Life cycle analysis (LCA) of Jatropha biofuel produced in Northern Ghana

GHG balance

Contracting company :	Audited company :
Statoil hydro ASA Forusbeen 50 Forus NO-4035 Stavanger Norway	Biofuel Africa Ltd, a daughter company of BioFuel AS / BioDiesel Norge Verven 12C NO-4014 Stavanger Norway

Project nr: 08.0276

March 2009

CONTENT

FIGURES

TABLES

ACRONYMS

CDM : CLEAN DEVELOPMENT MECHANISM
CH_4 : METHANE
CO_2 : CARBON DIOXYDE
GHG : GREEHOUSE GASES
LCA : LIFE CYCLE ASSESSMENT
GWP : GLOBAL WARMING POTENTIAL
IPCC : INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
LHV : LOW HEATING VALUE
LUC : LAND USE CHANGE
N_2O : NITROUS OXIDE
SOM : SOIL ORGANIC MATTER

1. Background and objectives

Biofuels become a significant percentage of StatoilHydro's fuel sales. This is due to a combination of national mandates and incentives which have made the blending of biofuels economically interesting. More recently, international concern has mounted about the potential unintended environmental and social consequences due to the increase of biofuel production. A number of initiatives are underway to address these concerns including round tables on biofuels, independent studies, regulatory reporting of carbon and sustainability performance and development of sustainability standards.

The case study is the Jade Project in Ghana, located Northern Ghana, which includes the set up of a Jatropha plantation of 23.000 ha and of one Jatropha oil mill. This study covers the chain from the plantation of the Jatropha plants up to the storage of the Jatropha oil in Tema.

The objective of this mission is to collect the required data in order to calculate the GHG life cycle emission, determine the energy efficiency figures and evaluate some environmental impacts of a specific biofuel supply chain, following some international reference documents.

The project is currently under development: the first plantations in Northern Ghana have been set up in 2008 and not pressing facilities have been installed yet. A small scale Jatropha production is operated in a test farm in the Volta district and some aspect of the production can be assessed with reference to the test farm.

Since various technical alternatives are considered by Biofuel Africa at various stages of the supply chain, the LCA is a very useful tool to support the decision making in the project development. The impact of various relevant alternatives on the GHG balance is addressed in this report.

2. Methodology

The life-cycle analysis (LCA) covers the chain from the Jatropha plantation up to the Jatropha oil storage tank in Tema including the inland transportation. It takes into consideration the following documents:

- "Well-to-wheels analysis of future automotive fuels and powertrains in the European context" report of JRC/EUCAR/CONCAWE[1],
- IPCC, 2006, "IPCC Guidelines for National Greenhouse Gas Inventories",
- "The Greenhouse Gas Protocol", A corporate accounting and reporting standard, World Business Council for Sustainable Development, World Resources Institute, 2004.
- ISO 14064 standard.

First of all, the following steps have been performed:

- defining the boundaries of the system (stages to be considered, direct and indirect emissions...),
- defining the set of GHG relevant in this study.

A field audit has been carried out from 9 to 13 December 2008. The project area in Tamale, as well as the test farm in Volta district have been visited. It was possible to understand how Jatropha cultivation is operated, and to assess the characteristics of the land meant to be converted into Jatropha plantation. Meetings with various stakeholders have allowed us to learn more about the local context and issues. It has also been possible to run a test to estimate tractor diesel consumption in field operations.

Various literature sources have been gathered to compare the expectations with similar LCA assessments of biofuels (for Jatropha and other agricultural resources).

The GHG balance has been calculated for the base case, and also for a number of alternative options, since several technical possibilities are still considered at various stages of the supply chain. Finally, a sensitivity analysis of the GHG balance model has been performed, in order to assess how this balance will be impacted if some critical parameters (for which there is a certain level of uncertainty) happen to differ from what has been assumed in the base case computation.

Next to these calculations, an environmental impact assessment (EIA) study has been carried out by SGS Ghana. The reporting is available in a separated document (Environmental assessment and audit report : Jade project). The scope of the EIA is to briefly determine the impacts of the project on air emissions, water, biodiversity and land use change.

---

[1] Since neither the international transportation of the Jatropha oil nor the refining process to produce bio-diesel, are within the scope of this LCA, a comprehensive « well-to-wheels analysis » approach was not possible in this case. Availability of data permitting, the LCA might be extended to end use in the future.

3. Scope of the GHG evaluation

GHG emissions from a system / product / activity can be restricted to direct emissions or include a range of indirect emissions. In order to clarify the differences between direct and indirect effects, three “scopes” (scope 1, scope 2, and scope 3) are defined for GHG accounting and reporting within *The Greenhouse Gas Protocol* (World Business Council for Sustainable Development, World Resources Institute, 2004).

