (ii) minimum requirements on GHG reduction and NEB requirements on biodiesel shall be established.

Key words: *Jatropha*, Biodiesel, GHG, Net energy balance, Air pollutants, Land use change.

Acknowledgment

I am grateful to my supervisors Dr. Nebiyeleul Gessese and Professor Memory Tekere for the guidance and support they provided me in the course of this work.

With thanks, I acknowledge the financial support that I received from the Austrian Development Cooperation, Coordination Office for Development Cooperation, in Addis Ababa where I am currently working. And, in particularly I would like to express my appreciation to the current Head of Office, Mr. Heinz Habertheuer for his encouragement and support.

My special gratitude goes to my family, brothers and sister for their support and encouragement I received during the course of this work.

Contents

List of Tables

Table of Figures

Acronyms

ACBSE:	Anbessa City Bus Services Enterprise
ASTM:	American Society for Testing and Materials
B5:	A biodiesel-diesel oil blend containing 5% biodiesel and 95% diesel oil by volume.
CEC:	Council for European Commission
CH_4:	Methane Gas
CML:	Centrum voor Milieuwetenschappen (Institute of Environmental Sciences)
CN:	Cetane Number
CO:	Carbon Monoxide
CO_2:	Carbon Dioxide
DEFRA:	**Department for Environment, Food and Rural Affairs, UK.**
DOC:	Diesel Oxidation Catalyst
DPF:	Diesel Particulate Filter
EC:	European Commission
ECPT:	Ecosystem Carbon Payback Time
EIA:	Energy Information Administration / Environmental Impact Assessment
EN:	European National
EPA:	Environmental Protection Authority

EU:	European Union
FAME:	Fatty acid methyl ester
FAO:	Food and Agriculture Organization
FFA:	Free Fatty Acid
FTAE:	Federal Transport Authority of Ethiopia
FU:	Functional Unit
GABi:	Ganzheitlichen Bilanzierung (holistic balancing), LCA Software
GEMIS:	Global Emission Model for Integrated Systems, LCA software
GJ:	Giga Joule
GHG:	Greenhouse Gas
GoE:	Government of Ethiopia
GWP:	Global Worming Potential
HC:	Hydro Carbon
HoAREC:	Horn of Africa Regional Environment Centre
H_2SO_4:	Sulphuric Acid
IEA:	International Energy Agency
IEFU:	Institut für Energie- und Umweltforschung (Institute for Energy and Environmental Research).
IPCC:	Intergovernmental Panel on Climate Change
ISO:	International Standard Organization
JME:	*Jatropha* Methyl Ester

JRC:	Joint Research Centre (of EC)
K:	Potassium
LCA:	Life Cycle Assessment
LHV:	Lower Heating Value
LUC:	Land Use Change
MELCA:	Movement for Ecological Learning and Community Action
MJ:	Mega Joule
MME:	Ministry of Mines and Energy (Ethiopia)
MWE:	Ministry of Water and Energy (Ethiopia)
N:	Nitrogen
NEB:	Net Energy Balance
NER:	Net Energy Ratio
NEV:	Net Energy Value
NEY:	Net Energy Yield
N_2O:	Nitrous Oxide
NOx:	Nitrogen Oxides
NRER:	Non Renewable Energy Requirement
Oeko:	ÖKO-Institute, Institute fur angewandte Ökologie (Institute for Applied Ecology)
P:	Phosphorus
PISCS:	Policy Innovation Systems for Clean Energy Security

PKT: Passenger Kilometre Travelled

PM_{10}; $PM_{2,5}$: Particulate Matter of Aerodynamic Diameter of 10 and 2,5 micro meter, respectively

SETAC: Society of Environmental Toxicology and Chemistry

SOC: Soil Organic Carbon

SOx Sulphur Oxides

SVO: Straight Vegetable Oil

TWC: Three- Way Auto Catalyst

UNEP: United Nations Environment Protection

USD: United States (of America) Dollar

US-EPA: Environmental Protection Agency of USA

VKT: Vehicle Kilometre Travelled

1 Introduction

Biofuels (biodiesel and ethanol) have attracted considerable interest and investment in both developed and developing countries by virtue of being renewable energy sources and having high potential as substitute to petroleum fuel. For developed countries, the key argument used in increased production and use of biofuels are energy security, their potential for reducing Greenhouse Gas (GHG) emissions and hence contribution to climate change mitigation efforts, and support to rural development both in their own countries and the global south (CEC, 2006). For developing countries that have little or no oil production, the major drivers are the potential that biofuels have in reducing petroleum fuels import bill as well as the possibilities of exporting biofuels to developed countries.

The major target for biofuels development both in developed and developing countries is the transport sector. Globally, the transport sector accounts for over 70% of the petroleum fuel consumed and contribute to about 23% of the energy related CO_2 emissions (IEA, 2008). Considering current development trends, the actual magnitude of emission from this sector is expected to increase with the expansion of motorised transportation services (IEA, 2008). The directives of the Council of European Commission (CEC, 2009) which was issued to address concerns regarding possible pitfalls with regard to GHG reductions, states that biofuels used to displace petroleum fuel should have a net GHG reduction of 35% by 2011 and 50% beyond 2015. The implication of this directive is clear – countries that produce biofuels for export have to meet this criterion.

In Ethiopia, the transport sector is also the single most important sector that relies on imported petroleum fuel. Within a ten-year period (2000 to 2010) the annual consumption of petroleum fuels in Ethiopia has almost doubled, reaching 2 million metric tons (NBE, 2011). The rate of increase in volumes of petroleum fuels import has been considerably more significant in the last five years and seems to be consistent with increased economic activities (NBE, 2011). In 2005/6, Ethiopia spent over USD 856 million (equivalent to 86% of its export earning) for importing petroleum fuels; by 2008 the cost had increased to USD 1,6 billion and exceeded the corresponding year export earnings by 10% (NBE, 2009). Information on petroleum fuel prices shows that prices escalated from 50 USD/barrel crude oil in 2005 to over 100 USD/barrel in 2011 (EIA, 2011).

Increasing volume of petroleum fuel import coupled with increased price of petroleum has been severely taxing the foreign currency earnings of developing countries like Ethiopia and is one of the major factors that have attracted the interest of the Government of Ethiopia to consider biofuel use in the transport sector. In terms of product, diesel oil accounts for over 50% of the total volume of petroleum fuels imported to Ethiopia, and almost all of the diesel oil is used in the road transport sector. Interest in local production and use of biofuels such as biodiesel is therefore understandably focused on at least partial substitution of diesel oil in the road transport sector.

The Government of Ethiopia (GoE) released its first Biofuels Development and Use Strategy in September 2007 (MME, 2007). The three objectives of the strategy are: (i) to produce sufficient amount of plant based biofuels for substituting imported petroleum fuels, (ii) to export biofuels to other (mainly developed) countries to earn foreign currency while contributing to the global GHG reduction efforts and (iii) to contribute to agriculture based rural development of the country.

GoE's biofuels strategy underpins that in achieving these objectives the development of biofuels will not compete with food production or use land suitable for crop production (MME, 2007). It states that mainly '*marginal*' and '*degraded*[1]' lands will be used to produce feedstock suitable for production of biodiesel. One of the plants positively emphasized in the document is *Jatropha curcas* L. (*Jatropha*). As stated in the strategy document, *Jatropha* requires relatively fewer inputs to establish and produce good amount of seeds, and helps reclaim degraded land. The strategy document put total land areas suitable for *Jatropha* plantation at 23,3 million hectares but this estimates leaves ambiguity as to what proportion is degraded or marginal, and what proportion is already being used by the local people for purposes other than food crop production. The Ethiopian biofuels development and use strategy has attracted both international and local investors. These investors have acquired large tracts of land that are not marginal, and this may result in land-use change which in effect could defeat the stated environmental objectives (MELCA, 2008)[2]. Little is known about the overall economic, environmental and social costs and benefits of such shifts to advise planners and policy makers.

Life Cycle Assessment (LCA), as well as other material flow models, are being increasingly used in various industrial sectors and at different decision-making levels in order to seek out environmentally friendly solutions to industrial production involved in the production of biodiesel and ethanol (CEC, 2009; DEFRA, 2008). LCA has emerged

---

[1]However, the strategy document does not define the term "Degraded" or "Marginal" land, and this leaves ambiguity as to what constitutes degraded or marginal lands. Citing various sources, an issue paper on "Degraded Land and Sustainable Bioenergy Feedstock Production" (OeKo, 2008), provided the following definitions for the term marginal land - "Marginal land is defined as an area where a cost-effective production is not possible under given site conditions (e.g. soil productivity, cultivation techniques, agriculture policies as well as macro-economic and legal conditions). It further describes the term marginal land as "an economic term which may not factor in subsistence agriculture", and noted that such land might supply fuelwood, feed materials and medicine to the local peoples. It defines land degradation "as a long-term loss of ecosystem function and services, caused by disturbances from which the system cannot recover unaided and as such the term degraded land is related to the land-productivity potential."

[2] A summary of the stus of biodiesl development in Ethiopia is presented in Annex E.

as a key approach among a set of "second generation" analytical tools for understanding the overall environmental consequences of production to consumption activities. In its simplest form, LCA is an input-output material balance model, which follows a product or a system during its entire life, i.e. from "cradle to grave". The cradle is the point where a raw material is taken from its natural environment, and the grave is where the product or its component are returned to the natural environment as waste or recycled for further use.

As suggested by Europe's Society of Environmental Toxicology and Chemistry (SETAC) (UNEP, 2005), LCA incorporates a number of distinct steps. Firstly, there is goal definition and determination of scope, followed by life cycle inventory. In the inventory phase all material and energy inputs and outputs, effluents and emissions produced by a product within various system boundaries and established on a case-by-case basis, are quantified and calculated (CML, 2001; UNEP, 2005). This inventory serves as the basis for the life cycle impact assessment in the subsequent phase of the analysis. Here the different types of environmental impacts generated at different points over a certain product's life cycle are estimated, classified and characterized according to different types of environmental problems, such as acidification, depletion of stratospheric ozone, eutrophication, photochemical-oxidant formation, eco-toxicology, and global warming. This phase is then followed by an improvement assessment where environmental, technical and economic improvements during the life cycle are suggested (UNEP, 2003). The environmental damage caused by the various environmental impacts (identified in the first four phases described above) on human health, eco-system, resources, and biodiversity is converted into monetary value using weighing factors to calculate environmental load units of products.

In this study the major focus will be assessment of the environmental benefits and costs of production and use of *Jatropha* biodiesel in the road transport sector of Ethiopia by applying LCA methodology. In particular, focus will be made on assessment of two key metrics - net GHG reduction and Net Energy Balance (NEB) - with the objective to assess the environmental benefits of biodiesel production for substitution of transport diesel oil. Several studies (for example; Achten *et al*., 2010; Prueksakorn *et al.*, 2010; Whitaker and Heath 2010; Mortimer, 2011) employed these metrics for assessing net GHG emission reduction and NEB of *Jatropha* biodiesel in developing countries. The specific methods used and findings of these studies are included under the literature review section of this proposal. The choice of net GHG emission reduction and NEB will allow identification of major parameters with significant influence on the environmental viability of *Jatropha* biodiesel production in Ethiopia and help to inform the biofuels development policy making and review processes.

1.1 Problem statement and rational

1.1.1 Statement of the Problem

Proponents characterise *Jatropha* as a resilient plant which grows well on and improves degraded and marginal lands with potential seed yield of up to 12 tons per hectare per year. However, several studies caution against the assertion that *Jatropha* requires very little or no inputs to grow and yields good amount of and quality seeds (Jongschaap *et al.*, 2007; FAO, 2008; FAO and PISCS, 2009). Likewise, Achten *et al.* (2010) and Jongschaap *et al.* (2007), argue that *Jatropha* yield from marginal or degraded land, unless supplemented with irrigation water and fertilizer, at best will also be marginal and may not be economical. The literature also indicates that the GHG balance (or net GHG emission reduction) and the net energy balance (energy of biofuels produced less the fossil energy input used) – the two major factor driving biofuels development - differ significantly and are not necessarily always positive. Differences may arise from location of production site and end-uses of the plant oil, or due to difference in agricultural practices employed (Jongschaap *et al*., 2007).

The actual environmental and economic benefit of *Jatropha* based oil production will depend on several local (e.g., land productivity) and international factors (price of petroleum fuels) and cannot be presumed to be always positive. Factors affecting the degree of the environmental and economic sustainability of production and use of *Jatropha* oil will be determined by a number of factors including seed yield per hectare, and agricultural input requirements (irrigation water, fertilizer, chemicals, etc.). Where *Jatropha* plantations are established on lands with significant above ground and below ground carbon stock as well as land with high soil carbon content, a significant carbon debt is expected to occur (Fargione *et al*., 2008; Mortimer, 2011).

Difference in agricultural practices and land-use change, as well as production inputs in the downstream production chain of *Jatropha* oil (transportation of seed and oil, extraction of oil and biodiesel production) influence whether the whole production system could provide significant environmental benefit in terms of GHG reduction and reduction in petroleum fuel consumption.

It is, therefore, necessary to assess and understand the major local factors influencing the environmental benefits and the potential for sustainable production and use of *Jatropha* biodiesel in Ethiopia. In particular, it is necessary to address net GHG emission reduction and NEB resulting from substitution of diesel oil with *Jatropha* biodiesel over its entire lifecycle. It is also important to investigate the implication on the extent of land area requirements for producing the volume of biodiesel required for blending with projected diesel oil demand.

1.1.2 The rationale

The promotion of *Jatropha* as having high potential to improve the country's energy security while at the same time providing environmental and rural economic benefits is still based on claims but field level data are lacking to substantiate or refute these claims. Large-scale development based on claims could be misleading and should be assessed using available knowledge and research outputs on production and use of *Jatropha* oil. To help avoid possible negative environmental impacts and other pitfalls, it is important to conduct realistic assessment on the energy security and environmental advantages of local development and use of *Jatropha* biodiesel in Ethiopia. To the knowledge of the researcher, though similar studies have been done elsewhere (e.g. Achten *et al*., 2010; Mortimer, 2011), no such studies have been conducted in Ethiopia.

1.2 Research objectives and questions

The objective of this research work was to evaluate the GHG emission reduction potential and NEB of *Jatropha* biodiesel thus contributing towards better understanding of major factors that influence the life cycle environmental impacts of *Jatropha* biodiesel production and use in Ethiopia.

The specific objectives of the research work were to:

(i) examine the environmental and economic benefits of using *Jatropha* biodiesel for partial substitution of diesel oil used in the transport sector using the commonly used indicators - the net energy balance, and the relative GHG emission reduction of biodiesel over the fossil energy input used to produce it (Jackson, 1993), and by estimating the carbon debt (or credit) resulting from land use changes (LUC) occurring due to cultivation of *Jatropha*[3], and

(ii) based on results of the research work (including GHG emission reduction potential and net energy balance of *Jatropha* biodiesel production in Ethiopia), propose specific sustainability criteria to be considered by GoE to help avoid and/or minimise impact of land use change and, improve petroleum fuels displacement potential of *Jatropha* biodiesel.

The use of biodiesel in the Addis Ababa public transportation systems will be considered as a specific case study.

1.3 Study hypothesis

The hypothesis of the research is that local production of *Jatropha* biodiesel provides a significant potential for substitution of diesel oil and for reducing GHG emissions in the transport sectors of Ethiopia.

[3]Reductions in GHG emissions and NEB are the two major environmental and resource use parameters to be analysed. GHGs emission reduction is estimated as the net reduction of emissions (in CO_2 equivalent) resulting from substitution of *Jatropha* biodiesel for diesel oil, and NEB is computed as the difference of the net biodiesel energy produced less net energy of fossil fuels (or non-renewable energy) used for its production while delivering the same level of service or useful energy.

2 Literature review

The literature review work mainly focuses on the agronomy of *Jatropha* and seed yield potentials, processes involved in biodiesel production for *Jatropha* seed and the potential uses, and assessing metrics that are appropriate and widely employed for comparative assessment of use of biodiesel as a substitute to diesel oil.

2.1 Botanical description of *Jatropha curcas* L.

Jatropha curcas L. (*Jatropha*) is described as a plant that is well adapted to soils with poor nutrients or lands that are categorised as land that are *marginal or degraded.* Generally this is defined as land not suitable for crop production (OeKo, 2008a). *Jatropha* is a small tree that grows to about 5 meters, sheds its leaves during dry season, and adapts well to arid and semi-arid conditions (Heller, 1996). Achten (2010) reported that in marginal or degraded lands, planting *Jatropha* will help to restore soil fertility and increase both soil and above ground carbon. He provided an estimate of carbon sequestration rate of 2,25 ton CO_2/ha-yr in the standing biomass of *Jatropha* plantation – a figure which is estimated to be higher than the rate of carbon sequestration in marginal/wet lands, but significantly lower than dry forests.

2.2 *Jatropha* cultivation and seed yield

Reported seed yield from *Jatropha* (plantations) vary from as low as 0,2 to 0,8 ton/ha-yr in Cape Verde, to 8 ton/ha-yr in Mali (Heller, 1996). Heller (1996) also indicated that in most of the reports providing yield figures, information on the age of trees and methods of plant propagation are not available rendering these figures less useful for further policy analysis and investment decisions. He estimates that at least 2-3 ton of seeds/ha-yr can be achieved in semi-arid areas, and that reported crude fat content of the seed ranges from 28,4 to 42,3%. In India reported yield figures for an experimental *Jatropha* plantation on marginal soils ranges from 0,6 to 1,4 ton seed/ha-yr for a 2,5 year old plantation, and for a rain fed *Jatropha* plantation on a marginal land reported yield was 3,2 to 4,1 ton seed/ha-yr. (Jongschaap *et al.*, 2007).

Early proponents, as way of promoting *Jatropha*, have used a combination of good characteristics - notably high adaptability of the tree to degraded lands and dry climate with high seed and oil yield figures (Euler and Gorriz, 2004)[4]. This however is hardly backed with evidence, or supported with scientific studies (Jongschaap *et al.*, 2007). The International Fund for Agricultural Development (IFAD, 2010) states that many investments (or investment proposals), and governments and company policy decisions, promoting the development of *Jatropha* are not backed with sufficient scientific knowledge and argues that identifying the actual potential of the plant from what is claimed is an essential first step. Seed yield per hectare cannot be the same for degraded lands and for land with adequate nutrients and moisture, or from degraded lands that are irrigated and soil nutrient is supplemented by application of chemical or biological fertilisers.

Analysing the locations of herbarium specimens and plantations of *Jatropha curcas L.* Maes *et al*. (2009) observed that *Jatropha* is mostly found in temperate climates that have hot summer but no dry season. Only few were found in semi-arid and none in arid climates, and that ninety-five present of the specimens analysed grew in areas with a

[4] Euler and Gorriz, (2004, p 3) states that "Results of past *Jatropha* projects in Nicaragua, Belize and India in terms of actual economic, social and environmental effects have been mostly not noticeable, poor and disastrous. They were more projection than reality driven."

mean annual rainfall above 944 mm per year and mean annual temperature of 19,3–27,2 ^{o}C. They argued that the observed precipitation preferences shows that *Jatropha* is not common in arid and semi-arid climates and seed yield from plantations established in these areas would be generally low. Francis *et al.* (2005) reported that to get higher yields (up to 5 ton seed per ha) 900 to 1200 mm of water is needed.

Based on the comprehensive information they collected and analysed, Jongschaap *et al.* (2007) reported seed yield figures from different countries and institutions. Jongschaap *et al.* (2007) argue that the high yield figures could only be attained in good soils with good moisture level or in marginal land that is irrigated and supplemented with fertilizers (chemical, biological or a combination). In marginal lands with poor soil nutrient and inadequate moisture availability, potential yields are expected to fall in the lower range and the upper range will be most applicable to land with good soil moisture content and soil nutrients.

2.3 Water and nutrient requirement

2.3.1 Water use efficiency

A study by Kheira and Atta (2009) in Egypt showed irrigation water requirement of 6 l per tree per week for a growing period 30 weeks per year (development, flowering, and harvesting). This is equivalent to irrigation water demand of 450 m^3 (45 mm) per ha-yr.

Achten (2010) referring to an Indian case, estimated additional irrigation requirement of 1,5 mm or 15 m^3 per ha-yr for *Jatropha* plantation providing 1,7 ton seed per ha-yr at tree density of 2599 tree/ha. IFEU (2008) based on studies conducted in India estimated irrigation water requirement of 333 m^3 per ha per year (33 mm) for a plantation with tree density of 1677 for potential seed yield ranging from 1,42 to 2,38 to 4,4 ton per ha per year, and suggest that this irrigation water shall be provided at least for the first three years.

Gerbens-Leenes *et al*. (2009) estimated that water requirement (water foot print) for *Jatropha* biodiesel, on the average, is 20 m^3/l of *Jatropha* Methyl Ester (JME) (the corresponding figure for soy bean or rape seed biodiesel is 14 m^3/l). However Jongschaap *et al*. (2009) argued that, if actual water use with actual yield is compared, the water use of JME would be much lower than estimated by Gerbens-Leenes *et al.* (2009), and using data from a study conducted in South Africa (Gush, 2007)[5] the water use was put at 8,28 m^3/l JME.

Everson *et al*. (2012) investigating the water use dynamics of *Jatropha curcas* plant established in Ukulinga, an area with warm and hot summer and mild winter having mean annual temperature of 18,4 ^{o}C and receiving an average of 680 mm over 106 rain days. Their findings show that the average daily total water use by two year old *Jatropha* plants during a clear hot days in summer (December to February) was 3-4 mm/day while during winter (May to August when the plant shades it leaves), the water use was quite negligible, less than 1 mm/day. However the seed yield was also low with best seed yield reported being 348,8 kg/ha. It appears that based on this data[6] the annual max water demand was about 26 mm (or 260 m^3/ha-yr) and giving a water use efficiency of about 800 m^3/ton seed.

[5] In Water Use Aassessment of *Jatropha curcas*. J*atropha curcas* in South Africa: An Assessment of Its Water Use and bio-physical potential, eds. Holl M, Gush MB, Hallowes J, Versfeld DB.

[6] Estimated by assuming 1 mm per day water demand for the four months (May-August) and an average of 3 mm per day for the rest of the year.

2.3.2 Nutrient inputs

Considering that *Jatropha* plantations will be established on land that are considered marginal or of low productivity, continuous nutrient replenishment of the soil from decomposition of organic material or mineralization of the soil is expected to be minimal (Jongschaap *et al*., 2007).Where biomass from pruning of *Jatropha* trees will remain on the field but the whole fruit is removed and no process residue is returned back, the annual loss of major nutrient per ton of fruit was found to be 17,3 kg N, 7,9 kg P and 14,8 kg K, Table B.10, Annex B (Jongschaap *et al*., 2007; IFEU, 2008). Since *Jatropha* is not a nitrogen fixing plant, maintaining the soil fertility will demand application of adequate amounts of synthetic (or readily available organic) fertilizers[7].

2.4 Biodiesel production from *Jatropha* oilseeds

The major processes in the production of biodiesel production from seed oils include extraction of the oil from the seeds, filtration and purification of the crude oil to produce pure or refined oil. Most vegetable oils including seed oil of *Jatropha* have properties that area not suitable for direct use in and substitution of diesel oil in internal combustion (IC) engine used in transport. *Jatropha* oil has lower ignition temperature (flash point) than diesel oil and therefore can easily be ignited and become a fire risk. It also has lower heating (calorific) value (8-10% less than diesel oil), and these properties makes the oil of lower standard than diesel oil. Jatropha seed oil is therefore further processed to improve its properties using commercially available biodiesel production technologies.

[7] This assumption is based on a general argument that if feedstock shall be grown on marginal or degraded land to maintain or achieve acceptable seed yield level, nutrients up-take for plant growth and removed due to seed removal shall be replenished (Jongschaap et al., 2007).

2.4.1 Oil extraction and oil properties

Extraction of oil from *Jatropha* seeds can be done either by mechanical or solvent extraction methods[8]. The most common methods employed is extraction of oil by means of mechanical pressing (extrusion) of oil seeds as they are generally economical for small to medium scale oil pressing units. Oil presses with capacity ranging from tens of kg seed per hour to over a ton of seed per hour are commercially available (FACT, 2009). A schematic flow diagram of *Jatropha* oil production process is shown in Figure 1.

Henning (2000) as cited by Achten (2010, p 20) stated that the efficiency of oil extraction from engine driven mechanical pressing are in the range of 75 to 80% and generally the higher efficiency is achieved with two to three passes. Cooking the seed before mechanical extraction increases the efficiency to 89% (single pass) and to 91% with two passes (Beerens, 2007). Improvement in extraction efficiency however could be improved when the oil seeds are treated with steam before being pressed. Mechanically pressed seed produce oil with fines and this and any other impurities shall be removed before the oil can be used as feedstock in the production of biodiesel. Oil refining is commonly done using close filters. The whole process of pure *Jatropha* oil production (mechanical oil extraction and filtration) consumes 0,5 kWh/kg of pure oil produced (IFEU, 2008). On average pure *Jatropha* oil production would be in the range of 300-320 tons per ton of seed pressed (Achten, 2010).

Achten *et al*. (2010) indicated that the composition and pyisco-chemical characteristics of oil from oil seeds are influenced by environmental and genetic factors. The suitability and

[8] The solvent extraction process has oil extraction efficiency of over 95% and use hexane as a solvent to extract the oil from the seed. Solvent extraction process requires that the seed is initially crushed to pieces so that the oil in the seed is better exposed and dissolves into the solvent. The mixture containing dissolved oil and the hexane soaked crushed seed is passed first through an extractor that separates the crushed seed from the Hexane-oil mixture. Following this step the solvent-oil mixture passes through a steam heated stripper which separates the oil from the solvent. This process is not commonly used, particularly, in small to medium scale biodiesel units as the energy requirement and processes involved are more sophisticated.

cost of production of biodiesel is influenced by feedstock quality of which Free Fatty Acid (FFA), moisture and chemical that reduces the quality and yield of biodiesel.

Studies has reported FFA values ranging from 3,4% to values as low as 1,96% reported in as study conducted on seeds collected from 24 locations within India and a sample from Mozambique (Parthiban *et al*, 2011). Kinfu (2008) analysed the content of FFA and other characteristics of seed oil extracted from *Jatropha curcas L*. seeds collected in Ethiopia and reported a value of 1,97% wt. For *Jatropha* they reported FFA content of 0,18 to 3,40% wt. FFA and other pysico-chemical characteristics of *Jatropha* seed oil with significant bearing on the production of biodiesel are shown in Table 1.

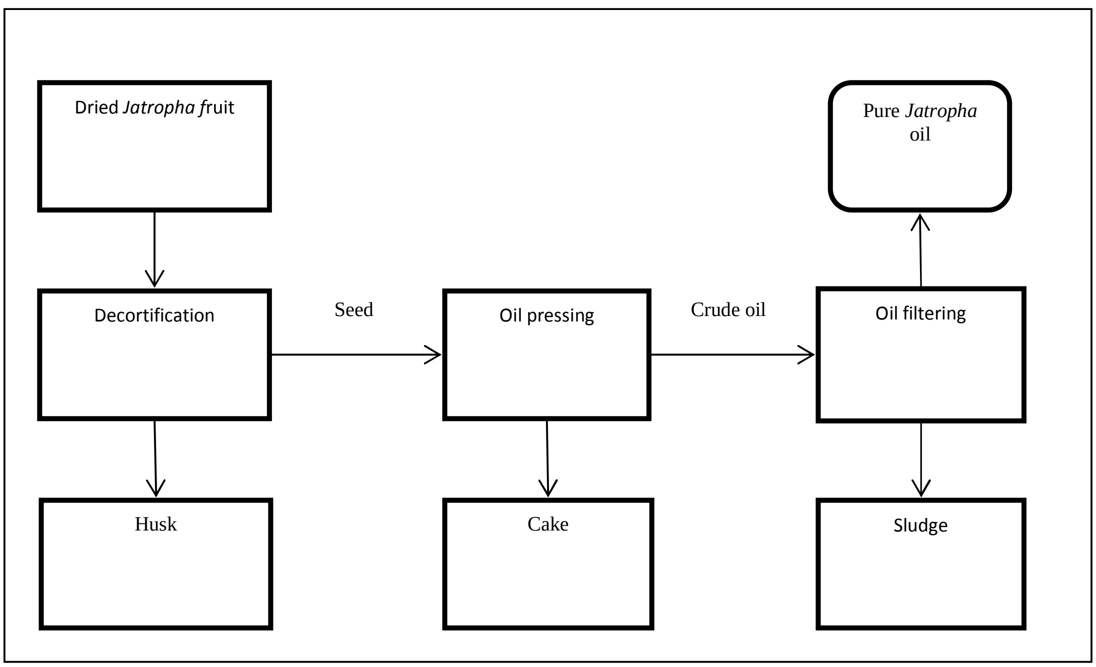

Figure 1. Schematic flow diagram of *Jatropha* oil production process.

Table 1. ***Jatropha*** **oil composition and characteristics**

	Unit	**Kinfu** ***(2008)***	**Achten** ***(2010) (mean)***	**Sanford** ***et al.*** ***(2009)***	***Parthiban et al (2011)***
Specific gravity/relative density	(g/cm³)	0,900	0,860 – 0,933 (0,914)		0,9105
Cetane number			38,0 -51,0 (46,3)		48,79
Calorific value	(MJ/kg)		37,83 – 42,07 (39,63)		
Kinematic viscosity	30°C (cSt)	19,74 (40°C)*	37,00 – 54,82 (46,82) (30°C)	33,90 (40°C)	
Free fatty acids	% wt	0,178	0,18 – 3,40 (2,18)	1,17	2,43
Iodine number		95,24 (gI_2/100g) check	92 – 114 (101) (mg iodine/g)		111,82
Acid number	(mg KOH/g)		0,92 – 6,18 (3,71)		4,83
Sulphur content			0 – 0,13 (% wt)	3,5 (ppm)	

Source: Kinfu (2008); Achten (2010); Sanford *et al*. (2009); Parthiban *et al* (2011).

2.4.2 Biodiesel production processes

The most common methods used for conversion of plant oils involve the reaction of plant oil with alcohols in the presence of a catalyst. The choice and appropriateness of a particular process used for production of biodiesel is influenced by the quality of feedstock. Most important qualities of the plant oil that influence the choice of biodiesel production process is the level of FFA, water and insoluble matters contents (Mosser, 2009). While the moisture and insoluble contaminant contents of feedstock can be lowered by filtration and purification processes (involving chemical treatment) the reduction of FFA content through such process is expensive as compared to esterification (or pre-transesterification process discussed below) (Major et al, 2009). Figure 2 presents a schematic flow diagram of biodiesel production process and Table 2 yield of biodiesel from Jatropha oil with different FFA.

Plant oil with FFA less than 3% (w/w) and low moisture (<0,1 %w/w) and contaminates such as phosphides (<15 ppm) can generally be converted to biodiesel production using alkyl-based transesterification reaction (Moser, 2009). In this process a base catalyst (sodium or potassium hydroxide) and methanol (or ethanol) are used to convert pure *Jatropha* oil to either Methyl alkyl esters (or Ethyl alkyl esters[9]) or biodiesel, as it is commonly known.

Direct transesterification of plant oils containing high FFA (>3% w/w) with commonly used base-catalyst and methanol will result in the formation of soaps (sodium salts) and water which effectively retard the reaction and results in very low yield and poor quality biodiesel (Major *et al*., 2009). Reduction in FFA content and other undesirable substances can be achieved with filtration and additional chemical inputs but this process usually further increases the cost of feedstock and reduces the financial variability of biodiesel fuels (Mosser, 2009).

[9] The uses of ethanol in transesterification process generally increases the renewability of the biodiesel in as much as the ethanol is produced with low amount of non-renewable (fossil fuel) inputs, as compared to use of methanol which is commercially produced using fossil fuels (notably natural gas). However, the reaction process of ethnaolysis which use ethanol fuel with base catalysts such as sodium or potassium hydroxides, is slower than is achieved using methnolysis, and the emulsion (products of reaction) is more stable making it difficult to separate the Fatty Acid Alkyl Ester (FAEE) and glycerol. In the case of methanolyis the emulsion due to phase difference is separated into an upper layer reach in Fatty Acid Methyl Ester (FAME) and a lower part rich in glycerol, and therefore these two co-products are easily separated (Moser, 2009).

Currently, to increase both yield and quality of biodiesel produced from high FFA feedstock, most commercial processes include an additional step called esterification. In this step the oil is esterified using acid catalysts (commonly H_2SO_4, or HCI) in the presence of excess amount of methanol. This process effectively converts the FFA to fatty acid methyl ester (FAME) and lowers the residual FFA to below 1% w/w, rendering the oil suitable for production of biodiesel using transesterification, and such process can achieve an overall biodiesel production efficiency of over 95% from pure *Jatropha* oil having FFA content of >3%. By-products of these processes include glycerine (5% of *Jatropha* oil input) and other by-products such as K_2OH.

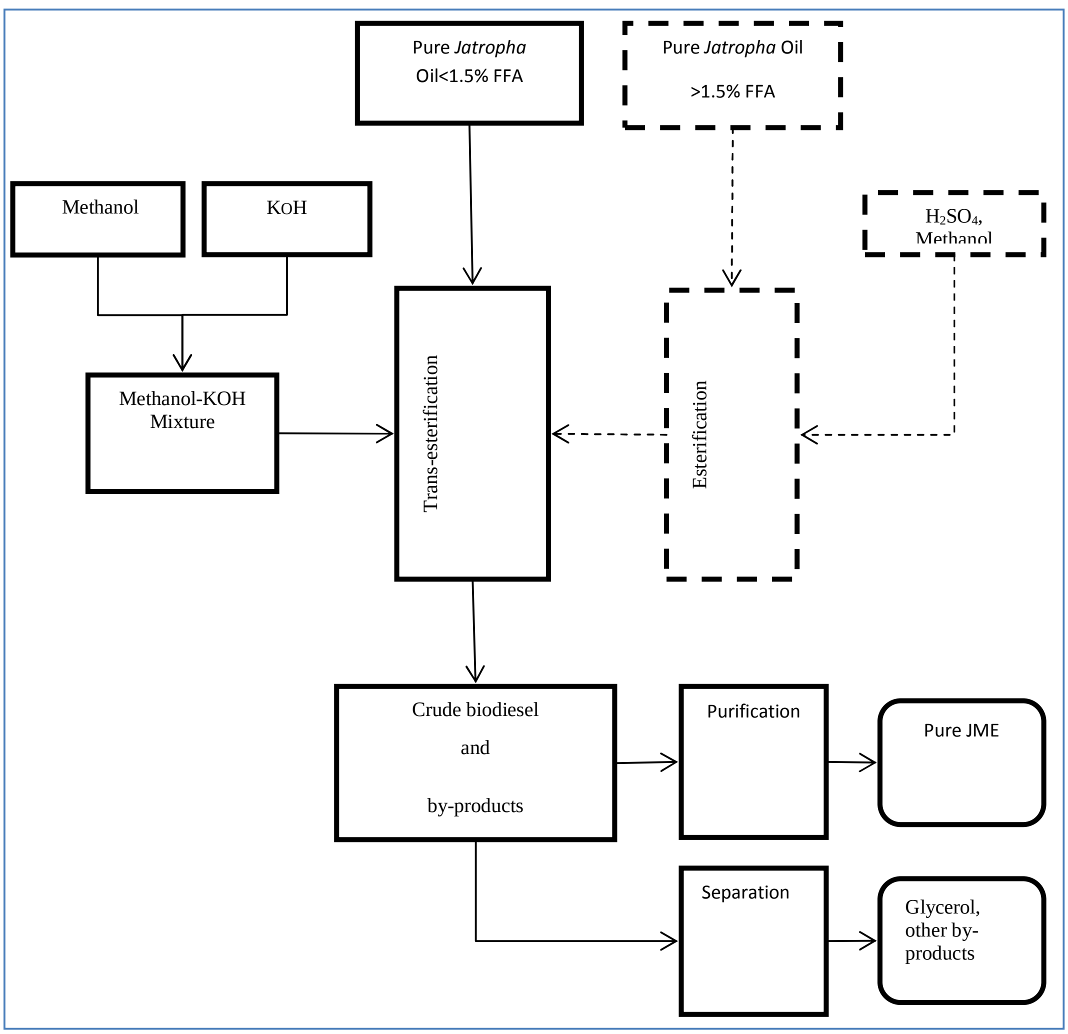

Figure 2. Schematic flow diagram of biodiesel production process.

Table 2. Biodiesel production from *Jatropha* oilseed of various FFA content.

FFA-content	*Processes / temp*	*Catalyst (%)*	*Alcohol (%)*	*Yield*	**Ref.**
15% w/w	Transesterification (65^oC)	NaOH (1% wt)	Methanol (28%w/w)	55% wt	(1)
15 % w/w	Esterification (65^oC)	H_2SO_4 (1% w/w	Methanol (6%w/w)	90% wt	
	Transesterification (65^oC)	NaOH (1.4 %w/w)	Methanol (24 %w/w)		
5.23% w/w	Transesterification (65^oC)	NaOH (1% wt)	Methanol (6:1 molar ratio)	92% wt	(2)
8.8% w/w	Transesterification (65^oC)	NaOH (1% wt)	Methanol (6:1 molar ratio)	76% wt	
8.8% w/w	Transesterification (70^oC)	KOH (1% wt)	Ethanol (8:1 molar ratio)	76% wt	

[1]Berchmans and Hirata (2008); [2] Kywe and Oo (2009).

2.4.3 Characteristics of *Jatropha* biodiesel and biodiesel standards

Studies by Kywe and Oo. (2009), and Berchmans and Hirata (2008) have demonstrated that employing a two-step process, that is esterification followed by transesterification – *Jatropha* oil with high FFA content (>3%) could be effectively converted to biodiesel with physical and chemical properties that are similar (and in some areas superior) to diesel oil.

The positive physical and chemical properties of biodiesel are mainly attributed to the higher Cetane Number (CN) and lubricity exhibited by most biodiesel fuels including JME. The physico-chemical properties of JME or *Jatropha* biodiesel in general, and ASTM and EU standards for diesel oil are shown in Table 3.

The CN is an important property of fuels used in diesel engines and indicates the speed at which the fuel injected into a diesel engine will auto ignite; hence requires short ignition delay. In USA, ASTM standard for conventional diesel fuel is set at minimum CN of 40 (ASTM D6751). For biodiesel ASTM D6751 sets a minimum of CN of 47, and in Europe the corresponding minimum CN for biodiesel is 51 (EN14214) and detailed specifications are presented in the Biodiesel Handbook by Gerhard *et al*. (2005). The CN of most biofuels is higher than diesel, and for JME reported CN values range from 50 to 56, with mean CN of 52,3 (Atchen, 2010). Generally higher CN is reported to have a positive influence and help reduce NOx emissions, and this property improves in reduction of NOx for older engines (vehicles) by reducing the ignition delay time.

Using the mean calorific (heating) value of data provided in Achten (2010), 39,65 MJ/kg (Table 3, below), it could be shown that the lower heating values (LHV) of JME is only about 7% lower than diesel oil (42,6 MJ/kg). Due to the higher relative density of JME (mean value of 0,875) compared to diesel oil (0,832), the volumetric energy content of JME (MJ/l) will be about 3% lower. Since in operation the same volume of fuel will be injected, expected power loss will be 3%. However actual engine test conducted using JME showed no loss in power (Gerhard *et al*. 2005).

Lubricity of fuel is important as it reduces engine wear. The introduction of low sulphur diesel oil has helped reduce tail pipe emission of sulphur compounds; low sulphur diesel has very low lubricity. Addition of 1 to 2% biodiesel will improve the lubricity of low-lubricity fuels to an acceptable level (Moser, 2009; Gerhard *et al.*, 2005)

Viscosity figures provide a measure of the degree of resistance to flow of a liquid and have bearing on the atomization of a fuel when injected. Higher viscosity fuel will be difficult to inject and are also causes of engine deposits (Gerhard *et al*., 2005).The viscosity of J-biodiesel, 4,84 - 5,65 mm^2/s, is generally higher than viscosity ranges of diesel oil (1,9–4,1 mm^2/s) ASTM, and 2,0–4,5 mm^2/s in the European diesel standard. However, with blends up to 20% JME, the viscosity of the blend will fall within ranges of both ATME and EN fuel standards.

Table 3. *Jatropha* biodiesel (JME) composition and characteristics

Parameters	Unit	Atchen (2010) (mean)	Kinfu (2008)	ASTM[1] D6751	EN[1] 14214
Specific gravity	(g/cm³)	0,864 - 0,880 (0,870)	O,8779	NS	0,860-0,900
Calorific value	(MJ/kg)	38,45 - 41, 00 (39,65)+	38,71#	NS	NS
Cetane number		50,0 - 56,1 (52,3)	53,41	47	51
Viscosity	(cSt = mm^2/s)	4,84 - 5,65 (30°C)	3,7* (40°C)	1,6-6,0 (40oC)	3,5-5,0
Iodine number	(g I_2/100g)	93 – 106	95,24	NS	120
Acid number	(mg KOH/g)	0,06 - 0,5 (0,27)	0,338	0,8 max	0,5
Sulphur content	% wt	0,0036	NA	0,0015	0,001

[1]**Source:** Gerhard *et al*. (2005).

NS: not specified in standards; NA: data not available.

2.5 Application of *Jatropha* biodiesel

Biodiesel that meets set standards can be used for fuelling compression ignition engines currently used in road transport (ASTM D6751, USA, EN 14214, Europe). The ASTM standard covers 100% or neat biodiesel (B100), or blends of 20% biodiesel with 80% diesel oil by volume (B20). Presently most common blends used are B2 and B5, although most engines can run on B20 without requiring engine or fuel system modifications or with negligible loss of power or efficiency, while trucks and vehicles with the necessary adaptation (fuel systems, and engine adjustment) can run on neat biodiesel (Gerhard *et al.* 2005).

2.6 Impacts of *Jatropha* biodiesel production and use

Sustainability issues are better addressed using life cycle assessment (LCA) methodology (EC, 2010). LCA is used by several authors to make comparative assessment of biofuels with petroleum fuel (IEFU, 2007; Achten *et al*., 2010; Whitaker and Heath, 2010). The International Standard Organization (ISO - 14040), defines LCA as the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle". One of the most common and important applications of LCA is its use for environmental comparison of products as proposed in this study. However, within the frame work of LCA, different metrics can be used to compare biofuels and other conventional fuels.

Two important and commonly used indicators of the environmental and economic benefits of biofuels are the net energy balance or ratio, and the relative GHG emission reduction of a renewable fuel product over the fossil energy input used to produce it (Jackson, 1993; Whitaker and Heath, 2010).

In its simplest form the NEB is the difference in the amount of energy of biofuels produced less the amount of primary energy used in the production process. The net energy ratio (NER) is described as the ratio of energy output to energy input. Both metrics may consider only energy of the primary product of the systems (e.g. biofuels) to direct energy inputs used in the process (fossil fuels). A more comprehensive assessment of NEB and NER involve accounting for both direct and indirect energy input into the systems, as well as accounting for the energy of the co-products.

Where the objective of producing biofuels is to partially or fully displace petroleum fuels, NER is defined as the ratio of energy in biofuels produced to petroleum fuels input in the process, and would be an indicator of how best the biofuels produced have leveraged the petroleum fuel input. An NER value of less than one means that the system does not support energy security efforts and direct use of the petroleum fuels would have been a better option, whereas NER with a value higher than one means that the systems in consideration have a positive energy balance (Maddox, 1978; Mulder and Hagens, 2008; Prueksakorn and Gheewala, 2008). The added advantage of NEB or NER is that they provide information for quick analysis of the GHG emission balance of energy systems (Mulder and Hagens, 2008). In cases where, for example, land is a limiting factor, instead of NEB, net energy yield (NEY) could be computed to present biofuel energy produced per hectare of cultivated land.

The GHG emission comparisons of two fuels will show whether the alternative fuel generates less GHG per unit of energy than the reference fuel on delivering the same services. The most important GHGs considered for comparison of biofuels with petroleum fuels are CO_2, N_2O and CH_4. These gases have different relative global warming potential (GWP) and their effects on the environment vary based on the reference time considered. The common method used is to convert all GHGs into their CO_2 equivalent by using their respective GWP for a specified period.