They are described as follows:

Scope 1: Direct GHG emissions
Direct GHG emissions occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment. Direct CO_2 *emissions from the combustion of biomass shall not be included in scope 1 but reported separately. GHG emissions not covered by the Kyoto Protocol, e.g. CFCs, NOx, etc. shall not be included in scope 1 but may be reported separately.*

Scope 2: Electricity indirect GHG emissions
Scope 2 accounts for GHG emissions from the generation of purchased electricity consumed by the company. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated.

Scope 3: Other indirect GHG emissions
Scope 3 is an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services.

This classification is particularly relevant when reporting is made at the company level, to make sure that no overlapping happens between the scopes of different companies.

Scope 1 and 2 are compulsory, while scope 3 is optional.

In the framework of this case study:

- Scope 1 includes in this case direct emissions from land use change, from fuel burning (in machines, vehicles, gensets…) and from the plantation.
- Scope 2 is likely to be not applicable in this case because, in the base case, we consider that the electricity used in the supply chain will be from own production (genset or steam turbine).
- Scope 3 is considered. The emissions sources relevant to scope 3 that we have included in the GHG computation are from the production of consumable products (fuel and fertilizer). Emissions from the life cycle of equipments (machinery, vehicles…) have not been considered.

4. General description of the supply chain

The Jatropha oil production can be divided into 3 major stages:

The **first stage** is the plantation set up. This stage takes place once in the plantation life cycle. The CO2 emissions related to this stage have to be allocated to the oil production throughout the plantation life cycle, which is expected to be 25 years.

The **second stage** is made up with all agricultural operations happening throughout one year (fertilizer application, mechanical cultivation and harvesting). The CO_2 emissions at this stage have to be allocated to the oil production in one year. The CO_2 emissions at this stage are surface-dependant: whatever the Jatropha yield those operations are the same for each ha plantation. The dose-response relationship between fertilizer input and oil yield is not part of the model: based on the expectations of Biofuel Africa Ltd, fixed figures are set for the fertilizer input and for fruit/oil output.

The **third stage** includes fruit transport and processing (de-husking, pressing) and oil transport to Tema harbour. Further operations (including oil transport from Tema to Europe, refining and distribution to end user) are not included in the scope of this life-cycle assessment.

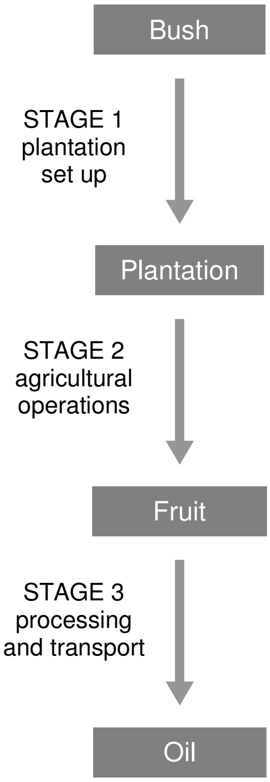

Figure 1 : Production stages

5. Detailed description of the supply chain and system boundaries

5.1. *Stage 1: plantation set up*

In stage 1 (Figure 2), the bush was found to be the initial land use is converted into a Jatropha plantation.

As far as GHG emissions are concerned, we have included in the scope:

- removal of initial vegetation (scope 1),
- soil carbon released after land use change (scope 1),
- fossil fuel combustion in machines and vehicles involved (scope 1),
- N_2O from on-site denitrification (scope 1),
- fossil fuel production: crude oil exploitation, transport to refinery, refining (scope 3),
- fertilizer production (scope 3).

GHG emissions from the following processes are not included in the scope:

- production and transport of machines and vehicles to site,
- transport of fossil fuel (from refinery to site),
- production and transport of seeds (negligible),
- charcoal valorisation[2].