The NEB and relative GHGs emissions are assessed based on a pre-defined functional unit or service to be delivered. Data to be collected to assess NEB also provide the necessary basis for computing GHG emissions – but to have a better understanding of GHG emissions, consideration is also given to land-use changes. A case in point will be the establishment of *Jatropha* plantation by clearing land which previously had significant above ground and below ground carbon stock, as well as significant soil carbon. Planting *Jatropha* on such lands could result in a negative GHG balance for some years until net GHG reduction is attained.

Several studies have estimated NEB, NER and GHG reduction potential of biofuels including *Jatropha* biodiesel (e.g. Achten *et al*., 2010; Prueksakorn *et al*., 2010; Whitaker and Heath, 2010; Mortimer, 2011). Whitaker and Heath (2010) conducted an LCA on local production and use of *Jatropha* biodiesel for use in the Indian road and rail transport sector. Considering a base case scenario with seed yield of 3,75 ton/ha-yr, and seed oil content of 35%, they computed the lifecycle GHG and diesel oil saving from use of different blends of biodiesel and diesel oil (B5, B10, B20 and B100) normalised per 1000 gross-ton-km. Their findings show that B5 will result in a net GHG saving of 3,4% and B100 72%. Their result also shows a higher net energy value (NEV)[10] for all blends. For B100 the NEV was positive for all modes of transportation, for other blends the NEV is negative but is still higher than for diesel oil. The NEV of blends improves nearly proportionally with increasing biodiesel content of the blend. Whitaker and Heath (2010) reported an NER[11] of 2,3 for B100 meaning that for every MJ of energy consumed in the process biodiesel production 2,3 MJ of energy is produced. In terms of net petroleum fuel demand reduction, B5 contributes to a reduction of petroleum fuels demand by 4,2% and B100 by 88%.

Prueksakorn *et al.* (2010) also reported a positive net energy balance and higher than one net energy ratio for JME produced locally and used in the road transport sector of Thailand. Considering the energy of biodiesel and co-products (seed husk and seed cake

[10]Whitaker and Heath (2010) used the term Net Energy Value (NEV) instead of NEB, and defined it as the biodiesel energy produced less net energy demand of the *Jatropha* biodiesel production systems. And, Net Energy Demand is defined as all sources of energy consumed by the system (e.g. oil, nuclear, renewable) minus energy saved or produced because of system off-set such as co-products or biomass combustion.

[11]Net Energy Ratio (NER) is defined as the ratio of biodiesel energy output (MJ) to Net Energy Demand (MJ), and net energy demand is computed as the total energy supplied to the systems from all sources (Whitaker and Heath, 2010).

and crude glycerine) they estimated a NEB 236 GJ per ha-yr. They reported an NER of 6 by considering full utilisation of the co-products and an NER of 1,4 units when only the biodiesel energy is considered. This study used a high seed yield per hectare (8.4 ton) but assumed lower seed oil content (23%) than used by Whitaker and Heath (2010). But still these assumptions imply that the crude oil production per hectare is higher by over 45% than was used by Whitaker and Heath (2010), or by Ndong *et al*. (2009) as discussed below.

Ndong *et al*. (2009) using relatively similar assumption regarding *Jatropha* seed yield and oil content to Whitaker and Heath (2010) reported a net GHG emission reduction of 72% for *Jatropha* biodiesel produced and used in Ivory Cost relative to transport diesel oil. They also reported a Net Energy Yield[12] (NEY) of 4,7 units%. Unlike Whitaker and Heath (2010), the NEY is computed as the ratio of biodiesel energy produced to energy of petroleum fuels used in the process. The definition as used by Ndong *et al.* (2009) is meant to show the amount of petroleum fuel that could potentially be saved by the systems being analysed.

In the studies discussed above (Ndong *et al*., 2009; Prueksakorn *et al*., 2010; Prueksakorn and Gheewala, 2008; Whitaker and Heath, 2010) the baseline case presented by the authors did not include the impacts of land use change on net GHG emissions - either by making assumption that *Jatropha* will be planted in degraded lands or abandoned agricultural lands in the 20 years of analysis period (or project life) they considered.

Mortimer (2011) estimated the impact of direct land use change resulting from a proposed investment for *Jatropha* plantation in the Dakatacha woodlands of Kenya. The author considered an average seed yield of 2,83 ton/ha-yr and seed oil content of 35%, with the

[12] In the Ndong *et al.* (2009) study, Net Energy Yield is defined as the ratio of energy of biodiesel produced (MJ biodiesel) over petroleum fuels energy used in the process (MJ petroleum fuels).

Jatropha planted on an existing or abandoned agricultural land, and the JME used locally to displace transport diesel oil, he estimated that a net GHG emission reduction of 44% is achievable.

However, Mortimer (2011) argue that if the proposed investment is implemented at Dakatacha woodlands and uses lands that are not currently cultivated, the GHG emission reduction potential will depend on the size and rate of removal of carbon sequestered in the land to be cleared. Based on available data and information, the author argued that the Dakatacha woodland cover could be characterised as scrub land, or as forest lands with different canopy cover.

Mortimer (2011) considering scrub lands (with above ground and soil carbon stock of 84 ton/ha-yr) converted for *Jatropha* plantation, estimated that the net GHG emission reduction will be -233%, and for land with a 30% canopy cover (carbon stock of 101 ton/ha-yr), the net GHG emission will be -402%. Romijn (2010) makes similar analysis taking the African Miombo woodlands and following the methodology employed by Fargione *et al*. (2008)[13]. His findings show that *Jatropha* biofuels produced from large scale *Jatropha* plantations in these woodlands, which in native state have 20-60% canopy cover, would result in carbon debt of more than 30 years. The implication is that carbon debt resulting from conversion of land with high initial carbon stock requires decades to be offset by the GHG savings accruing from use of *Jatropha* biodiesel.

[13] Fargione *et al*. (2008) defined the term "carbon debt" as the amount of CO_2 released during the first 50 years of the process of land conversion (loss of organic carbon stored in plant biomass and soils as a result of burning or microbial decomposition). The time to repay the carbon debt of biofuels from converted land is function of the life cycle GHG emissions reduction of biofuels relative to the petroleum (fossil) fuel they substitute.

2.7 Impacts of various biodiesel blends on heavy duty motor vehicles

A study by US- EPA (2002) showed that the relative magnitude of emissions resulting from combustion of biodiesel blends in heavy duty vehicles (buses and trucks) is significantly lower for, HC, CO and PM_{10}, while small increase in emissions of NO_X is observed with increasing percentage of biodiesel in the blend . The change in emissions resulting from use of different biodiesel-diesel oil blends is shown in Figure 3 (US-EPA 2002; Gerhard *et al*., 2005).

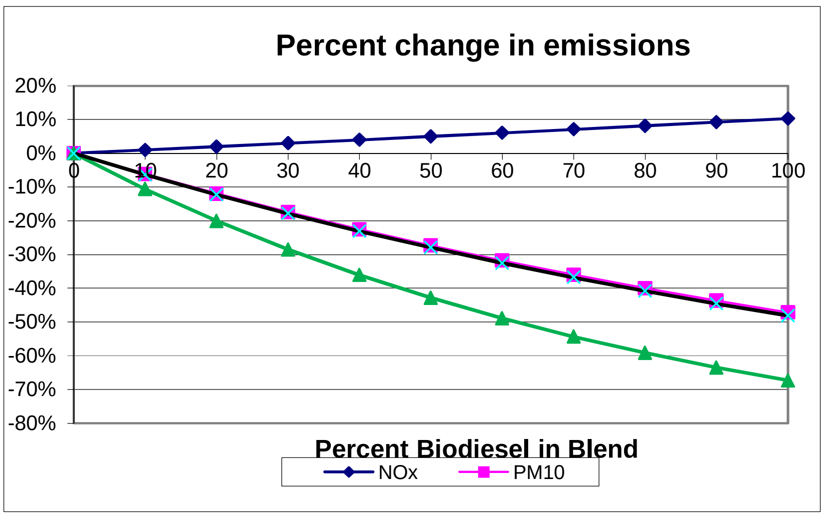

Figure 3. Variation in air emissions with change in biodiesel content in biodiesel-diesel oil blends.

3 Methodology

The study uses a life cycle assessment method, and assesses the GHG emission reduction potential and net energy balance for *Jatropha* biodiesel, in particulate JME, produced and used in the road transport sector in Ethiopia. The standard life cycle assessment framework consists of four major steps: Goal Definition; Scope Definition; Inventory Analysis, and Impact Assessment.

Both quantitative data and qualitative information are collected and analysed. Data for systematic analysis and interpretation of results in *Jatropha* seed production and processing, research studies and papers published in peer reviewed journal publications, and data from databases of LCA software (GEMIS, BioGrace).

Accordingly the researcher has adopt the above framework to this proposal and the specific goal and scope of the study, the methods for data acquisition and data analysis, and the specific impact assessment as specified below.

3.1 Goal definition

As the study attempts to make a comparative assessment of the environmental impacts associated with JME and diesel oil use in diesel oil fuelled trucks in Ethiopia, it will assess and present LCA results on the GHG emission reduction and petroleum fuels demand reduction potential of locally produced JME. The result is expected to provide evidence and hence better insight on the potential benefits and limitation of local production and use of JME in Ethiopia.

3.2 Scope of the research work

The study will focus on comparison of environmental performance of JME using two metrics: (i) net energy ratio (MJ biodiesel produced per MJ petroleum fuels input), and (ii) GHG emissions reduction per functional unit. The study will assess emissions associated with elemental flow (resource consumption, land use change, emissions into air) and those that are associated with product inputs (for seed production, seed and oil processing and transportation). Different cultivation scenarios for production of *Jatropha* seeds will be considered. This includes consideration of medium to large-scale plantations, irrigated or rain-fed, application of chemical fertilizer and/or organic fertilizers. The end-use option for *Jatropha* based oil considered in this study is the production and use of *Jatropha* biodiesel, and particularly, use of JME in the transport sector of Ethiopia.

3.3 Functions and functional units to be considered

The function will be use of biodiesel blend, B5, in the road transport sector to partially displace diesel oil. The functional unit (FU) chosen is one GJ of energy supplied to a diesel engine. The reference flow is 27,88 litre of diesel oil. Delivering one FU will require 30,20 litre of JME.

3.4 System boundary

The systems analysed is the whole production chain involved in production of JME and include cultivation, oil production, transesterfication and biodiesel transport to a blending centre. The JME production system is then compared with diesel oil production systems that include crude oil extraction, processing and transportation of diesel oil to consumption centres. The analysis is limited to analysis of impacts of these fuels in the road transport sector of Ethiopia as shown in Figure 4.

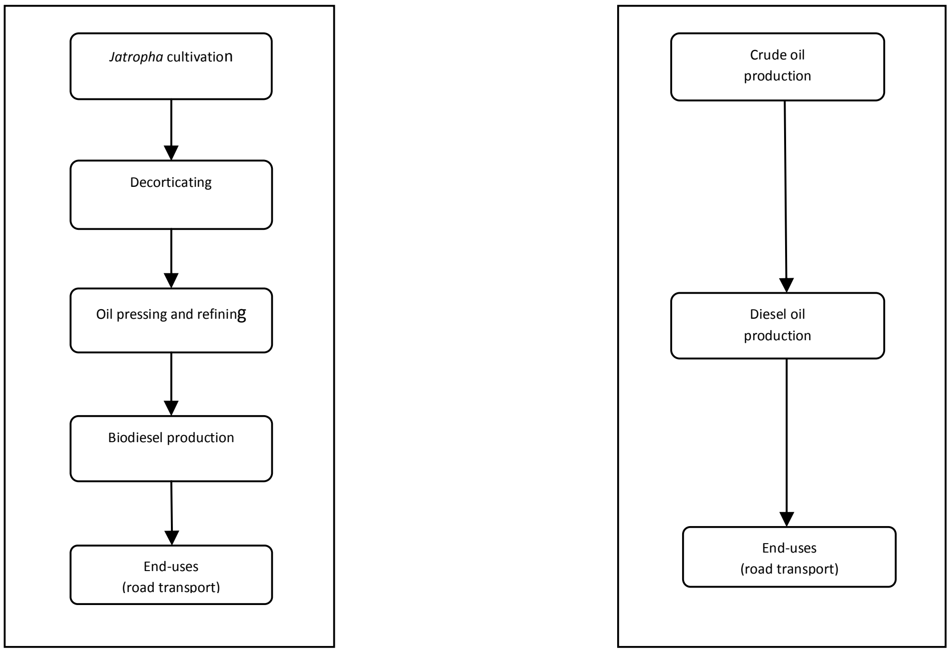

Figure 4. System boundary for JME (left), and the reference diesel oil production system (right)

3.5 Assumptions for the Baseline case

- **Cultivation:** for the baseline case *Jatropha* plantations is considered to be developed on degraded land - land with very low volume of above and below ground biomass. Land is lightly and partially ploughed with tractor to remove above ground biomass but causing minimum soil disturbance. Irrigation water is assumed to be necessary and the amount is determined based on recommended irrigation water requirement (IFEU, 2008). Soil nutrient is supplemented and replenished with (i) addition of synthetic fertilizers (for the first three year), (ii) by returning all process residues (husk and seedcake) to the plantation, and (iii) biomass from pruning of trees is left on the field to improve soil fertility, structure and texture.

- **Seed yield:** 2.38 t/ha-yr and tree density 2500 trees per ha with 2 by 2 meter spacing. This yield level is assumed to be the annual average achievable throughout the 20 years life time of the plantation.
- **Location of *Jatropha* plantation**: A private *Jatropha* plantation developed about 135 km from Addis Ababa was used for estimating fuel and emissions resulting from transport and use of imported material and diesel oil.
- **Oil extraction and biodiesel production:** the seed is transported from the plantation to the nearest electrified town (35 km from plantation) using small trucks where the seed is pressed, cleaned and transesterified. The biodiesel is then transported using small oil tankers (20000 litre capacities) to a blending unit in Addis Ababa (100 km).
- **Imported materials and fuel**: Synthetic fertilizers are imported from Germany, the Netherlands and Russia and transported by ship to the port of Djibouti. Diesel oil and other refined petroleum products imported to Ethiopia are supplied from Saudi Arabia (60% of volume) and United Arab Emirates (25%). These products are first transported by sea to the port of Djibouti, and then to Addis Ababa and the major cities using 40 ton oil trucks.
- **Electric power supply:** The national electric grid of Ethiopia is supplied mainly from hydropower electric generation stations (over 95%) and the remaining from diesel powered generators, and has a grid emission of 0,006 t CO2eq/MWh (Energy Changes, 2008).

3.6 Inventory analysis and impact assessment

Data and information on inputs and outputs from unit processes shown in Figure 5 is accessed from databases of LCA models, peer reviewed research papers (journal articles), similar previous LCA studies, reference materials and books, and equipment and process manufacturers' specifications.

Table 4 below shows raw materials input and outputs into and out of the unit-processes considered (flows along the horizontal line). The materials flow is computed on the basis of one FU of JME. In this study direct GHG emissions from land management (application of fertilizers) and indirect N_2O-N emissions from N volatilisations is considered.

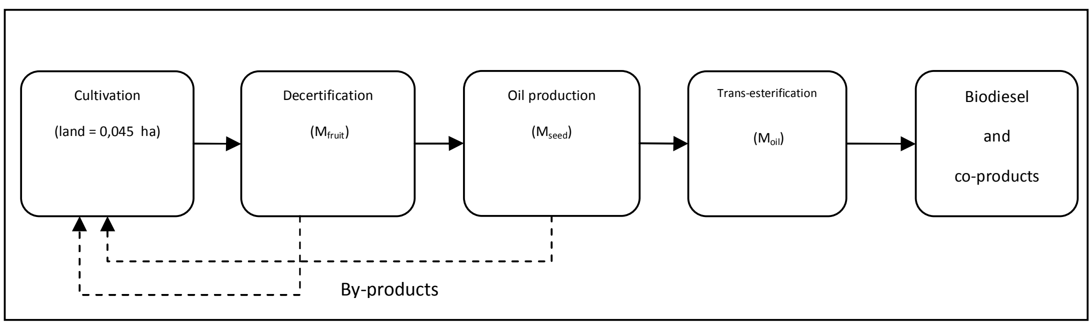

Figure 5. Process flow diagram used for inventory analysis

Table 4. Base case scenario: inputs, JME production, and major by-product outputs in the process of production of one FU.

Inputs to	Qty (kg)	Outputs from	Qty (kg)
Decertification unit			
Fruit (dry)	172,0	Seed	107,5
		Seed coat	64,5
Oil pressing unit			
Seed	107,5	Crude *Jatropha* oil	31,4
		Seedcake	76,1
Oil refining unit			
Crude *Jatropha* oil	31,4	Pure *Jatropha* oil (PJO)	28,3
		Sludge	3,1
Transesterification unit			
Pure *Jatropha* oil	28,3	JME	26,88
Chemicals #	6,6	Glycerine (5%PJO)	2,52
	345,9		340,4

Source: Own computations based on IFEU (2008). # the difference between input and outputs are other process by-products and wastes (IFEU, 2008).

Table 5. Impact categories (see IFEU study and others)

Impact categories	Parameter assessed	Values computed
Global warming potential	Total GHG emissions (CO_2, N_20, CH_4) in CO_2eq.	g CO_2eq. per FU g $C0_2$eq. per ha-yr
Resource depletion (Non-renewable energy sources)	MJ of non-renewable energy (fossil fuels)	MJ per FU
Health impacts of air pollutants	Total air pollutants emissions (*HC, CO,* $N0_X$, PM_{10})	g (air pollutants) per vehicle and /or passenger-km travelled

The specific impacts categories considered, parameters assessed and values computed in this study are shown in Table 6. GHGs considered are CO_2, N_2O and CH_4, and GWP in CO_2eq is computed by using IPCC 100 year radiative forcing equivalence of 298 for N_20 and 25 for CH_4 (IPCC, 2007). Under the base case scenario no land use impact is included.

Table 6. Parameters considered and impacts assessed.

	Energy inputs		***GWP*** **(CO_2,N_2O,CH_4) [CO_2eq]**		***Air emissions*** ***(HC , CO, $N0_{X}$, PM)***
	Indirect	**Direct**	**Indirect**	**Direct**	**Direct**
1. Cultivation					
Cultivation - tractor		$MJ_{diesel\ oil}$/ha	$g/MJ_{diesel\ oil}$		
Irrigation pumped		$MJ_{diesel\ oil}$/ha	$g/MJ_{diesel\ oil}$		
Chemical fertilizers	MJ/kg	MJ/ton-km	$g/kg_{fertilizer}$	$g/kg_{fertilizer}$	
Oganic fertilizers				$g/kg_{fertilizer}$	
Pesticide/insecticide	MJ/kg	MJ/ton-km	$g/kg_{pesticide}$	$g/kg_{pesticide}$	
2. Production of *Jatropha* oil					
Dehusking		$MJ_{diesel\ oil}/ton_{fruit}$			
Oil pressing		kWh_e/ton_{seed}			
Oil filtering	$MJ/kg_{chemical}$	kWh_e/ton_{CJO}			
3. Biodiesel production					
Transesterification unit		$MJ/ton_{biodiesel}$		$g/kg_{product}$	
Methanol	MJ/kg		$g/kg_{product}$		
KOH	MJ/kg		$g/kg_{product}$		
H_2SO_4	MJ/kg		$g/kg_{product}$		
4. Transportation		MJ/ton-km		$g/MJ_{diesel\ oil}$	
Final uses (road transportaion)					
5. Use of biodiesel	MJ/kg	MJ/kg	$g/MJ_{biodiesel}$	$g/MJ_{biodiesel}$	$g/MJ_{\textbf{biodiesel combust}}$
6. Production and use of diesel oil	MJ/kg		$g/MJ_{diesel\ oil}$		$g/MJ_{diesel\ oil\ combusted}$

Source: Adapted from Achten (2010).

Table 7. Baseline data: material and energy inputs to JME production systems

Processes	Parameters	unit	Input data
***Jatropha* cultivation**	Seed yield	ton/ha-yr.	2,38
	Tractor use	l-diesel/ha-yr.	55
	Pump - Irrigation water	l-diesel/ha-yr.	56
	Urea as Nitrogen eq. (N)[a]	kg/ha-yr.	81
	DAP as P205eq.	kg/ha-yr.	31
	Potassium phosphate (K20)	kg/ha-yr.	89
	Pesticide[1]	kg/ha-yr.	0,156
Dehusking of seeds	Mechanical dehusking	MJ-diesel/ton-capsule	92,6
Oil production			
Oil pressing	Mechanical press	kWh/kg-seed	0,15
Filtering	Mechanical filter	kWh/kg-CJO	0,014
Biodiesel production(transesterification)			
	PJO	kg/kg-biodiesel	1,05
	Electricity (hydropower)	kWh/kg-biodiesel	0,42
	Steam/process heat	MJ/kg - biodiesel	0,1
	Methanol	kg/kg-biodiesel	0,2
	KOH	kg/kg-biodiesel	0,026
	H_2SO_4	kg/kg-biodiesel	0,02
	Glycerine purification	kWh/kg-biodiesel	0,29
Transportation biodiesel	Truck (20000 litre capacity)[2]	l-diesel/ton-km	0,0175
Biodiesel/diesel blending	Electric power[3]	kWh/t-biodiesel	8,7

[a] Fertilizer is assumed to be supplied only for the first three years.

Data from IFEU (2008), except for [1,3] Paz and Visser (2011) and [2] BioGrace (2012).

3.7 Method use in assessing GHG impacts of land use change and land management

3.7.1 GHG impacts of land use change

The GHG impact of production and use of JME from conversion of different categories of land which potentially could be converted to *Jatropha* plantation is estimated following Tier 1 IPCC methodology (IPCC, 2006). In general if land is cleared and repeatedly ploughed the total carbon loss due to LUC is computed by assuming (i) that above ground biomass (AGB) stock as well as below ground biomass (BGB) are fully removed and burnt on site (or are used as fuel wood or after converting to used charcoal) and (ii) the change in soil organic carbon (SOC) will be computed considering land management practice before and after the conversion (if, for example, non-crop land after conversions to crop land is repeated ploughed without SOC amendment, such conversion and management will result in significant loss of SOC). However, while converting land to perennial crops such as *Jatropha* requires removal of above and below ground biomass, loss of SOC is expected to be minimal. This assumption is based on the fact that use of machinery for intensive land ploughing is not necessary when planting perennial trees such as *Jatropha* (Mortimer, 2011).

First the net Cstock change from conversion of lands to *Jatropha* plantation is computed. The net GHG emission reduction of JME is then used to estimate the number of years required to repay the net GHG emissions resulting from LUC. The following relations are used to compute change in Cstock and the payback period.

(i) ΔC_{stock} – net change in C_{stock} due to land conversion to *Jatropha* plantation, and

(ii) ECPT - Ecosystem Carbon Payback Time as defined by Gibbs *et al*. (2008), and shows the number of years it takes for the life cycle GHG reduction achieved by substitution of JME for diesel oil to compensate for GHG emission resulting from LUC.

Where:

$\Delta C_{stockluc}$ **(t C/ha)** = $C_{stock\ before} - C_{stock\ after}$

ECPT = (44/12)*$\Delta C_{stockluc}$ /$CO_{2eq\ saved\text{-}biodiesel}$ **[Equation 1]**

And,

$\Delta C_{stockluc}$ is carbon stock change as a result of conversion from generic land-use category to crop land if ΔC_{luc} is negative there is a decrease in C-stock in "after" compared to "before" land use, and indicate emission of CO_2 to the atmosphere. The factor 44/12 (molecular weight of CO_2 over C) is used to convert C to CO_2.

$C_{stock\ before}$ **and** $C_{stock\ after}$ are respectively the carbon stock per ha of land before and after conversion to biofuel plantation, and include both above ground and below ground biomass and soil carbon (t C/ha),

ECPT is the ecological carbon payback time in years and

$CO_{2eq\ saved\text{-}biodiesel}$ is the magnitude of CO_2eq saved from displacement of diesel oil by biodiesel (t CO_2/ha-yr).

3.7.2 GHG impact of land management

In this study N_2O, the most significant and a potent emission, associated with application of synthetic and organic fertilizers is considered.[14] Following IPCC guidelines (IPCC,

[14]Other non-CO_2 emissions may be associated with different type land management employed and this may include CH_4 , and NOx emissions from burning of biomass on land converted

2006) and based on the assumptions made and considerations described below both direct and indirect N_2O emissions associated with use of fertilisers are estimated.

In estimating direct N_20 emissions the study considers use of synthetic fertilizers (UREA and DAP) in the first three years of the *Jatropha* planation development, and assumes that all pruned biomass from standing *Jatropha* trees and process residues (husk and seedcake) will be returned to the *Jatropha* planation. Accordingly, the direct N_20 emissions is estimated using the following relation (IPCC, 2006)

$N_2O = (F_{SN} + F_{on} + F_{CR})*EF1*44/28)$ [g N_2O/ha-yr] **[Equation 2]**

Where;

F_{SN} is the annual amount of synthetic fertilizer N applied to soils (kg N per ha-yr),

F_{on} annual amount of organic fertilizer as seedcake returned (kg N per ha-yr),

F_{CR} annual amount of N in pruned biomass returned to soils (kg N per ha-yr), and

EF1 is emissions factor for N (kg N_2O–N per kg N)

The indirect N_2O emissions associated with application of both synthetic and organic fertilizer use is estimated based on the relation (IPCC, 2006).

$N_2O = [(F_{SN}*Fract\text{-}_{GASF})+(F_{ON}+F_{CR})*Frac\text{-}_{GASM})*EF4*44/28]$ [kg N_2O/ha-yr] [**Equation 3]**

Where;

F_{SN} is the annual amount of synthetic fertilizer N applied to soils (kg N per ha-yr),

F_{ON} annual amount of organic fertilizer as seedcake returned (kg N per ha-yr],

F_{CR}: annual amount of N in pruned biomass returned to soils (kg N per ha-yr) and

$Fract_{\_GASF}$: fraction of synthetic N fertilizer that volatilizes as NH_3 and NOx (kg N volatilized per kg Applied)

$Frac\text{-}_{GASM}$: fraction of organic N fertilizer that volatilizes as NH_3 and NOx (kg N volatilized per kg Applied)

to other crop land (IPCC, 2006) Since the study assumes no on site open (field) burning to these particular emissions are not factored-in in these estimation of non-$C0_2$ emissions from land management.

A summary of the assumptions and factors considered for estimation of direct and indirect N_2O emissions from land management are presented in annex B, Tables B.12 and B.13.

3.8 Data sources for LUC impact analysis

Change in total carbon loss for the different land categories considered to be potentially available for conversion to *Jatropha* plantation is computed using data provided in the Background Guidelines for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme (JRC, 2010)[15]. The land types (categories) considered in assessing Cstock loss due to LUC includes woodlands, shrub lands and grass lands[16] and forest lands (Table B.14 and B.15, Annex B). The last category is included since forest lands in Ethiopia are converted (or were planned to be) converted to *Jatropha* plantation (MELCA, 2008) and these are shown in Table A.3, Annex A.

[15]This guideline is produced by the European Commission Joint Research Centre (JRC) and draws on IPCC 2006 National Greenhouse Gasses Inventories but improves the IPCC (2006) carbon stock data by factoring in regional climate, soil type of previous land use category.

[16]The Biofuel Development and Use Strategy of Ethiopia (MME, 2007, page 14) states that lands for biofuels feedstock development will be allocated in areas that are moisture stressed (low rainfall) and degraded arid and (semi-) arid areas. The strategy document estimated that 23 million ha of land could be made available for biodiesel production.

4 Results and discussion

4.1 Results of baseline analysis

4.1.1 Non-renewable energy requirement and savings

Under the baseline case total estimated non-renewable energy requirement (NRER) is 353 MJ per FU with a corresponding NEB of 647 MJ of JME. The NER computed for comparison with other studies is 2.61 and implies for each MJ of JME produced 0,38 MJ of non-renewable energy is consumed. The NEY which is the difference between total energy of JME produced less total input (384 MJ which includes 31 MJ of energy from hydropower) is about 616 MJ. The major contributors to consumption of energy are the cultivation sub-process (61%) and transesterification (33%) and are shown in Table 8 and Figure 6.

Table 8. Summary of GHG and NRER for baseline case.

Sub-processes	GHG emissions ($g\ CO_2eq/FU$)	NRER (MJ/FU)	Electric energy inputs (hydro based) (MJ/FU)
Agricultural			
Cultivation inputs	**18890**	**216,8**	-
Diesel tractor	7467,0	89,1	-
Diesel fuel (irrigation)	7534,8	89,9	-
Urea as Nitrogen (N)	3248,1	26,9	-
DAP (P_2O_5)	212,9	3,2	-
Potassium phosphate	349,3	5,8	-
Pesticides	77,7	1,9	-
Land management	**21663**	**-**	
Oil pressing	**1335**	**15,9**	**16,6**
Mechanical dehusking	1334,6	15,9	
Screw press	0,1		16,1
Refining	0,00		0,5
Transesterification	**3961**	**115,9**	**14,1**
Electricity	0,1		11,3
Steam/process heat	0,0		2,8
Methanol	1632,6	107,0	-
KoH	1824,5	6,8	-
H_2SO_4	503,9	2,1	-
Transport	**1657**	4,39	**-**
Sub-total	**47506**	**353**	**31**

Source: Own Computation.

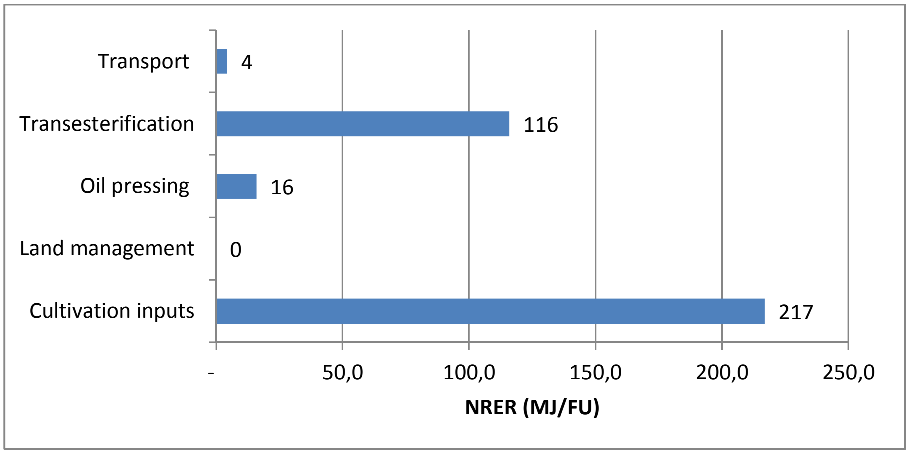

Figure 6. NRER of the JME production system by major processes

4.1.2 Global Warming Potential

The result of the base case analysis shows that under these specific considerations JME will provide 43,3% GHG reduction as compared to use of diesel oil per FU (GJ)[17]. The JME production system produced a total GWP of 47,5 kg CO_2 per FU of which 85,2% is from agricultural activities (cultivation 39,6%, and land management 45,6%). The significant amount of GHG emission from land management is due to direct and indirect emissions of N_2O resulting from use of fertilizers and particularly from oxidation and volatilization of Nitrogen contained in both synthetic and organic fertilizers. GHG emissions from use of diesel oil for tractors and water pumping are shared almost equally and accounts for 80% of the GHG emissions under the cultivation sub-process. Emissions from use of synthetic fertilizer are mainly attributed to urea (7% of cultivation).

The transesterification process accounts for 8% of total GHG. Transportation of seed, JME fertilizer and diesel oil account for 3,5% of the total GWP. The minimum

[17] Compared to diesel oil emissions of 83,8g CO_2eq per MJ (CEC, 2009)

contribution comes from oil processing (2,3%). Figure 7 below shows specific contribution of the major sub-process to the GHG emission of the JME production process.

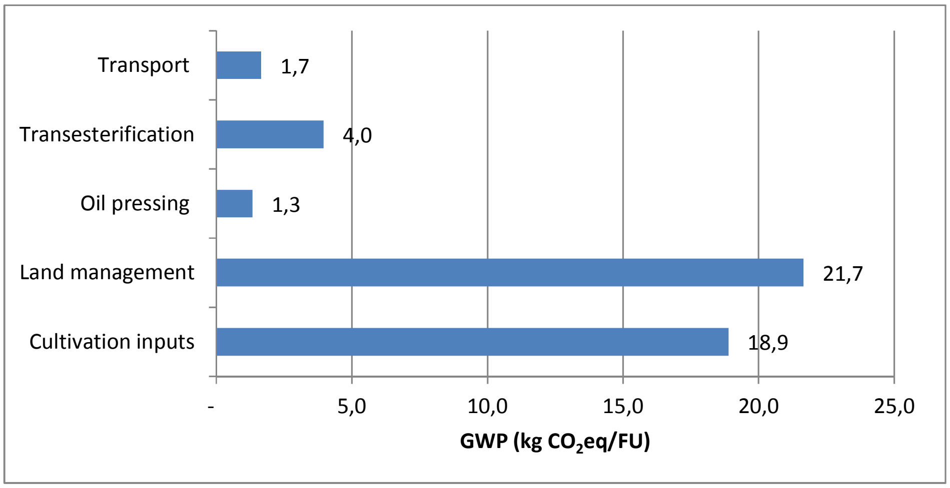

Figure 7. GWP of the JME production system by major sub-processes

4.1.3 Co-product credit

Under the base case scenario systems to account for contribution of co-products, in particular glycerine, systems expansion is used. Hence the JME is credited by deducting and GHG emissions and energy inputs which otherwise would have resulted for production of glycerine using current technologies.

For the purpose of comparison with other methods of crediting co-products, the study also employed allocation by (i) energy and hence apportioning both GHG emissions and energy consumption in JME production system between JME (demand product) and (ii) Glycerine (co-product), and by using system expansion where glycerine from the JME production process is credited with reducing energy expenditure and GHG emissions per unit mass of petroleum based glycerine production (Table 9).

Compared to the baseline GHG emissions, the impact of co-product credit using energy allocation is reduction of about 2% in total GHG emission per FU and the corresponding value for substitution method is a reduction by 5% allocation using substitution also shows that glycerine as co-produce reduced NRE requirement by 100 MJ per FU (based on net replacement of 40 MJ per kg of glycerine and production of 2,52 kg glycerine per FU, base case, no-allocation of 47,5g CO_2eq per FU corresponding to GHG saving of 43,3%).

Table 9. GHG saving resulting from application of energy allocation and substitution.

Method of crediting	GHG allocated (g CO_2eq per FU)	Net GHG saving (%)
Energy allocation		
Biodiesel	45,3	46%
Glycerine	2,2	
Substitution		
Biodiesel	43,0	49%
Glycerine	4,5	

Source: own computation.

4.1.4 Sensitivity Analysis

The base line result had indicated that GHG emissions of the whole JME production process are due to cultivation input and therefore the variation in these inputs is expected to influence the final result of both the net GHG saving and NRER. The impact of individually varying diesel oil consumption for tractor and irrigation water pumping and varying the amount of urea used is shown in Figure 8. The impact of varying these inputs independently by -20% and 20% results in change of total GWP per FU by -1,5% to 1,8% relative to the base line GWP value and are small as fertilizers are applied only in the first three years of plantation development[18]. The variation of results as function of the above variables is expected due to the generally linear relationship between the inputs and final result of the model output.

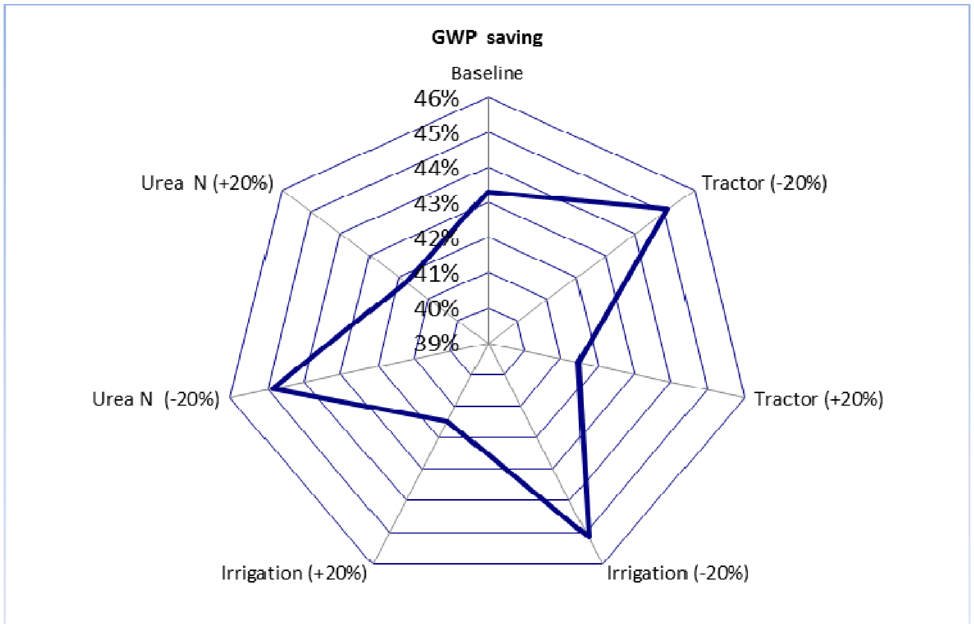

Figure 8. Change in GWP saving due to variation in cultivation inputs.

4.2 Scenario development and analysis

Based on the above contribution analysis, cultivation is the major contributor to both the total GWP and NRER and this is mainly due to the use of agricultural inputs particular synthetic fertilizer and consumption of diesel oil for irrigation and tractor services. Although land management is also an important contributor to GWP, this biogenic emission is difficult to control. The transesterification sub-process is important in terms of

[18] For example considering that all three types of fertilizers are used annually, under the base case, GWP would have been 69 g CO_2 per MJ of JME and the corresponding GWP saving would have been only 17,5%, with a NER of 1,8.

its contribution to total NRER but less so with respect to GWP due to use of hydropower energy that has very low emission factor. Since, not only agricultural inputs, but the combination of all inputs, soil fertility and local climate are major factors that influence crop yield level, four scenarios for which corresponding parametric values shown in Table 10 are analysed and compared with the results of the base case scenario (input application regime is similar for all scenarios, that is synthetic fertilizer use is only in the first three years and all other input are applied annually).

The NRER and GWP results of the different scenarios considered above are presented in Figure 10 and 11. As could be inferred from Figure 9 the highest NRER is for scenario B_1 due to the higher input but relatively lower yield than scenario B_2.

The GWP contribution of cultivation input (both aggregated and by type of inputs) and the aggregated GWP the whole seed production (cultivation inputs as well as application of fertilizers) is shown in Figure 10.

Table 10. Scenarios assessed and specific parameters considered

Parameters	Unit	Scenario[1] A_1	Scenario A_2	Base case	Scenario B_1	Scenario B_2
Yield level	t seed/ha	1,0	1,42	2,38	4,44	7,8
Tractor	l diesel/ha-yr.	27,5	55	55	141	141
Irrigation water	m^3/ha-yr.	27,8	55,5	56	55,5	55,5
N-fertilizer[2]	kg/ha-yr.	0	48	81	141	141
P_2O_5-fertilizer	kg/ha-yr.	0	19	31	56	56
K_2O-fertilizer	kg/ha-yr.	0	53	89	139	139
Pesticide	kg/ha-yr.	0,156	0,156	0,156	0,156	0,156

[1]Scenarios A1: low yield minimum input; A2: low yield low input; B1: high yield low input, B2: max yield high input. Scenarios A1, A2 and B1 and the base case are based on IFEU 2008. Scenario B2 considers maximum potential yield estimated by Jongschaap *et al*. (2007) with same inputs as B1.[2] All synthetic fertilizer input are applied only in the first three years of plantation development.

4.3 Land use efficiency

The land use efficiency is a function of seed yield per hectare and volume and type of cultivation inputs. For the four scenarios considered Scenario B2 has the lowest land area requirement, 0,014 ha per annum per FU and the highest saving in GWP. Scenario A1, having the lowest yield has highest land requirement 0,108 ha per annum per FU, but in terms of saving GWP is relatively better (359 kg CO_2 per ha-yr) than A2 which shows net saving of 327 kg CO_2 per ha-yr, which is expected to be mainly the consequence of use of synthetic fertilizers that appears not to be compensated by the relatively higher yield that is assumed.

Table 11. Land area requirement and efficiencyper FU for the different scenarios

Parameters	*A1*	*A2*	*Base case*	*B1*	*B2*
Land area (ha/FU)	0,108	0,076	0,045	0,024	0,014
GWP saving (kg CO_2/FU)	38,6	24,8	36,3	38,3	48,1
GWP saving (kg CO_2/ha-yr)	359	327	803	1583	3491
GWP (kg CO_2/ha-yr.)[1]	420	780	1 052	1 877	2 588

[1]These values are later used in the land use change impact section to estimate the ECPT of each scenario.

Figure 9. NRER and GWP results for the scenarios considered with base line

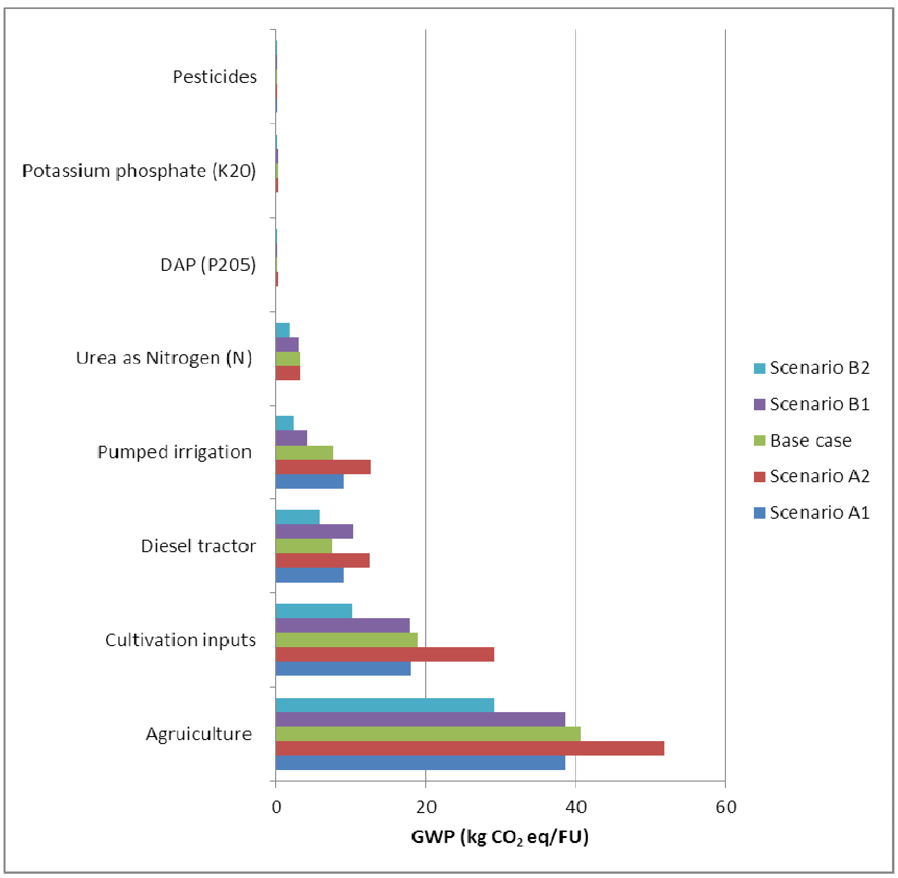

Figure 10. Contribution of cultivation inputs to GWP under the different scenarios considered

4.4 Impacts of land use change on the GHG balance of JME

Losses of Cstock from conversion of land under natural vegetation to agricultural lands for production of biofuels feedstock are major causes of net CO_2 emissions. The magnitude of Cstock losses as CO_2 (released in to the atmosphere) is generally highest when land under well stocked natural forests is converted for biofuels feedstock production. Conversion of degraded or marginal lands to perennial crops such as *Jatropha* can potentially increase both SOC and aboveground and belowground Csock (IPCC, 2006).

In this section, the net GHG emission reduction potential of JME produced using *Jatropha* oil seed produced by conversion of different categories of land: forest land, woodland, shrub lands, and grassland and crop lands, is analysed.

4.4.1 Emissions from land use change and ECPT - Base case

The total carbon debt per ha of land resulting from conversion of various land categories to *Jatropha* plantation is shown in Figure 11. The result shows that the highest Cstock loss and hence CO_2 emission occurs when converting shrub land and forest lands. In contrasts converting grass land, degraded forest land could have a net positive impact due to increase in above and below ground biomass.

For JME to provide short to medium benefits (20 years period) the saving from the lifecycle GHG emissions of JME over diesel oil shall off-set the GHG emissions resulting from LUC annualised over 20 years, as recommended in IPCC (2006) and required in by EC (CEC, 2009). Considering the baseline annual life cycle GHG saving of 47,5 kg CO_2/FU), the ECPT required for offsetting the GHG associated with conversion of different forest and shrub lands to *Jatropha* plantation would range from 50 to over 600 years (Figure 12), with highest ECPT corresponding to forests lands with high canopy cover. This analysis does not consider allocation of GHG between JME and glycerine.

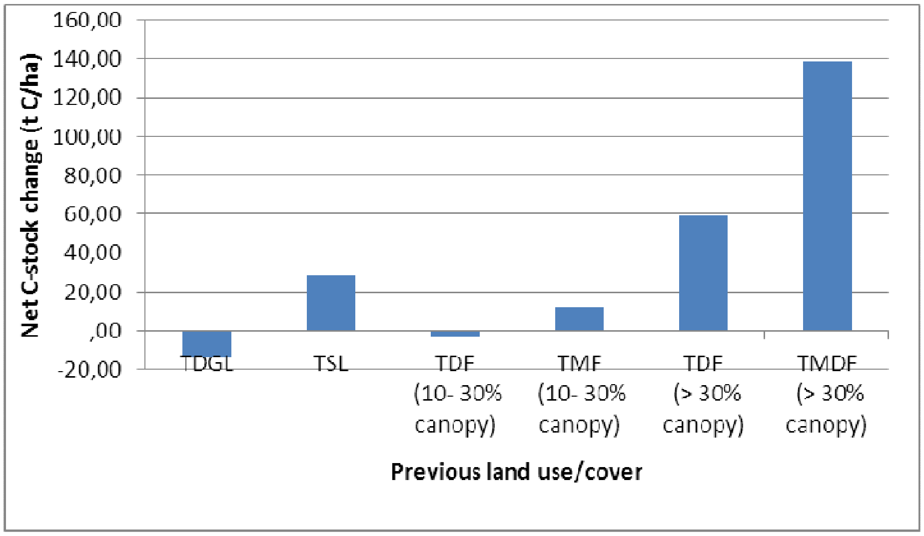

Figure 11. Net Cstock change from conversion of different land uses to *Jatropha* plantation

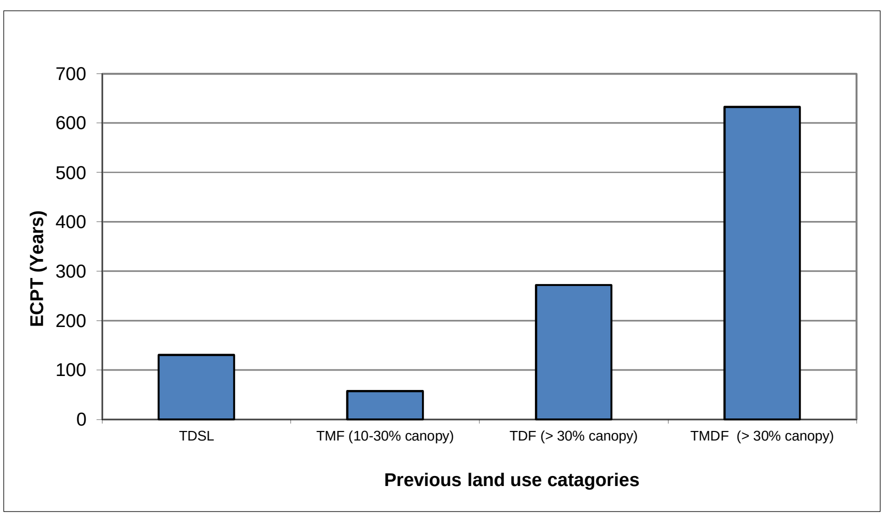

Figure 12. ECPT required to compensate net change in C-stock resulting from conversion of different land use types to *Jatropha* plantation in Ethiopia

4.5 Effects of higher seed yield on net GHG emissions of JME

The GoE has no set standard or minimum GHG saving requirement for local production and use of JME or any biofuels and hence it may be likely that JME production and uses may be largely determined by cost rather than GHG reduction benefits. However, as was already indicated (MME, 2007), the country also aims to export biofuels and one very likely market expected to be targeted will be the EU member states. The EU directives, (directives 2009/28/EC page 57) state that GHG emissions saving from use of biofuels use in the road transport sector (displacing diesel oil), shall be at least 35%, and with effect from 1 January 2017 the saving shall be 50%, and the requirement increases to 60% beginning 1 January 2018 for biofuels produces in installations where production begins on or after 1 January 2017. The above result shows that only JME produced on land converted from grass shows net life cycle GHG saving.

With all other factors remaining the same (that is with little or no change in agricultural inputs such as synthetic fertilizers and irrigation water) the impact of higher seed yield will be the reduction of GHG emissions associated with conversion of lands with high C-stock.

The impact of seed yield ranging from 2 to 12 t/ha-yr, on the net GHG benefits of JME produced on converted shrub lands and tropical forest lands is shown in Figure 13. For tropical shrub land the net GHG emission of JME per FU would be lower than diesel oil displaced only if seed yields exceeding 4 t/ha-yr are attained, and for tropical forests the net GHG remains negative even for a maximum yield of 12 t/ha-yr, while tropical forest with 10-30% canopy cover with low Cstock (14 t C/ha), would provide a positive GHG benefit even at lower seed yield of 2 t/ha-yr due to the relatively higher Cstock considered to be achieved per hectare of *Jatropha* plantations.

It appears that only *Jatropha* plantations established on grass lands, crop lands or degraded forest would provide net GHG benefits even at lower seed yield rates of 2 t/ha-yr, and provide net GHG benefits by displacing diesel oil used in local transport sector, or provide an opportunity for export of JME. For *Jatropha* plantations established on previously shrub lands meeting the 50% GHG reduction would require that seed yield should reach 10 to 12 t/ha-yr, and for forest lands with high Cstock no short-term GHG gain is expected even at the maximum attainable yield of 12 t/ha-yr.

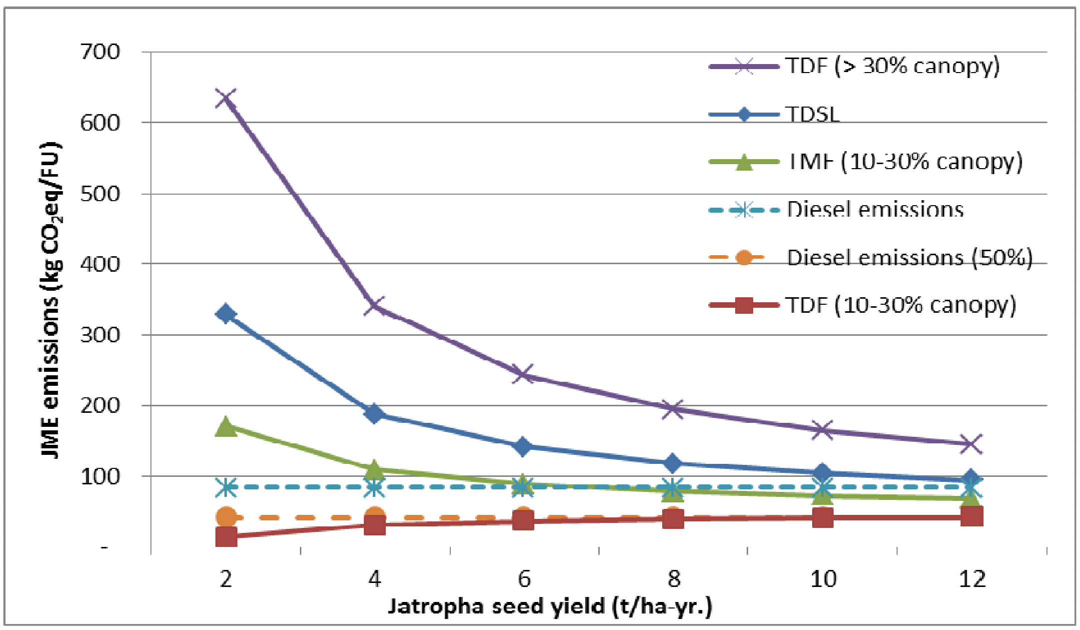

Figure 13. Estimates of impact of seed yield on total GHG emissions of JME produced on various land use types in Ethiopia.

4.6 Potential demand for JME and land resource availability

4.6.1 Demand for JME

Potential demand for JME at the national level is computed assuming a minimum blend of 5% JME or use of B5 in the road transport sector for 10 years beginning 2015. In 2010 Ethiopia imported 1,31 million ton (1,57 million m^3) of diesel (NBE, 2011) of which over 80% was used in the road transport sector (MWE, 2011). At an annual growth rate of 7% (MoFED, 2010) the total diesel oil demand for the road transport sector will reach 1,76 million m^3 by 2015 and rises to 2,47 million m^3 by 2020.

Table 12 shows that for the annual seed yield of 2.38 t/ha (and basic assumptions made under the base case) displacing 5% of transport diesel oil, that is use of B5, would imply that by 2015 a total of 132 thousand ha of land should be under mature *Jatropha* plantations, and should be continuously expanded at an average rate of 12,000 hectares per year to meet the JME demand by 2020 and 2025.

Table 12. Land area requirement for implementing B5 mandates, 2015 to 2025, base case scenario.

	Unit	2015	2020	2025
Total projected diesel consumption	thousand m^3	2.205	3.093	4.338
Projected diesel oil demand road transport	thousand m^3	1.764	2.474	3.470
JME demand (B5)	thousand m^3	88	124	174
Land area requirement	thousand ha	132	185	260

[1]Computed based on estimated percentage of road transport diesel consumption min 80% of total national import, and 0,67 m^3 of JME per ha-yr (base line).

4.6.2 Land resources

Considering that biofuels plantation development will mainly be concentrated on the drier, low rainfall, areas of part of the country (MME, 2007), and using land cover data from MoA (2004), the most likely categories of land types that could be considered as potential available land for *Jatropha* plantation in Ethiopia will include: land classified as woodlands, shrub lands and grass lands. The total area of land under these categories (as sown in Annex, Table A.1) is about 70 million hectares (woodland 29,5, shrub land 26,3 and grass lands 14,5 million ha) and account for over 60% of the total land of the country (MoA, 2004). If these lands are considered to be available and suitable for *Jatropha* plantation the land area required to produce JME for a B5 blend would be very small; 0,13% of the total and still less than 1% of the grass lands.

However, it would be unlikely that *Jatropha* plantations would be developed in areas with very low moisture as these areas would not provide commercially viable yields. Taking woodlands, shrub lands and grass lands in regions where relatively higher annual rainfall is received, 500 mm and above, and where land allocation for biofuels development is reported (MELCA, 2008), the total land area under the above categories would be 33.8 million ha, and of this land area requirement for B5 will be about 3%.

5 A case study: Impacts of Running Anbassa City Bus Service Enterprise bus fleets with biodiesel-diesel oil blends on their GHG and air pollutant emission

5.1 Background

The analysis and discussion presented under this section is intended to assess the magnitude of GHG and air pollution emissions resulting from introducing biodiesel blends for running Anbassa City Bus Services Enterprise (ACBSE) fleets. ACBSE is a public enterprise providing passenger transportation services in and around Addis Ababa city. To provide a basis for comparison, the impact of introducing biodiesel blends (B2, B5, B10 and B20) on emissions of GHG and air pollutants from ACBSE fleets is compared with the two other major public transportation services provided by private operators; mini-bus and midi-bus taxis.

ACBSE was selected as a potential candidate where biodiesel blends could be used based on the premise that, if use of blends makes economic sense to ACBSE, then the use of biodiesel blends in this company could also provide environmental benefits in terms of GHG reduction, while also contributing to the improvement of the local air quality in Addis Ababa city.

5.2 Emissions from vehicles

The type and magnitude of emission from vehicles are dependent on a number of factors including vehicle's engine-exhaust system design, age of vehicle, operating conditions, maintenance, and the quality of fuel used (UNEP, 2009a, b). The type and magnitude of vehicle emissions are higher for older vehicles, vehicles that do not receive adequate maintenance, and those that do not already have or are not retrofitted with emission reduction technologies.

Emissions from vehicles include both GHGs (CO_2, N_2O and CH_4) and air pollutants with significant adverse effects on human health. The major air pollutants include nitrogen oxides (NOx), particulate matter (PM) unburned hydrocarbons (HC) and volatile organic compounds (VOC) (WHO, 2004). Vehicles meeting emissions standards set by EU and other developed countries such as USA, are equipped with exhaust treatment technologies – a three way auto catalysts (TWC) for light duty gasoline vehicles, and diesel oxidation catalysts (DOC) and diesel particulate filter (DPF) for vehicles running on diesel oil (UNEP, 2009a).

The vehicle fleets in Addis Ababa (and generally in Ethiopia) is characterized by high proportion of older and poorly maintained vehicles. Most of the vehicles are second hand Japanese and European manufacturer and recently heavy duty vehicles (trucks and buses) from China. Most of the vehicles imported to Ethiopia both second hand and new comes fitted with exhaust treatment technologies. However, due to the high sulphur content of both gasoline and diesel oil used in the country, all exhaust treatment technologies fitted on vehicles operated in Ethiopia are believed to have been destroyed or ineffective[19].

Vehicles running on high sulphur diesel oil generate high level of sulphur compounds that reduce engine life, corrode vehicle parts, and render the exhaust treatment technology

[19] Ethiopia phased out use of leaded gasoline as of January 2004, and therefore the exhaust treatment technologies such as TWC on older gasoline cars has also been negatively affected or are already non-functional.

ineffective. Air pollutants from combustion of petroleum fuel with high sulphur factor generates more air pollutants than new and well maintained vehicles running on low sulphur (500 ppm or less). In countries such as Ethiopia where diesel oil sulphur content is high, emissions of and exposure to air pollutants including oxides of sulphur from vehicles operating in urban areas is considered to be a major contributor to the deterioration of urban air quality (UNEP 2009a; Etyemezian 2005).

Figure 14 and 15 show the sulphur content of diesel oil and gasoline used in Ethiopia (FTAE, 2012). Although in the last two to three years the sulphur content of both diesel oil and gasoline has decreased. Current level of 5000 ppm (0.5%wt) for diesel oil is still ten times more than the maximum sulphur level of 500 ppm required for efficient operation of exhaust treatment technologies such as DOC. Similarly, for gasoline vehicles, for the TWC to efficiently operate, the sulphur content of gasoline used shall not exceed 300 ppm (MECM, 1998). The Ethiopian standard for diesel oil is maximum sulphur content of 5000 ppm and a minimum of 50 ppm, and for gasoline the maximum sulphur content is limited to 1000 ppm (ES 2004; ES 2008).

The Environment Protection Authority of Ethiopia (EPA), following WHO (2004) outdoor air pollution guidelines has, in 2004 produced air emission guidelines “Guideline Ambient Environmental Standards for Ethiopia” (EPA, 2004). The air emissions guideline provide “guideline values” for major pollutants including SO_2, NO_2, Ozone O_3, and $PM_{2.5}$ and PM_{10}, but at present is not enforced.

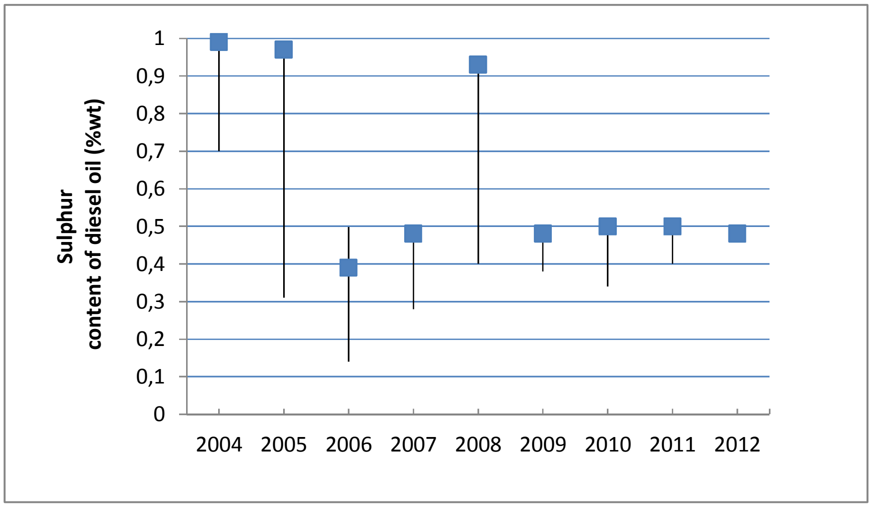

Figure 14. Sulphur content of diesel oil improted and used in Ethiopia's road transport sector (the marker represents the average annual sulphur content and the top and botom of each vertical lines the max and min content of sulphur)

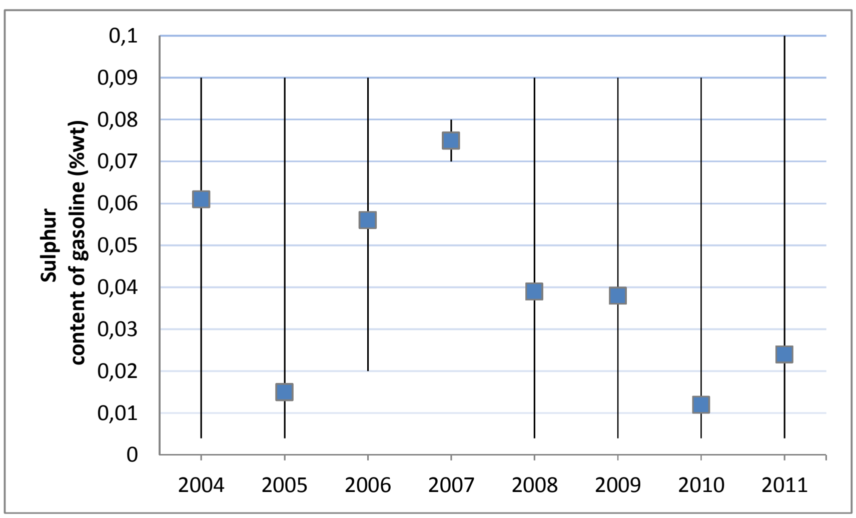

Figure 15. Sulphur content of gasoline used in Ethiopia's road transport sector (the marker represents the average annula sulfure content, and the top and botom of each vertical lines the maximum and mininmum content of sulfur)

5.3 Public transportation services in Addis Ababa

From the total motorised person-trips made in Addis Ababa the share of public transport accounted for about of 80% of total person-trips made in 2007, with ACBSE accounting for 28% and mini-buses taxis for 52% (COWI, 2007). And since 2006/7 the public transportation service has expanded by introducing new midi-buses imported from China, and older intercity midi-buses that, on a rotational basis, are permitted to provide services within Addis Ababa.

5.3.1 The Anbassa City Bus Service Enterprise

ACBSE provides public transportation services in 93 different routes that connect the major parts of Addis Ababa City (ACBSE, 2012). Until 2010, all buses used by ACBSE were rigid single-decker buses with a total passenger capacity of 102 (seating capacity 30 people). In 2010/11, the enterprise had dispatched 295 buses and provided transport services to 98.3 million passengers (Annex C, Table C1). The number of buses owned by ACBSE in 2012 by service years is shown in Figure 16.

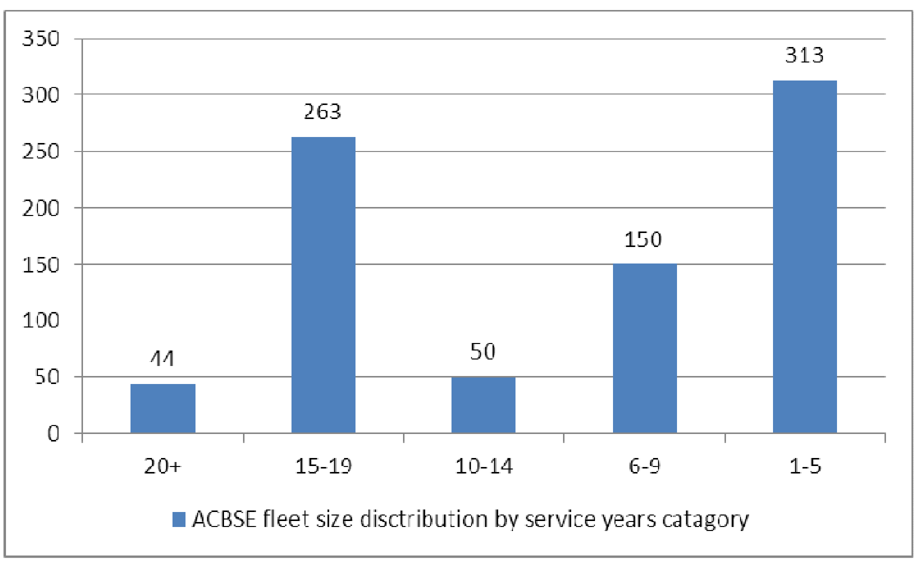

Figure 16. ACBSE bus fleet distribution by service years.

5.3.2 Mini- and midi-bus taxis

Mini-bus and midi-buses **taxis** are the other two major public passenger transportation service providers in Addis Ababa. The total number of mini-bus taxi operating in Addis Ababa is estimated at 12 500, and most of these min-buses have been in operation for the last 15-20 years (COWI, 2007) and include a variety of Toyota mini-bus models with a total of 12 seats. Figure 17 presents the age distribution of mini-bus vehicles registered in Addis Ababa city.

COWI (2007) reported that min-bus taxis operate on 105 routes, make 6-8 round trips per day with an average trip length of 5,4 km. On average each min-bus is estimated to have transported 132 persons per day and with fleet availability of 75% a total of 1,2 million passengers per day. The midi-buses include dedicated midi-buses that are relatively recently introduced (2006 onwards). Other midi-bus models providing public transportation services in Addis Ababa are mainly ISUZU light duty trucks converted to buses in local workshops, these midi-buses are licenced to provide intercity transport but some are currently allowed to provide transportation services within Addis Ababa. Both types of midi-buses have 22-25 seat capacity and accommodate 15-20 standees when full.

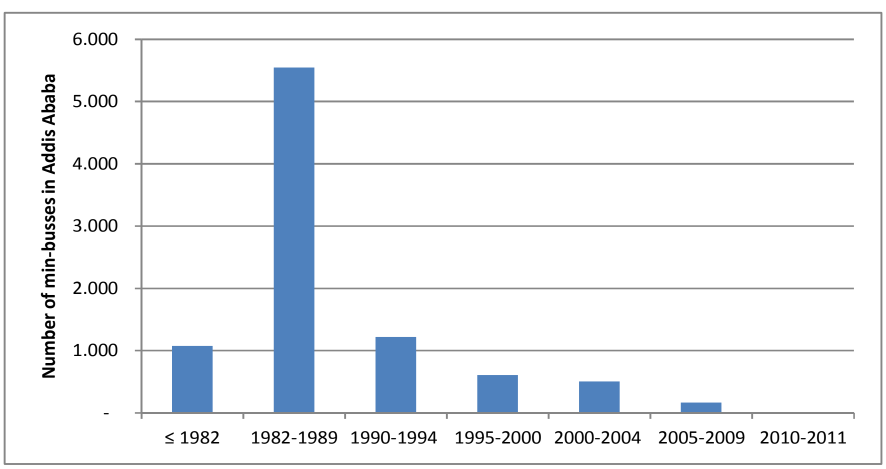

Figure 17. Age distribution of mini-bus vehicles registered in Addis Ababa city.

Table 13. Public passenger transport services - basic data

Vehicle category	Average passenger (pass/trip)	Average trip length (km/vehicle)	Daily trips (trips/vehicle)
City Bus (ACBSE)[1]	96,0	11,0	15,7 (13,6)#
Min-bus [2]	9,2	5,4	16
Midi-bus[3]	25,0	7,0	16

Source: [1] IBIS (2005). Study of urban public transport conditions in Addis Ababa, Ethiopia. IBIS Transport Consultants Ltd, March 2005 (based on data from ACBSE, on Anbassa route analysis of January 2005); [2] COWI (2007). National Transport Master Plan Study, Working Draft Master Plan, APPENDIX 1.8, Urban Transport, Ethiopia; [3] Own estimates, # value in parenthesis is average daily strip per bus estimated based on 2010/2011 total distance covered by ACBSE fleets, keep the average trip length at 11 km per vehicle.

5.4 Approach

5.4.1 Estimation of emissions from public transport sector

The type and magnitude of emissions generated from the public transportation sector is influenced by the level of activity (A), the modal structure (S); the fuel intensity (I) and the emission factor (F) by fuel type. Equation 2, generally known as the "ASIF" equation provides a concise representation of the relation between emissions from a particular public transportation mode (Schipper *et al*., 2007).

$$E = A*S*I*F \qquad \text{[Equation 4]}$$

Where for each mode: **A** is average vehicle kilometre travelled (VKT per vehicle); **S** is the number of vehicles; **I** is the fuel intensity (l/VKT), and **F** is the emission factors by fuel type (gram of pollutant per litre of fuel consumed).

5.4.2 GHG and air emissions performance metrics

In this study, the GHG and air pollutants emissions from ACBSE fleets is analysed by adopting the following two key performance metrics:

(i) Annual emissions per vehicle km travelled (VKT), and

(ii) Emission per passenger-km travelled (PKT).

The emission per VKT provides an operational efficiency and indicates the overall energy efficiency and the GHG intensity of fuel used, and emission per PKT provides a measure of the efficiency of the service provided, and for a given type of vehicle decreases with increasing passengers occupancy rate (Climate Registry, 2010; Vuchic, 1981).

The emissions reduction potential of using different levels of biodiesel blends is computed and compared with a base case (use of only diesel oil). The change in the quantity of combustion products from heavy duty diesel engines run on various levels of biodiesel blends is estimated by using the following relation developed by US-EPA (US-EPA, 2002).

$$\%\Delta_{\text{emission},\,x} = (\exp[a_x * Vol_{Biodiesel}]-1)*100\% \qquad \textbf{[Equation 5]}$$

Where %Δ emission, x is the percentage change in quantity of air emission "x," "exp" is the natural logarithm, "a_x" is a constant corresponding to each type of air pollutant assessed, and $Vol_{Biodiesel}$ is the percentage volume of biodiesel in the biodiesel-diesel oil blend. The values of the coefficient "a" for the different air pollutants are shown in Table 14.

Table 14. Values of the coefficient "a" used in Equation 5.

Pollutants	Coefficient "a"
CO	-0,006561
HC	-0,011195
NOx	0,0009794
PM_{10}	-0,006384

Source: US-EPA (2002).

In addition to the GHG performance indicators indicated above, other performance indicators shown in Table 15 were computed to help capture other fleet efficiency and productivity measures following Vuchic (1981).

Table 15. Key performance metrics used in assessing urban bus services performance

Vehicle-km/vehicle	The total vehicle km reported divided by the fleet size in operation, and shows the efficiency of vehicle use.
Annual Passenger–km/vehicle	Total passenger-km divided by total number of vehicles operated. This indicator show how much work is done by one vehicle.
Vehicle-km/l	The total vehicle-km performance divided by total amount of diesel fuel consumed. This indicator shows the technical fuel efficiency of a vehicle.
Passenger-km/l	The total passenger-km performance divided by total amount of diesel fuel consumed. This indicator shows the energy efficiency of actually utilized services.

Source: Vuchic (1981).

5.5 Data sources

A time series data, 2004/5 to 2011/12, on total fleet size, number of operational vehicles, total distance covered by all vehicles, and total number of passengers carried was collected from ACBSE. Data for min- and midi bus taxi are from previous studies (COWI, 2007).

5.6 Assumptions and scenario development

Although, the fleet is categorized using the EURO emissions standard classification and the service years as proxy to date of manufacture within the Euro Emission Standard classes, the emissions factor corresponding to each Euro class is applicable if the fuel quality standard is also respected. Hence, given that the sulphur content of diesel oil in Ethiopia still very high 5000 ppm, the emissions from operation of all buses is assumed to be equivalent to a Euro I standard buses.

The following two scenarios, S1 and S2, are assessed and compared with a base case which assumes that ACBSE will continue to run its fleets on diesel oil, and that the service level provided by a single operational bus remains unchanged when using biodiesel blended fuel.

S1: Introduction of biodiesel blends: Beginning 2015, ACBSE bus fleet will run on various levels of biodiesel-diesel oil blends (B2, B5, B10 and B20). Specification of imported diesel oil to the country including the present sulphur content of 5000 ppm (0.5% mass) remains unchanged.

S2: Introduction of biodiesel blends B2, B5, B10 and B20: by 2015 ACBSE fleet continues to run on diesel oil with biodiesel blend levels ranging from B2 to B20, while imported diesel oil specification remains unchanged, but the content of sulphur in the diesel oil is reduced to less than 500 ppm.

5.7 Results and discussion

5.7.1 Performance of ACBSE

Over the last eight years, 2004/5 to 2010/11, the overall performance of the ACBSE in terms of annual passengers transported per bus as well as the average fuel efficiency is shown in Table 16. In this period, average annual passenger transported per bus has declined by half. The fuel efficiency, km travelled per litter of diesel oil, computed using total diesel oil consumption to total distance travelled by total number of bus dispatched in 2010/11was lower by 30% compared to 2004/5.

Table 16. Performance of ACBSE, 2004/5 to 2010/11

Fiscal Year	Annual average Vehicle-km/vehicle	Annual average Passenger/vehicle (thousand)	Average fuel efficiency (km/l)
2004/2005	62 682	606	2,86
2005/2006	64 135	550	2,89
2006/2007	53 013	479	2,44
2007/2008	44 962	432	1,88
2008/2009	53 398	338	1,84
2009/2010	52 748	342	1,89
2010/2011	54 737	333	2,00

Source: Own computation based on data from ACBSE (2012).

The decline in annual passenger per bus and also VKT, could be partly attributed to the introduction of the midi-busses that provide transport service on a relatively longer routes (8-10 km)[20] and therefore possibly compete with ACBSE fleets. The decline in fuel

[20] Midi-buses provide longer distance services (8-10 km) at a relatively higher price per passenger than ACBSE buses for the same distance, but availability of mini-bus service is high and hence passengers waiting time is considerably lower. Compared to cost of traveling the same distance with mini-bus taxis, midi-bus fare is much cheaper. These two factors appear to be major factors for introducing midi-bus taxi by the city administration.

efficiency could possibly be attributed to low efficiency of not well maintained and serviced aging fleets.

5.7.2 Baseline GHGs and air pollutant emissions

For the baseline case 2010/11 PKT and corresponding fuel consumption data of ACBSE are projected to 2015 and 2020 assuming that growth for public transportation services will increase at an annual rate of 9% (MoFED, 2012). The projection further assumes that the baseline average fuel efficiency of ACBSE fleets (km per litre) and PKT per bus remains unchanged.

The annual total emissions and specific emissions per vehicle and per PKT for 2010 and projections for 2015 and 2010 are shown in Table 17. The base line GHG emissions in CO_2 equivalent are computed using life cycle GHG emission factor for diesel oil (83.8g CO_2/l), and for the air pollutants the baseline air emissions factor are adopted from the international vehicle emission model (UNEP, 2009b).

Table 17. Total PKT, diesel oil demand and GHG and air pollution emissions from ACBSE fleets for 2010 to 2020

		2010	2015	2020
Total pass-km (million pass-km)		1 550	2 385	3 670
Total diesel oil consumption (000 litres)		8 089	12 446	19 150
GHG (ton)	CO2eq	24 307,5	37 400,0	7 544,6
Air pollutants (ton)	CO	190,5	293,2	451,1
	HC	40,9	62,9	96,7
	NOx	329,4	506,8	779,8
	PM_{10}	21,6	33,3	51,2
	S0x	15,7	24,1	37,1

Source: own computation

5.7.3 Results of Scenario I

Under scenario I, the annual saving of GHGs from use of different levels of biodiesel-diesel oil blends is shown in Table 18 and Figure 18. The net GHG saving from one litre of diesel displaced by one litre of biodiesel (using results of the base case results, with no land use change impact and no co-product credit considered) is 1300 g CO_2eq[21].

The result shows that introducing B5 in 2015 will provide a net GHG reduction of about 320 tons CO_2eq. And increasing the blend to B20 by 2020 will increase the potential saving to almost 5000 tons of CO_2eq/yr.

Table 18. Baseline projected GHG emissions and GHG emissions reduction from the use of four different blends (tons CO_2eq).

		Reduction in GHG emissions			
	Base case	B2	B5	B10	B20
2015	37400	323,9	809,7	1619,4	3238,8
2020	57545	498,3	1245,8	2491,7	4983,4
% change		-0,9%	-2,2%	-4,3%	-8,7%

Source: Own computation.

[21] The net emission reduction per litre of biodiesel is = [43.3% emission reduction gained from substitution of one unit of diesel oil energy with equal amount of biodiesel energy]*[83.8 gCO2 /MJ diesel oil] *[35.86 MJ/l diesel oil].

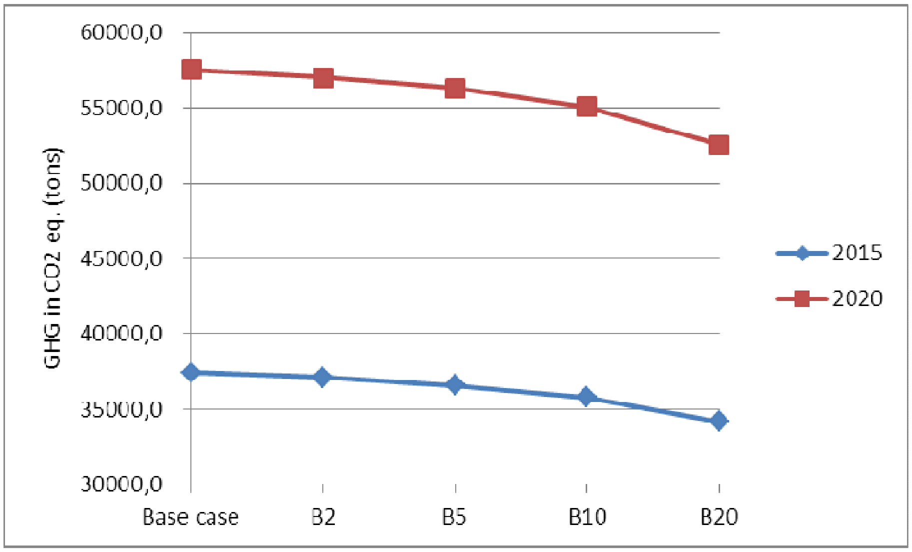

Figure 18. Trend in total annual GHG emissions reduction from use of different biodiesel blends.

The relative change in emissions of air pollutants from use of different biodiesel blends is presented in Table 19. The relative change estimates are based on the relation, Equation 5, developed by US-EPA (US-EPA 2002), while change in sulphur oxides emission is assumed to be proportional to the volume of diesel displaced.

The result show that emission of NOx increases nearly proportionally to increase in biodiesel content of the blends, while the actual magnitude of change appears to be relatively small, higher biodiesel blend level in general results in reduction of all other air pollutants ranging from:1,3% reduction for CO and HC with B2, rising to 13% with use of B20. Highest benefit appears to be the reduction in total HC emissions which is directly proportional to the volume of the biodiesel in the blend.

Table 19. Scenarios I, baseline projection of air emissions from ACBSE and percentage emissions reductions resulting from use of different biodiesel blends, 2015.

	Change in emissions			
Air pollutants	B2	B5	B10	B20
CO	-1,30%	-3,23%	-6,35%	-12,30%
HC	-2,21%	-5,44%	-10,59%	-20,06%
NOx	0,20%	0,49%	0,98%	1,98%
PM_{10}	-1,27%	-3,14%	-6,18%	-11,99%
SOx	-2.00%	-5.00%	-10.00%	-20.00%

Source: Own computation

5.7.4 Results of Scenario II

The results of implementation of Scenario II, shows that reducing the sulphur content of diesel oil from 5000 ppm to 500 ppm will provide significant emission reduction in terms of S0x emissions, and when combined with the impact of a well-functioning DOC fitted buses, the total emissions of all major pollutants except NOx, compared to the projected baseline emissions, could be reduced by 60 to 90% for CO and HC, and 20-30% for PM_{10} (UNEP 2009a). Table 20 shows the potential reduction in CO, HC and PM and SOx achieved by importing diesel oil with lower sulphur content,(500 ppm), retrofitting vehicles with DOC, and the relative percentage reduction of CO, HC and PM and SOx achieved through introduction of different biodiesel blend relative to DOC.[22]

The reductions of most of the air pollutants will, however, incur additional capital and operating costs. UNEP (2009c) estimates that the additional cost of importing a litter of

[22] Reduction NOx is possible with DPF but effective performance of PDF requires availability of ultra-low, less than 50 ppm sulphur in diesel oil, which is not expected to happen soon in Ethiopia.

diesel oil with sulphur content of 500 ppm would have modest increase in cost of fuel and, since DOCs fitted in older buses are considered to have already been destroyed, or become ineffective, achieving these emission reduction levels will require additional capital expenditures of USD 600 to 2000 per DOC (UNEP, 2009c).

Table 20. Magnitude of air pollutants emissions reduction from use of DOC and the relative contribution of Biodiesel blends to impacts of use of DOC on CO, HC and PM_{10}

	2015	Reduction	Emissions reduction of blends relative to DOC			
Air emissions	**base case**	**DOC**	**B2**	**B5**	**B10**	**B20**
CO	293,2	175,9	2%	5%	11%	20%
HC	62,9	37,7	4%	9%	18%	33%
PM_{10}	33,3	6,7	6%	16%	31%	60%
S0x	24,1	21,7	2%	6%	11%	22%

Source: Own computation.

5.8 Comparison of GHG and air pollutants emissions from ACBSE with min- and mid-bus taxis

The base case emissions from ACBSE are compared to emissions generated by mini-bus and midi-bus taxis operated in Addis Ababa. The total annual air pollutant emissions per vehicle and per PKT for the three public transportation services are shown in Table 21 and Table 22.

On a per vehicle basis, the estimated for the average daily emissions of SOx and PM_{10} from ACBSE bus are higher than the corresponding emissions from a mini-bus and midi-bus; HC from ACBSE is also twice as much higher than from midi-bus. This appears to be mainly due to the higher daily activity (distance) covered by single ACBS bus compared to either mini-bus or midi-bus taxi.

CO and HC emissions are highest for mini-buses. The high CO and HC emissions from min-buses is mainly attributed to the high emission factor (Table C.5, Annex C) associated with gasoline engines use in most of the min-buses, and their age (15-20 years of service), making mini-bus taxis the major contributors to CO and HC, but less so for SOx and PM10 which respectively is associated with combustion of high sulphur fuels and diesel engine operations. However, when comparison is made on the basis of service delivered – emissions per PKT - the ACBSE bus shows significantly better emission performance than both the mini-bus or midi-bus taxis (except on particulate matter emissions when compared to min-buses). Further enhancement in emissions performance for ACBSE could be achieved when use of biodiesel blends is considered.

Table 21. Base case scenario: emission of air pollutants for the three modes of public transportation in Addis Ababa (g/vehicle-day)

	CO	HC	NOx	SOx	PM_{10}
City bus (ACBSE)	1 770	379	3 059	145	201
Min-bus (private)	4 579	764	218	4	1
Midi-bus (private)	962	185	1 681	77	75

Source: Own computation

Table 22. Base case scenario: emission of air pollutants for the three modes of public transportation in Addis Ababa (g/PKT)

	CO	HC	NOx	SOx	PM_{10}
City bus (ACBSE)	0,12	0,03	0,21	0,01	0,01
Min-bus (private)	5,76	0,96	0,27	0,01	0,00
Midi-bus (private)	0,34	0,07	0,60	0,03	0,03

Source: Own computation

6 Conclusions and recommendation

6.1 Conclusions

GHG emission impacts of JME

- For the base case, where no land use change impact is considered, the substitution of diesel oil with JME will provide about 43% GHG emission reduction relative to diesel oil used in the transport sector.
- For the analysis period considered (20 years), conversion of lands such shrub lands and forest lands with canopy cover of over 30% will produce more GHG emission per annum than can be saved by substitution of JME for diesel oil.
- Using the GHG saving potential computed under the base case scenario, the ECPT required to off-set the total GHG emissions due to land use change range from 50 to 600 year, with the higher ECPT corresponding to shrub lands and forest lands with above 30% canopy cover.

Net energy balance

- In most of the cases considered and analysed local production and use of JME compared to diesel oil use in transportation shows positive impact in reducing non-renewable (fossil fuel) energy demand and contributes to resource conservation, and at a country level it will contribute in reducing the total volume of diesel oil import.

Land requirement for implementing B5 mandate and land use efficiency

- Total land area required for meeting B5 mandate in Ethiopia, compared to available agricultural land, is relatively small, less than 1% of grass land, or 3% of what is claimed to be available and indicated in the GoE biofuels strategy.
- However, the actual land area required will be a function of the land use efficiency which in turn is influenced by actual and or achievable seed yield per ha at optimal land management practices.
- Estimating land area availability using very crude indicators such as land cover data will not be adequate and may lead to gross overestimation of actual land that is available and suitable for development of *Jatropha* plantations.

The ACBSE case study shows that:

- The positive GHG impact of use of JME-diesel oil blend increases with increasing level of biodiesel in the blend but increasing the JME content of the blends also contributes to increase in emission of NOx, although at a relatively lower rate than the emission reductions achieved for CO, HC PM_{10} and SOx.
- Introducing low sulphur diesel (500 ppm or less) and use of DOC on all operational buses of ACBS will have significant impact in reducing CO, HC PM_{10}. The net impact of introducing low sulphur diesel oil and DOC, compared to relative reduction achieved with B5 will be; CO emissions will be lower by a factor of 12, HC and PM_{10} by a factor of 7 and 25, respectively, and SOx by a factor of 2.
- Use of biodiesel blends in Addis Ababa could have a significant impact on reduction of air pollutants emission and contribute to the improvement of local air quality.

6.2 Recommendation

- Land availability and suitability assessment using sufficiently adequate methodology need to be developed and used for estimating the potential land that could be used for development of *Jatropha* or other oilseed bearing plants in Ethiopia.
- Set minimum GHG reduction and NEB requirements on biofuels including JME: standards specifying minimum net life cycle based GHG reduction requirement and NEB (or NEY) of biodiesel fuels relative to diesel oil shall be introduced to ensure sustainability of biodiesel production and use as well as contribution of biodiesel to energy security.
- Adopt standard computational procedures for estimating GHG and NEB: consistency in estimation of relative net GHG emission reduction and NEB, and making fair comparison of biodiesel with diesel oil need to follow standard procedure. This requires employing LCA methodology that incorporates LUC impacts as presented in this study, and the establishment and regular updating of LCA-database,
- Adopt standard computational procedures for conducting financial and economic viability of biofuels. The procedure should be designed to address and show how the benefits accruing from JME/biofuels development projects (programs) are shared with local communities.

6.3 Future research needs

- **Land suitability and availability assessment** is a key issue that should be addressed with due consideration, and an important input for informing the policy making process and improving the GoE’s biodiesel development strategy.
- **Environmental and Financial / economic feasibility of:**

- JME production under different production scale: (i) large-scale plantation with central oil processing and JME production unit; (ii) small-scale *Jatropha* seed production by small holder farmers as seed supplier to decentralised oil processing unit with central JME production unit.
- Biodiesel production from alternative oil-seed plants indicated in the biofuels strategy of Ethiopia Castor (*Ricinus communis*), Palm oil (*Elaeis guineensis*) as well as other multipurpose trees such as Moringa (*Moringa oleifera*), Neem (*Azadirachta indica*) that are well adapted to low rainfall lowland areas of the Country.
- Use of straight Oil (*Jatropha* and others) for industrial furnaces/boilers.

* **Application of a comparative multi-criteria decision making tools** for providing a more comprehensive analysis which integrates environmental sustainability and economic viability of biodiesel production from a set of oilseed plants (*Jatropha*, Neem, Pongamia (*Milletia pinnata*) and Moringa) in Ethiopia.

References

Achten W 2010. Sustainability Evaluation of Biodiesel form *Jatropha Curcas* L. Life Cycle Oriented Study. PhD thesis, Katholieke Universiteit Leuven, Belgieum.

Achten W, Almeida J, Fobelets V, Bolle E, Mathijs E, Singh VP, Tewari DN, Verchot LV & Muys B 2010. Life cycle assessment of *Jatropha* biodiesel as transportation fuel in rural India. Applied Energy 87, 3652-3660. *https://perswww.kuleuven.be/~u0053809/Publications/WA_AE2010_OpenAccess.pdf*. Accessed 1 February 2011.

Beerens P 2007. Screw-pressing of *Jatropha* seed for fuelling purposes in less developed countries. MSc dissertation Eindhoven University of Technology.

Berchmans HJ & Hirata S 2008. Biodiesel production from crude *Jatropha curcas* L. seed oil with a high content of free fatty acids. Bioresources Technology 99: 1716-1721, ScienceDirect. *http://www.Jatropha-alliance.org.* Accessed 5 August 2011.

BioGrace 2012. Biofuel GHG calculation tool, version 4B Public. *http://www.biograce.net*. Accessed 18 September 2012.

CEC 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. On the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

CEC 2006. An EU Strategy for Biofuels. *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0034:FIN:EN:PDF*. Accessed 10 January 2011.

Climate Registry 2012. Performance Metrics for Transit Agencies. http://ebookbrowse.com/performance-metrics-for-transit-agencies-v-1-0-pdf. Accessed 20 November 2012.

CML 2001. Life Cycle Assessment: An Operational Guide to ISO Standards. Final report May 2001. Institute of Environmental Science (CML) at the Leiden University, Netherlands.

COWI 2007. National Transport Master Plan Study, Working Draft Master Plan, APPENDIX 1.8, Urban Transport, Ethiopia.

DEFRA 2008. Review of Work on the Environmental Sustainability of International Biofuels Production and Use. A Report by AEA Technology plc EC 2010. International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. Joint Research Centre - Institute for Environment and Sustainability First edition March 2010. Luxembourg.

EIA 2011. Weekly OPEC Countries Spot Price FOB Weighted by Estimated Export Volume (Dollars per Barrel). *http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=WTOTOPEC&f=W,* Accessed 22 January 2011.

Energy Changes 2008. Calculation of the emission factor of Ethiopia's electric power system according to UNFCCC methodological tool "tool to calculate the emission factor for an electric system."

EPA 2004. Ambient Environment Standards for Ethiopia Guideline. Addis Ababa.

ES 2008. Ethiopian Standard, ES 624:2008, gasoline for motor vehicles - specification. Quality and Standard Authority of Ethiopia. Addis Ababa.

ES 2004. Ethiopian Standard, ES 993:2004, Diesel fuel oil - specification. Quality and Standard Authority of Ethiopia. Addis Ababa.

Etyemezian V, Tesfaye M, Yimer A, Chow JC, Mesfin D, Nega T, Nikolich G, Watson JG & Wondemagegn M 2005. Result from a pilot scale air quality study in Addis Ababa. Atmospheric Environment 39 (2005). *http://www.sciencedirect.com/science/journal/13522310/39/40.* Accessed on 6 December 2012

Euler H & Gorriz D 2004. Case Study "*Jatropha Curcas*". Global Facilitation Unit for Underutilized Species (GFU), Frankfurt, Germany. *http://www.cropsforthefuture.org/publication/strategic-document/Case%20Study%20Jatropha%20curcas%20in%20India.pdf.* Accessed 10 February 2013.

Everson CS, Mengistu MG & Gush MB 2012. A field assessment of the agronomic performance and water use of *Jatropha curcas* in South Africa, Biomass and Bioenergy (2012) xxx I-II. *http://www.sciencedirect.com.oasis.unisa.ac.za/science/article/pii/S0961953412001432*. Accessed 12 August 2012.

FACT 2009. *Jatropha* Handbook 2nd edition, FACT Foundation, NL, June 2009.

FAO 2008. The State of Food and Agriculture. Biofuels: prospects, risks and opportunities.

FAO & PISCES 2009. Small-Scale Bioenergy Initiatives. Brief Description and Practical Lessons on Livelihood Impacts from Case studies in Asia, Latin America and Africa. Final Report by Practical Action Consultants.

Fargione J, Hill J, Tilma D, Polasky S & Harowthorne P 2008. Land Clearing and the Biofuel Carbon Debt. Journal of Science vol. 319. http://climateknowledge.org/figures/Rood_Climate_Change_AOSS480_Documents/Fargione_Land_Clearing_Biofuels_Science_2008.pdf. Accessed 05 December 2011.

Francis G, Edinger R & Becker K 2005. A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of *Jatropha* plantations. Natural Resource Forum 29:12–24.

FTAE 2012. Final Draft Report on Pilot Global Fuel Economy Initiative Study in Ethiopia. Addis Ababa, Ethiopia,

Gerbens-Leenes W, Hoekstra A & Van de Meer TH 2009. The Water Footprint of Bioenergy. PNAS, June 23 2009, Vol 106, No. 25, 10219-10223. *http://www.pnas.org/cgi/doi/10.1073/pnas.0812619106.* Accessed 10 August 2012.

Gerhard K, Jon Van G & Jürgen K 2005. The Biodiesel Handbook. AOCS press, Champaign, Illinois.

Gibbs HK, Johnston M, Foley JA, Holloway T, Monfreda C, Ramankuty N & Zaks D 2008. Carbon payback time for crop-based biofuels expansion in the tropics: the effects of changing yield and the technology. Environmental Resource Letters, IOP publications. *http://www.sage.wisc.edu/pubs/articles/F-L/gibbs/gibbsetalERL2008.pdf.* Accessed 10 January 2012.

Heller J 1996. Physic nut. *Jatropha curcas* L. Promoting the conservation and use of underutilized and neglected crops. International Plan Genetic Resources Institute, Rome. *http://www.bioversityinternational.org/fileadmin/bioversity/publications/pdfs/161_Physic_nut__Jatropha_curcas_L.pdf* . Accessed 10 November 2011.

HoAREC 2009. International Bio-fuels Conference Proceeding No.1 .Status of Bio-fuels Development and use in Ethiopia.

Holl M, Gush MB, Hallowes J & Versfeld DB 2012. Water use assessment of *Jatropha curcas*. *Jatropha curcas* in South Africa: An Assessment of its water use and bio-physical potential. *http://www.aqscenion-publishing.com/BIZ/Jatrophawater.pdf*, Accessed 10 August 2012.

IBIS 2005. Study of urban public transport conditions in Addis Ababa, Ethiopia. IBIS Transport Consultants Ltd, March 205.

IEA 2008. Transport, Energy and CO_2. Moving Towards Sustainability. http://www.iea.org/publications/freepublications/publication/transport2009.pdf. Accessed 10 February 2012.

IFAD 2010. *Jatropha*: A Smallholder Bioenergy Crop. The Potential for Pro-Poor Development Integrated Crop Management Vol. 8–2010

IFEU 2008. Basic Data for *Jatropha* Biofuel Production and Use - Updated Version. IFEU - Institute for Energy and Environment Research. Germany.

IFEU 2007. Screening life cycle assessment of *Jatropha* biodiesel. IFEU - Institute for Energy and Environment Research. Germany.

IPCC 2007. Fourth Assessment report (AR4) WG1 Chapter 2, Atmospheric Constituents and in Radiative Forcing, table 2,14, page 212. *http://www.climatechangeconnection.org/emissions/documents/GWP_AR4.pdf*. Accessed 18 Sept 2012.

IPCC 2006. Guidelines for National Greenhouse Gas Inventories. N_2O Emissions from Managed Soils, and CO_2 from Lime and Urea Application.

Jackson T (ed) 1993. Renewable energy: prospect for implementation. SEI, Journal of Energy Policy. Butterworth-Heinemann. Oxford, UK.

Jongschaap REE, Corré WJ, Bindraban PS & Brandenburg WA 2007. Claims and facts on *Jatropha curcas* L. – Global *Jatropha curcas* evaluation, breeding and propagation programme. Plant Research International, Wageningen, UR. *http://www.fact-fuels.org/media_en/Claims_and_Facts_on_Jatropha_-WUR*. Accessed 1 February 2011.

JRC 2010. Background Guide for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme Drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. EUR 24573 EN. Luxembourg. http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/15261/1/biofuel_guide_final.pdf. Accessed 10 June 2011.

Kinfu M 2008. Investigation of Alternative Locally Available Feedstock Sources for Biodiesel Production in Ethiopia. MSc thesis in Environmental Sciences, Addis Ababa University, School of Graduate Studies Environmental Science Program.

Kheira A & Atta A 2009. Response of *Jatropha curcas L*. to water deficits: Yield, water use efficiency and oil characteristics. Accessed 5 October 2012.

Kywe TT & Oo MM 2009. Production of Biodiesel from *Jatropha* oil (*Jatropha Curcas*) in pilot plantation. World Academy of Science, Engineering and Technology 26:, 477-483. *http://www.Jatropha-alliance.org*. Accessed 05 Aug 2011.

Maddox P 1978. Energy Modelling and Net Energy Analysis. “Net energy: Concepts, Issues and Case Studies (Collection)”. In Encyclopaedia of Earth. Eds. Cutler J. Cleveland. Washington DC.

Maes WH, Trabuccoa A, Achten W & Muys B 2009. Climatic growing conditions of *Jatropha curcas L*. Biomass and Bioenergy, 33:1481-1485.

Majer S, Langer MF, Zeller V, & Kaltschmitt 2009. Implication of biodiesel production and utilisation on global climate – literature review. European Lipid Science Technology 111: 747-762.

MECM 1998. The Impact of Gasoline Fuel Sulphur on Catalytic Emission Control Systems. Manufacturers of Emission Controls Association. Washington, DC.

MELCA 2008. Rapid Assessment of Biofuels Development Status In Ethiopia. Proceeding of the National Workshop on EIA and Biofuels. Addis Ababa.

MoA 2004. Woody Biomass Inventory and Strategic Planning Project (WBISPP), Final Report, Addis Ababa.

MoFED 2012. Climate Resilient Green Economy. Federal Democratic Republic of Ethiopia.

MoFED 2010. Growth and Transformation Program, Federal Democratic Republic of Ethiopia,

MME 2007. Biofuels Development and Use Strategy, Ethiopia. Addis Ababa.

Moser BR 2009. Biodiesel production, properties, and feedstock. *http://biodieselfeeds.cfans.umn.edu/articles-general/2009-Moser-Biodiesel%20production.pdf.* Accessed 10 June 2012.

Mortimer ND 2011. Life Cycle Assessment of Refined Vegetable Oil and Biodiesel from *Jatropha* Grown in Dakatcha Woodlands of Kenya. *http://www.actionaid.org.uk/doc_lib/kenyan_Jatropha_final_report.pdf.* Accessed 10 June 2012.

Mulder K & Hagens NJ 2008. Energy Return on Investment: Towards a Consistent framework. Ambio Vol. 37, No. 2, 2008.

MWE 2011. Energy Balance and Statistics for years 2005/6 - 2009/10. Addis Ababa.

Nadew 2012: Personal Communication. Director, Biofuels Development and Utilization Directorate, MWE, Ethiopia.

NBE 2011. National Bank of Ethiopia: Annual Report 2010/11. Addis Ababa.

NBE 2009. National Bank of Ethiopia: Annual Report 2008/09. Addis Ababa.

Ndong R, Monterjaud M, Girons OS, Gabrielles B, Pirot R, Domergue M & Sablayrolles C 2009. Life Cycle Assessment of biofuels from *Jatropha curcas* in West Africa: a field study. Bioenergy 1:197–210.

OeKo 2008. Degraded Land and Sustainable Bioenergy Feedstock Production. Issue paper. ÖKO-Institute, Darmstadt.

Parthiban KT, Selvan P, Paramatma M, Kannan SU, Kumar P, Subbulakshmi V &Vennila S 2011. Pysico-chemical characterization of seed oil from *Jatropha curcas* L. genetic resources. Journal of Ecology and the Natural Environment, 3:163-167.

Paz A & Visser P 2011.Greenhouse Gas calculation Jatropha value chain. Sun Biofuels Mozambique SA. Report produced for Sun Biofuels Mozambique SA and *Jatropha* Alliance. *http://www.Jatropha-alliance.org/fileadmin/documents/GHG_calculations_Sun_Biofuels_Mozambique_SA__final.pdf*. Accessed 1 January 2011.

Prueksakorn K & Gheewala SH 2008. Full Chain Energy Analysis of Biodiesel from *Jatropha curcas* L.in Thailand. The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand. *http://www.energy-based.nrct.go.th/Article*. Accessed 20 January 2011.

Prueksakorn K, Gheewala SH, Malakul P & Bonnet S 2010. Energy analysis of *Jatropha* plantation systems for biodiesel production in Thailand. Energy for sustainable development. *http://www2.mtec.or.th/website/doc_sys/upload/17_Jatropha_Plantation_Energy_ESD10%5B1%5D.pdf.* Accessed 20 January 2011.

Jatropha

Romijn HA 2011. Land Clearing and greenhouse gas emissions for *Jatropha* biofuels on African Miombo Woodlands. Energy Policy (2010). *http://www.Jatropha.pro/PDF%20bestanden/Romijn%20GHG%20Emissions%20from%20Jatropha%20Biofuel%20revised%20%20for%20FACT%2003-07-2009%5B1%5D.pdf.* Article in Press. Accessed 10 March 2011.

RSB 2012. Towards Sustainable Biofuels in Ethiopia. A report produced by the secretariat of Roundtable on Sustainable Biofuels, Energy Centre Ecole Polytechnique Fédérale de Lausanne.

Sanford SD, White MJ, Shah SP, Wee Claudia, Valverde AM & Meier RG 2009. Feedstock and Biodiesel Characteristics Report. Renewable Energy Group Inc. *http://www.regfuel.com/sites/default/files/pdf/Feedstock%20and%20Biodiesel%20Characteristics%20Report.pdf.* Accessed 9 May 2012.

Schipper L. Cordeiro M & Wei-Shiuen NG 2007. Measuring the Carbon Dioxide Impacts of Urban Transport Projects in Developing Countries. *http://pdf.wri.org/measuring-co2-impacts-transport-projects-developing-countries.pdf.* Accessed November 2012.

UNEP 2009a. Cleaning up Urban Bus Fleets with a focus on developing and transition countries. *http://www.unep.org/tnt-unep/toolkit/TOOLKIT-USERMANUAL.pdf.* Accessed 12 December 2012.

UNEP 2009b. How to clean up your fleets. Toolkit User Guide/Version 2/May 2009. *http://www.unep.org/tnt-unep/toolkit/TOOLKIT-USERMANUAL.pdf*. Accessed 12 December 2012.

UNEP 2009c. Clean up Your Fleet Textbook. *http://www.unep.org/tnt-unep/toolkit/ToolkitTextBook.pdf*. Accessed 12 December 2012.

UNEP 2005. Life Cycle Approaches: The road from analysis to practice. UNEP/ SETAC Life Cycle Initiative. *http://www.unep.fr/shared/publications/pdf/DTIx0594xPA-Road.pdf*. Accessed 1 January 2011.

UNEP 2003. Evaluation of Environmental Impacts in Life Cycle Assessment. Meeting report Brussels, 29-30 November 1998, and Brighton, 25-26 May 2000.

US-EPA 2002. A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, Draft technical report, USEPA.EPA420-P-02-001, 01.10.2002A

Whitaker M & Heath G 2010. Life cycles Assessment of the use of *Jatropha* Biodiesel in the Indian Road and Rail Sectors. Technical Report NREL/TP-6A2-47462 May 2010. *http://www.nrel.gov/docs/fy10osti/47462.pdf*. Accessed 10 January 2012

WHO 2004. Outdoor Air Pollution: Assessing the Environmental Burden of Disease at National and Local Level. *http://www.who.int/quantifying_ehimpacts/publications/ebd5.pdf*. Accessed 12 November 2012.

Vuchic VR 1981. Urban Public Transportation: system and technology. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

Annexes

Annex A

Table A.1. Areas under woodlands, shrub lands and grasslands in Ethiopia (thousand ha)

Region	Woodlands	Shrub land	Grass lands	Total
Oromiya	9823	7750	4294	21868
SNNPR	1388	2435	1715	5538
Gambella	1167	149	970	2286
Beneshangul-Gumz	2473	1422	162	4057
Amhara	1040	4353	2696	8089
Tigray	294	1841	1159	3294
Afar	164	3025	1403	4591
Somali	13200	5384	2168	20751
Total	**29549**	**26359**	**14567**	**70475**

Source: MoA 2004. Woody Biomass Inventory and Strategic Planning Project (WBISPP), Final Report, Addis Ababa

Table A.2. Woodland and shrub lands of Ethiopia, vegetation, climatic conditions and current uses.

Woodland and Shrub land	Elevation (masl)	Rainfall(mm)	Current use
Broadleaved Deciduous Woodlands: These woodlands dominate the woodlands and shrub lands of the western and southern lowlands in the Tekeze, Abay and Omo-Gibe valleys. Characteristic species of this woodland type are Combretum collinum, Combretum molle, Acacia polyacantha, Acacia seyal and Terminalia brownii.	300-1700	800-1400	They are not heavily used economically mainly due to malaria and tsetse fly. The presence of Oxytenanthera abyssinica makes them susceptible to frequent fires
Acacia Woodlands: They are the climax vegetation for the higher rainfall areas of the rift valley in Amhara and Tigray Regions. They are dominated by Acacia species such as A. tortilis, A. seyal, A. etbaica, A. mellifera and A. Nilotica	1500-2000	800 to1000	
Lower Semi-arid Boswellia-Commiphora-Acacia woodland-shrub land: They are found in areas with lower annual rainfall ranging from. This together with overgrazing has left much of the soil bare which is susceptible to both wind and water erosion.		700 to 500	They have been depleted in recent years in order to supply wood for charcoal. Much of the vegetation has also been cleared for agriculture particularly in the rift valley
Lower Semi-Arid to Arid Acacia-Commiphora woodland-shrub land: They occur mainly in the southern, eastern and central parts of the country. It has Acacia tortolis, Acacia seyal, Acacia senegal, Acacia etbaica.	900-1900	500 to 350	They have been depleted in order to supply wood for charcoal. They are also cleared for agriculture mainly in the rift valley.
Arid Sparse Shrubland: The vegetation consists of deciduous shrubs mostly Acacia species. The vegetation consists of shrubs of Acacia tortilis, Salvadora persica and Zizyphus spp.	<1400	< 350	

Source: MoA 2004. Woody Biomass Inventory and Strategic Planning Project (WBISPP), Final Report, Addis Ababa

Table. A.3. Land allocated and promised to biodiesel investors

Biodiesel company	Land allocated or under negotiation (ha)	Region Location	Present land use	Remark
Horizon PLC	53 000	Gambela	Natural forest	
East African Holdings	40 000	Gambela	Dense forest	
Jatropha biofuels agro-industry	80 000	Benshangul Gumz	Forest area	
IDC	15 000	Benshangul Gumz	Multipurpose	
Sun Biofuesl / NBC	80000	Benshangul Gumz	Forest, woodland, range land	
Ambasel *Jatropha* Project	20 000	Benshangul Gumz	Natural forest	Applied 80,000 ha
Floral Eco Power Ethiopia	15 000	Missing data	Forest, bush land, cultivated land	Required 200,000
Global Energy Ethiopia	2500	SNNPR	Agricultural land	Planned 7,500 ha, contract with 25,000 out growers
Vatic international	50 000	ANRS	Farm land	
Total	355 500			

Source: MELCA 2008.

Annex B

Table B.1 Heating values and density of diesel oil and JME

	Unit	Value	Ref.
LHV diesel	MJ/kg	43,10	Calculated
	MJ/l	35,86	Biograce
Density of diesel oil	kg/lt	0,832	BioGrace
LHV FAME (JME)	MJ/kg average	37,20	BioGrace
	MJ/l	33,11	BioGrace
Density of JME	kg/l average	0,890	Calculated
JME equivalent to FU	kg	26,88	to provide 1 FU of JME

Source: BioGrace 2012. Biofuel GHG calculation tool, version 4B Public.

.

Table B.2 Embedded energy of materials input and associated emissions in the production and use of chemical input (cultivation and biodiesel production processes)..

Inputs	**GHG emission coefficient**				**Fossil energy**
	gCO_2/kg	gCH_4/kg	gN_2O/kg	$gCO_{2\text{-}eq}$/kg	MJ_{fossil}/kg
Cultivation					
N-fertilizer (kg N)	2827,0	8,68	9,6418	5917,2	48,99
P_2O_5-fertilizer (kg P_2O_5)	964,9	1,33	0,0515	1013,5	15,23
K_2O-fertilizer (kg K_2O)	536,3	1,57	0,0123	579,2	9,68
CaO-fertilizer (kg CaO)	119,1	0,22	0,0183	130,0	1,97
Pesticides	9886,5	25,53	1,6814	11025,7	268,40
Biodiesel production					
Sulphuric acid (H_2SO_4)	193,9	0,55	0,0045	208,8	3,90

Source: BioGrace 2012. Biofuel GHG calculation tool, version 4B Public.

Table B.3. Cultivation process: inputs and associated fossil fuel energy consumption and GHG emissions

Input	Unit	Qty	fossil fuel energy (MJ/l or kg-input)	Fossil fuel energy (MJ/ha-yr.)	GHG Emissions (per ha-yr.)				GWP (g CO2eq per FU)
					g CO2	g CH4	g N2O	g CO2equ	
Diesel tractor	l-diesel/ha-yr.	55,0	35,9	1972,3	165275,1	0,0	0,0	165275,1	7.467,0
Diesel fuel (irrigation)1	l-diesel/ha-yr.	55,5	35,9	1990,2	166777,6	0,0	0,0	166777,6	7.534,8
Urea as Nitrogen (N)	kg/ha-yr.	12,2	49,0	595,2	34348,1	105,5	117,1	71894,7	3.248,1
DAP (P205)[3]	kg/ha-yr.	4,7	15,2	70,8	4486,8	6,2	0,2	4712,8	212,9
Potassium phosphate (K20)	kg/ha-yr.	13,4	9,7	129,2	7159,6	21,0	0,2	7732,5	349,3
Pesticides	kg/ha-yr.	0,156	268,4	41,9	1542,3	4,0	0,3	1720,0	77,7
Total				4800	379589	137	118	418113	18890

Source: own computations based on baseline data provided in table 7.

Note: Assumed that ifor the first three years - fertilizer input will be granted - then after returned coat and seed cake will be used,

Hectare of land per FU = 0,0452

Table B.4 Oil extraction process: inputs and outputs for per FU (1000 MJ of JME)

Input	Unit	Quantity	Energy per FU	GHG Emissions Per FU			
			(MJ)	g CO2	g CH4	g N2O	g CO2equ
Mechanical dehusking	MJ-diesel/ton-capsule	92,57	15,93	1334,61			1334,61
Screw press	kWh/kg-seed	0,15	16,13	0,10			0,10
Refining	kWh/kg-CJO	0,014	0,52	0,00			0,00
Total			32,57	1334,71	0,00	0,00	1334,71

Source: own computations based on baseline data provided in Table 7.

Ethiopia's gird emission factor = 0,006 kg CO2 eq. / kWh (Source: Energy Changes, 2008. Calculation of the emission factor of Ethiopia's electric power system according to UNFCCC methodological tool "tool to calculate the emission factor for an electric system)

".

Table B.5. Biodiesel production process: inputs and outputs per FU (1000 MJ of JME)

Biodiesel production	Unit	Quantity	Energy per FU (MJ)*	GHG Emissions per FU g CO_2	g CH_4	g N_2O	g CO_2eq
Electricity	kWh/kg-biodiesel	0,42	11,29	0,07			0,07
Steam/process heat	MJ/kg - biodiesel	0,10	2,76	0,02			0,02
Methanol	kg/kg-biodiesel	0,20	106,99	498,91	38,98	0,53	1632,61
KoH	kg/kg-biodiesel	0,03	6,76	374,84	27,45	2,56	1824,48
H_2SO_4	kg/kg-biodiesel	0,02	2,10	104,25	7,39	0,72	503,91
Total			129,90	978,08	73,82	3,82	3961,09

Source: own computations based on baseline data provided in Table 7.

* Except for Electricity which is in kWh

Table B.6. Emission from transportation of process inputs

	Unit (ton load)	Emission (g CO2/ton of load)*	Load (ton/FU)	Emission (g CO2/FU)
Seed to oil processing unit				
Truck small (3,5 ton capacity)	ton seed	3681	0,1075	395,8
Biodiesel to Addis Ababa	ton JME			
Truck (20000 litter capacity)		13673	0,0269	367,5
Fertilizer import	ton fertilizer	227777	0,00225	513,2
Diesel oil import	ton diesel oil	91578	0,00415	380,4
Total				1657,0

Source: Own computation

Computed based data shown in Table B7. below ;

Land area requirement ha-yr./FU = 0,0452

Table B.7.Emissions associated with see freight and inland transport of diesel oil (g CO2 eq./ton)

Sea freight	Distance (Km)	Fuel efficiency # (MJ/ton-km)	EF* (g CO2eq/ton-km)	EF (g CO2eq/ton-diesel oil)
Saudi Arabia, Jeddah to Djibouti#	1224	0,124	11	13219,6
In land road transport				
Djibouti to Addis Ababa	887	1,008	88,34	78358,6
Total transport emissions				91578,2

Source: BioGrace 2012. Biofuel GHG calculation tool, version 4B Public.

Fuel efficiency of ship, bulk tanker (using fuel oil), 0,124 MJ/ton-km; Emission factor heavy fuel oil (HFO) for maritime transport 87,200 g CO2 eq./MJ

Table B.8. Emissions associated with sea freight and in land transport of fertilizer (g CO2 eq./ton)

	Distance (km)	Fuel efficiency # (MJ/ton-km)	EF* (g CO2eq/ton-km)	EF[1] (g CO2eq/ton-fertilizer)
See freight				
Amsterdam, NL to Djibouti#	8732	0,204	18	155015
In land				
Djibouti to Addis Ababa	887	0,936	82,03	72762
Total			**99,78**	**227777**

Source: Own computation.

* Data source: **Source**: BioGrace biofuel GHG calculation tool, version 4B Public.

Fuel efficiency Ship / product tanker 50kt (Fuel oil) 0,204 MJ/ton-km; Energy content HFO for maritime transport 87,20 g CO2 eq./MJ

Emission factor for Diesel oil 87,64 g CO2 eq./MJ

Table B.9. Emissions associated with local *Jatropha* seed and JME transport (g CO2 eq./ton)

		Quantity	Distance (km)	MJ diesel/ ton load	g CO2/ton load[1]
Truck 3,5 ton dry cargo	l-diesel/ton-km	0,0175	70	43,92752	3681
Truck (20000 litter capacity)	l-diesel/ton-km	0,0175	260	163,15936	13673

Source: [1] Own computation. (based on data from BioGrace biofuel GHG calculation tool, version 4B Public

Energy content diesel oil, MJ/l = 35,86, Emission factor for Diesel oil 83,80 g CO2 eq./MJ

Table B.10. NPK composition of *Jatropha* tree and fruits[1]

	N (% wt.)	P (% wt.)	K (% wt.)	Composition (% of fruit)[2]
Coat /Husk	0,109	0,041	2,350	**35,50**
Seed cake	3,820	1,750	1,440	**44,80**
Wood/stem	3,340	0,090	2,870	

[1] Jongschaap *et al.* 2007. Claims and facts on *Jatropha curcas* L. – Global *Jatropha curcas* evaluation, breeding and propagation programme. Plant Research International, Wageningen, UR. http://www.fact-fuels.org/media_en/Claims_and_Facts_on_*Jatropha*_-WUR. Accessed 1 February 2011

[2]IFEU (2008), basic data for *Jatropha* production and use, Updated version, June 2008.

Table B.11 Fertilizer values of residues per ton *Jatropha* fruit, ha and FU

	N (kg)	P (kg)	K (kg)
Per ton of Fruits			
Coat	0,387	0,146	8,343
Seed cake	16,89	7,74	6,37
Per ha-yr. of land	**72,28**	**30,20**	**61,58**
Coat	1,47	0,55	31,77
Seed cake	64,33	29,47	24,25
Pruning residues	6,47	0,17	5,56
Per FU*			
Coat	0,0666	0,0250	1,4353
Seed cake	2,9065	1,3315	1,0956

Source: Own calculations based on IFEU (2008)

*Plantation area required 0,0452 ha per FU

Table B.12. Annual estimated emissions related to the production and use of synthetic fertilizer applied in cultivation of *Jatropha*.

				Per ha	Uncertainty range	
Sources	Variables	Sub-variables	Unit	Amount	Lower	Upper
DIRECT			kg CO2e / yr.	405	127	12090
PEN2O,soil,y			kg CO2e / yr.	403	121	12088
	GWPN20		kg CO2e / N20	298		
	PEN20-N,dir,y		kg N2O	1,35	0,41	40,56
			kg N20-N / yr.	0,86	0,26	25,81
		FSN,y	kg N / ha*yr.	13,77	13,77	13,77
		FON,y	kg N / ha*yr.	65,8	65,81	65,81
		FCR,y	kg N / ha*yr.	6,47	6,47	6,47
		EFN2O-N,dir	kg N2O-N / t N	0,010	0,003	0,3
PEurea,y			kg CO2 / yr.	2,43	6,075	2,43
	Murea,y		kg Urea/ ha*yr.	12,15	12,15	12,15
	EFCO2,urea		kg CO2eq / kg Urea	0,20	0,5	0,20
INDIRECT						
PEN2O,soil,y			kg CO2e / yr.	74	3	846
	PEN20-N,indir,y		kg N20/ yr.	0,25	0,01	2,84
		FSN,y	kg N / ha*yr.	13,77	13,77	13,77
		Fract -GASF	kg N volatised per t N applied	0,10		
		FON,y	kg N / ha*yr.	65,8	65,8	65,8
		FCR,y	kg N / ha*yr.	6,47	6,5	6,5
		Frac-GASM	kg N volatised per t N applied	0,20	0,05	0,5
		EF4	kg N-N2O-N / (kg NH-N + Nx-N Volatized)	0,01	0,002	0,05
Total				480	130	12937

Source: Own calculation based on data from IPCCC 2006. PECO2,soil,y = Project emissions of CO2 in year y resulting from changes in soil carbon stocks following a land use change or a change in the land management ; PEN2O,soil,y = Project emissions of N2O from land management at the plantation in year y; PEurea,y = Project emissions from urea application at the plantation in year y.

Table B. 13. Direct and indirect emission of Nitrous oxides from application of fertilizer containing Nitrogen

Direct emissions of N_2O	**Activity data**	**Equation (adjusted to input values in per ha-yr)**	**Emission factors used**	**Uncertainty** Range
Synthetic fertilizers considered • UREA (NPK: 46:0:0) • DAP (NPK: 18:46:0)	Amount of synthetic fertilizers applied/returned to plantation soil per year (and adjusted per hectare basis)	***N_2O* = (FSN + FPon + FCR)*EF1*44/28 [kg N_2O/ha-yr]** Where; **FSN** = annual amount of synthetic fertilizer N applied to soils, kg N per ha-yr **Fon =** annual amount of organic fertilizer as seedcake returned [kg N per ha-yr] **FCR** = annual amount of N in pruned biomass returned to soils [kg N per ha-yr] **EF1** for N [kg N_2O–N per kg N]	**EF1 = 0.01**	0.003 - 0.03
Organic fertilizers • Biomass from annual pruning • *Jatropha* fruit coat • Seedcake	Amount of organic fertilizers applied/returned to plantation soil per year (and adjusted per hectare basis)			
Direct emissions of CO_2 from UREA application	Amount of UREA applied per year per hectare basis	***CO_2 = M • EF * 44/12 [kg Co2/ha-yr]*** *Where:* **M** = annual amount of urea fertilization, **kg urea** per ha-yr **EF** = emission factor**, kg of C per kg of urea**	EF = 0.20	A default -50% uncertainty may be applied
Indirect N_2O emissions				
Synthetic fertilizers considered • UREA (NPK: 46:0:0) • DAP (NPK: 18:46:0) Organic fertilizers • Biomass from annual pruning • *Jatropha* fruit coat Seedcake	Amount of synthetic fertilizers applied/returned to plantation soil per year (and adjusted per hectare basis)	***N_2O* = [(FSN *Fract -GASF) + (FON +FCR)* Frac-GASM) *EF4*44/28 [kg N_2O/ha-yr]** Where; **FSN** = annual amount of synthetic fertilizer N applied to soils, kg N per ha-yr**Fon =** annual amount of N in *Jatropha* husk and seedcake returned [kg N per ha-yr] **FCR** = annual amount of N in pruned *Jatropha* biomass returned to soils [kg N per ha-yr] **Fract –GASF =** fraction of synthetic N fertilizer that volatilizes as NH_3 and NOx [kg N volatilized per kg Applied] **Frac-GASM =** fraction of organic fertilizer N fertilizer that volatilizes as NH_3 and NOx [kg N volatilized per kg N applied]. **EF4** emission factor for N2O from atmospheric emission deposition N on soils and water surface [N -N2O–N per (kg NH-N+Nx-N volatilized)]	**Fract –GASF =0.1** **Frac-GASM = 0.2** **EF4 = 0.01**	0.03-0.3 0.05 – 0.5 0.002 – 0.05

Source: IPCC 2006. Guidelines for National Greenhouse Gas Inventories. Chapter 11, N_2O Emissions from Managed Soils, and CO2 from Lime and Urea Application.

Table B.14. Carbon (C) pool of potential by land categories for conversions to *Jatropha* plantations (t C/ha)

	Carbon Stock in reference land use		
	ABG	SOC	Total
Grass land (non degraded)			
Tropical dry grassland	4,4	38,0	42,4
Tropical moist savannah	8,1	65,0	73,1
Shrub lands			
Tropical - Africa	46,0	38,0	84,0
Forest land degraded			
Tropical dry - Africa	14,0	38,0	52,0
Tropical moist deciduous - Africa	30,0	65,0	95,0
Forest more than 30% cover			
Tropical dry -Africa	77,0	38,0	115,0
Tropical moist-deciduous	156,0	65,0	221,0

Source: JRC 2010, Background Guidelines for the calculation of land carbon stock in biofuels sustainability scheme

ABG: above and below ground biomass**; SOC: soil organic carbon**

Table B.15. Carbon stock change coefficients for SOC

Climatic zone	Management	Land use F_{lu}	Management F_{mg}	Input F_{I}	Dc*Flu*Fmg*Fl (Dc default Soil carbon stock)	Ref (EC, 2010)*
Grass land						
Tropical dry grassland	Non degraded	1	1	1	Dc	
	Moderately degraded	1	0,97	1	Dc*0,97	Table 5, page 31
Tropical moist savannah	Non degraded	1	1,00	1	Dc	
	Moderately degraded	1	0,97	1	Dc*0,99	
Forest land						
Tropical moist/dry	Shifting cultivation/shortened fallow, cleared 3 yrs and natural regrowth	n/a	n/a	0,64	Dc*0,64	Table 13, page 86
	Shifting cultivation/mature fallow, cleared 3-5 yrs and natural regrowth	n/a	n/a	0,8	Dc*0,8	
Forest (and wooded savannah)						
Tropical moist/dry	Shifting cultivation/shortened fallow, cleared 3 yrs and natural regrowth	n/a	n/a	0,64	Dc*0,64	Table 11, page 82
	Shifting cultivation/mature fallow, cleared 3-5 yrs and natural regrowth	n/a	n/a	0,8	Dc*0,8	

Source: JRC 2010, Background Guidelines for the calculation of land carbon stock in biofuels sustainability scheme.

Annex C

Table C.1. ACBSE fleet size and performance data 2005-2011

Year	Fleet size (number of busses	Dispatched (number of busses)	Total distance covered (000 km)	Total passengers transported (000 people)	Total diesel consumption (000 l)
2005	674	381	23 881,8	230 826,8	8 352
2006	669	365	23 409,2	200 680,9	8 088
2007	669	386	20 463,1	184 920,5	8 376
2008	669	355	15 961,5	153.396,0	8 472
2009	669	301	16 510,1	101 601,7	8 749
2010	554	313	16 510,1	107 045,7	8 734
2011	554	295	16 147,5	98 335,0	8 089

Source: Data from ACBSE , 2012.

Table C.2. ACBSE bus fleets categorised by Euro Emissions standard class 2011.

	Bus manufacture / Model	Number of buses of this model	Year of service (range)***	Year of Production	EURO Emissions standard class
1	Mercedes	15	**29**	1983	Pre-Euro
2	DAF	198	**16**	1996	Euro II
4	DAF-Holland	146	**9**	2003	Euro III
3	DAF-Belgium	44	**8**	2004	Euro III
5	Bishoftu	280	**1**	2011	Euro III
6	Articulated (Bishoftu)	33	**1**	2011	Euro III
	Total	716			

Source: Data from ACBSE , 2012.

Note: The fleet size for 2012 was 820 buses of which 460 were dispatched. In 2012 of the total flees 320 were new, Bishoftu, buses. (Personal communication, ACBSE planning division)

Table C.3. Public passenger transport services - basic data

Vehicle category	Specific Fuel consumption (l/km)	Average passenger (pass/trip)	Average trip length (km/vehicle)	Daily trips (trips/vehicle)	Daily average performance (PKM/vehicle)
City bus (ACBSE)-diesel[1]	0,50	96,0	11,0	13,6	14.397
Min-bus (private)-gasoline[1]	0,15	9,2	5,4	16,0	795
Midi-bus (private)-diesel[2]	0,25	25,0	7,0	16,0	2.800

Source: [1] IBIS (2005), COWI (200), ACBSE (2012); [2] MoFED (2012) and own estimates.

Table C.4. Euro Emissions standard

Emission Standard	Year of introduction, EU	Fuel requirements
Pre Euro	<1992	
Euro I	1992 - 1995,	Unleaded petrol
Euro II	1996 – 1999, 2005 in China	500 ppm diesel & petrol
Euro III	2000 – 2004, 2007 in China	350 ppm diesel, 150 ppm petrol
Euro IV	2005 – 2008	50 ppm diesel & petrol
Euro V	2009 – 2013	
Euro VI	2014 -	

Source: UNEP (2009a)

Table C.5. Specific emission factors

Vehicle category		CO (g/km)	VOC (g/km)	NOx (g/km)	SOx (g/km)	PM10 (g/km)
Passenger cars:	**Petrol - without catalyst (1)**	**53,00**	**8,84**	**2,52**	**0,05**	**0,01**
	Petrol - with 3-way catalyst	18,00	0,78	1,17	0,05	0,01
	Diesel - without Particulate Matter filter	3,61	1,88	1,67	0,22	0,22
	Diesel - with PM filter	3,61	0,30	0,89	0,16	0,08
Light duty trucks & buses (2,2 - 4,5 tonnes):	**Light duty - pre Euro**	3,61	1,88	1,67	0,29	0,27
	Light duty - Euro I+II	3,60	0,19	1,64	0,26	0,13
	Light duty - III+IV	3,60	0,19	1,64	0,25	0,13
	Light duty - HEV	3,60	0,13	0,87	0,26	0,06
Medium duty trucks & buses (4,5 -15 tonnes):	**Medium duty - pre Euro**	8,59	1,65	15,33	0,69	0,67
	Medium duty - Euro I+II (2)	**8,59**	**1,65**	**15,01**	**0,69**	**0,67**
	Medium duty - Euro III+IV	5,35	1,15	9,20	0,69	0,29
	Medium duty - Euro V	2,45	0,89	4,41	0,69	0,07
Heavy duty trucks & buses (15 - 22 tonnes):	**Heavy duty - pre-Euro**	13,29	2,53	23,80	0,98	2,15
	Heavy duty - Euro I+II (3)	**11,80**	**2,53**	**20,40**	**0,97**	**1,34**
	Heavy duty - Euro III+IV	5,79	1,59	10,00	0,97	0,66
	Heavy duty - Euro V	4,05	1,43	7,00	0,97	0,46

Source: UNEP (2009b)

Values adopted (1) min-bus. (2) midi-bus, (3) ACBSE buses

Annex D

Table D.1. Biodiesel standard EN 14214 (Europe)

Biodiesel Standard EN 14214 (Europe)

Property	Test method	Limits min	Limits max	Unit
Ester content	EN 14103	96.5		% (m/m)
Density; 15°C	EN ISO 3675 EN ISO 12185	860	900	kg/m^3
Viscosity; 40°C	EN ISO 3104 ISO 3105	3.5	5.0	mm^2/s
Flash point	EN ISO 3679	120	°C	
Sulfur content	EN ISO 20846 EN ISO 20884		10.0	mg/kg
Carbon residue (10% dist. residue)	EN ISO 10370		0.30	% (m/m)
Cetane number	EN ISO 5165	51		
Sulfated ash	ISO 3987		0.02	% (m/m)
Water content	EN ISO 12937		500	mg/kg
Total contamination	EN 12662		24	mg/kg
Copper strip corrosion (3 hr, 50°C)	EN ISO 2160		1	
Oxidative stability, 110°C	EN 14112	6.0		hr
Acid value	EN 14104		0.50	mg KOH/g
Iodine value	EN 14111		120	g iodine/100 g
Linolenic acid content	EN 14103		12	% (m/m)
Content of FAME with ≥4 double bonds			1	% (m/m)
Methanol content	EN 14110		0.20	% (m/m)
Monoglyceride content	EN 14105		0.80	% (m/m)
Diglyceride content	EN 14105		0.20	% (m/m)
Triglyceride content	EN 14105		0.20	% (m/m)
Free glycerine	EN 14105, EN 14106		0.02	% (m/m)
Total glycerine	EN 14105		0.25	% (m/m)
Alkali metals (Na + K)	EN 14108, EN 14109		5.0	mg/kg
Earth alkali metals (Ca + Mg)	prEN 14538		5.0	mg/kg
Phosphorus content	EN 14107		10.0	mg/kg

Source: Gerhard *et al*. (2005). The Biodiesel Handbook.

Annex E

Biofuels development in Ethiopia

The GoE's Biofuels Development and Use Strategy issued in September 2007 (MME, 2007) had effectively provided ground for the initiation of a national biofuels development program in the Country. The main objectives of the strategy include local production and use of biofuels for substituting imported petroleum fuels, export of biofuels to other (mainly developed) countries while contributing to the global effort in reducing GHG, and contribute to the national agriculture based rural development. In the case of plant oil based biodiesel development, the biofuels strategy underlines the possibility and importance of using degraded lands for the development of *Jatropha*.

At the initial period the ease at which large areas of land were leased out (including the absence of enforcement on EIA), the low cost at which land was made available and the investment promotion incentives provided has attracted many prospective investors. According to *(MELCA, 2008)* in 2008 about 50 international and local prospective investors have shown interest to engage in biofuels development in Ethiopia, and ten foreign and local companies had leased 350 thousand hectares of land in the different parts of the country.

However, since there is no publicly available land use the type of land allocated to these investors included land under natural and dense forests, wood lands, bush lands, cultivated lands and farm lands (MELCA, 2008; RSB, 2012), and was not consistent with the aim and objectives of the strategy .

At present it appears that the initial high interest is moderated. Reasons include high cost of biodiesel feed stocks production (e.g. significantly lower actual seed yield than expected from *Jatropha*), lack of necessary infrastructures that support biodiesel development, and unavailability of clear directives and regulation on the use of biodiesel (e.g., Biodiesel standards). The negative environmental impacts associated with clearing of forest and other lands with significant vegetation cover had created opposition from environmentalist (both local and international). The overall impact was that most of the prospective investors had to evaluate and refocus, or abandon, their initial biodiesel development plan in Ethiopia.

Currently five companies and one or two NGOs are engaged in biodiesels production either from *Jatropha* or other oil-seeds bearing crops such as castor and palm oil (RSB, 2012; Nadew, 2012). The companies or NGOs developing *Jatropha* planation (or supporting *Jatropha* tree planting program) appears to be focused not only on production of biofuels feedstock but also on rehabilitation and re-vegetation of degraded lands (Nadew, 2012).