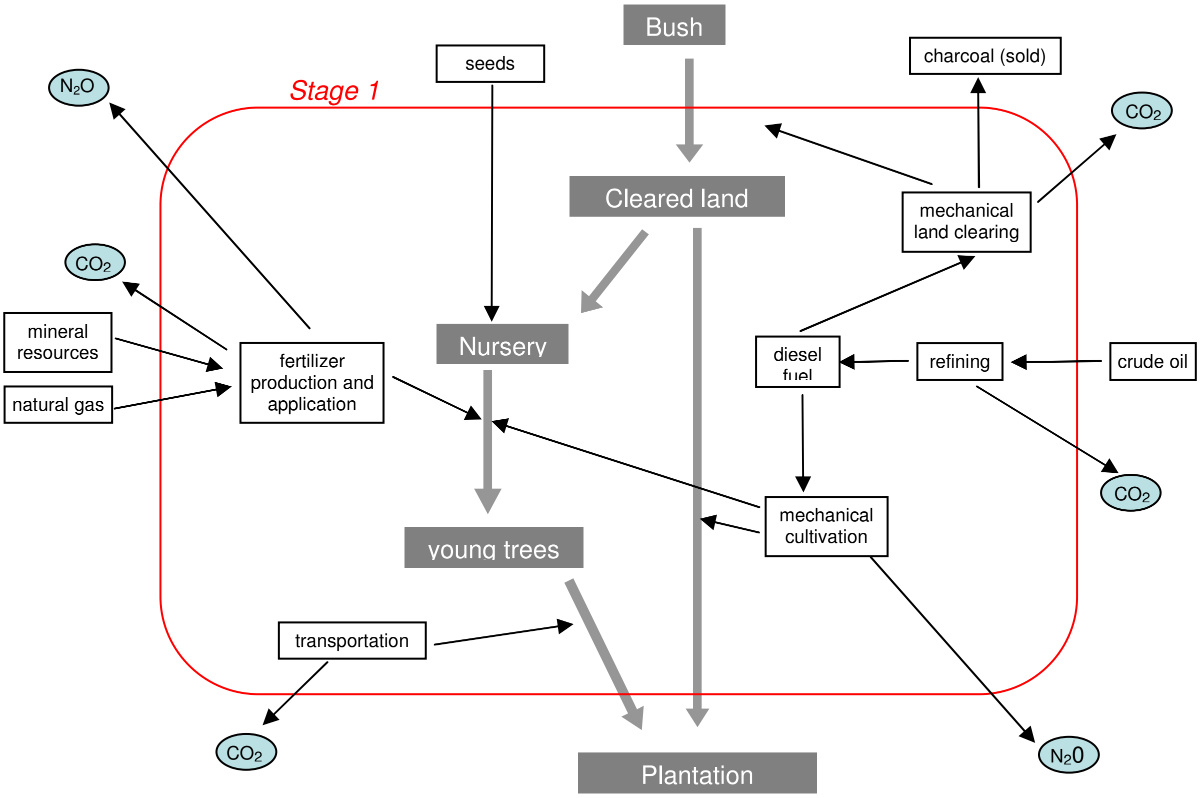

Figure 2 : System boundaries considered in the Jatropha oil production LCA : stage1

---

[2] Even though charcoal is exported from the system, it would not be appropriate to consider that its use by local people leads to CO_2 avoidance because the alternative source of energy for them is collecting wood from the savannah (which is does not lead to CO_2 emissions to the atmosphere as long as the resource is not overexploited).

5.2. Stage 2: agricultural operations

Within the scope of the life-cycle assessment, GHG emissions directly or indirectly due to agricultural operations include:

- fuel combustion in machines involved (scope 1),
- N_2O from on-site denitrification (scope 1),
- fossil fuel production: crude oil exploitation, transport to refinery, refining (scope 3),
- fertilizer production (scope 3).

GHG emissions from the following processes are not included in the scope:
- production and transport of machines and vehicles,
- transport of fossil fuel.

By products from stage 3 are used in stage 2 as fertilizer. Two options are possible (Figure 3 and Figure 4): either the cakes (resulting from pressing) are used as such, or the cakes are burnt in electricity generation facilities and only ashes are used as fertilizer. Additional mineral fertilizers are needed anyway, even though the required doses are expected to be very different depending on if cakes are burnt or not.

5.3. Stage 3: processing and transportation

Two scenarios are used in stage 3:
- option 1(Figure 3): the cakes are burnt for power generation and only their ashes are applied to the land as fertilizer.
- option 2 (Figure 4): the cakes are not burnt and they are applied as such on land.

Within the scope of the life-cycle assessment, GHG emissions directly or indirectly due to fruit transport and processing as well as oil transport include:
- production of the electricity needed to operate pressing and de-husking machinery (scope 1)[3],
- fuel combustion in vehicles involved in the transportation of fruit and oil (scope 1),
- fossil fuel production: crude oil exploitation, transport to refinery, refining (scope 3).

Beside those items, the avoided CO_2 due to electricity generation (if any) is taken into consideration. However, the ISO 14064 standard suggests to report avoided CO2 emissions from exported electricity, but do not allow to include it as such in the general balance.

GHG emissions from the following processes are not included in the scope:
- production of machines and vehicles,
- transport of fossil fuel,
- avoided CO_2 due to possibly valorised heat from steam turbine output (combined heat and power generation).

The reason why possible valorisation of the heat has not been accounted for avoided CO_2 is that options for the use of this heat are not clearly stated at this stage, so it is not sure at all that an effective reduction of GHG emissions is achievable this way. If any heat from cakes burning is used for drying the fresh fruit (not a very likely option actually) it won't lead to any exportation of energy outside the boundaries of the system, and it does not lead to any CO_2 emission avoidance (since the alternative source of heat for drying is Sun energy).

---

[3] The electricity production is within scope 1 if it is operated by the company itself. Only if the electricity is bought from an external source, it is considered as scope 2. Buying electricity from the public network is an open possibility under option 2, but since the electricity network is not reliable in Northern Ghana, gensets will be needed anyway, at least as backup.

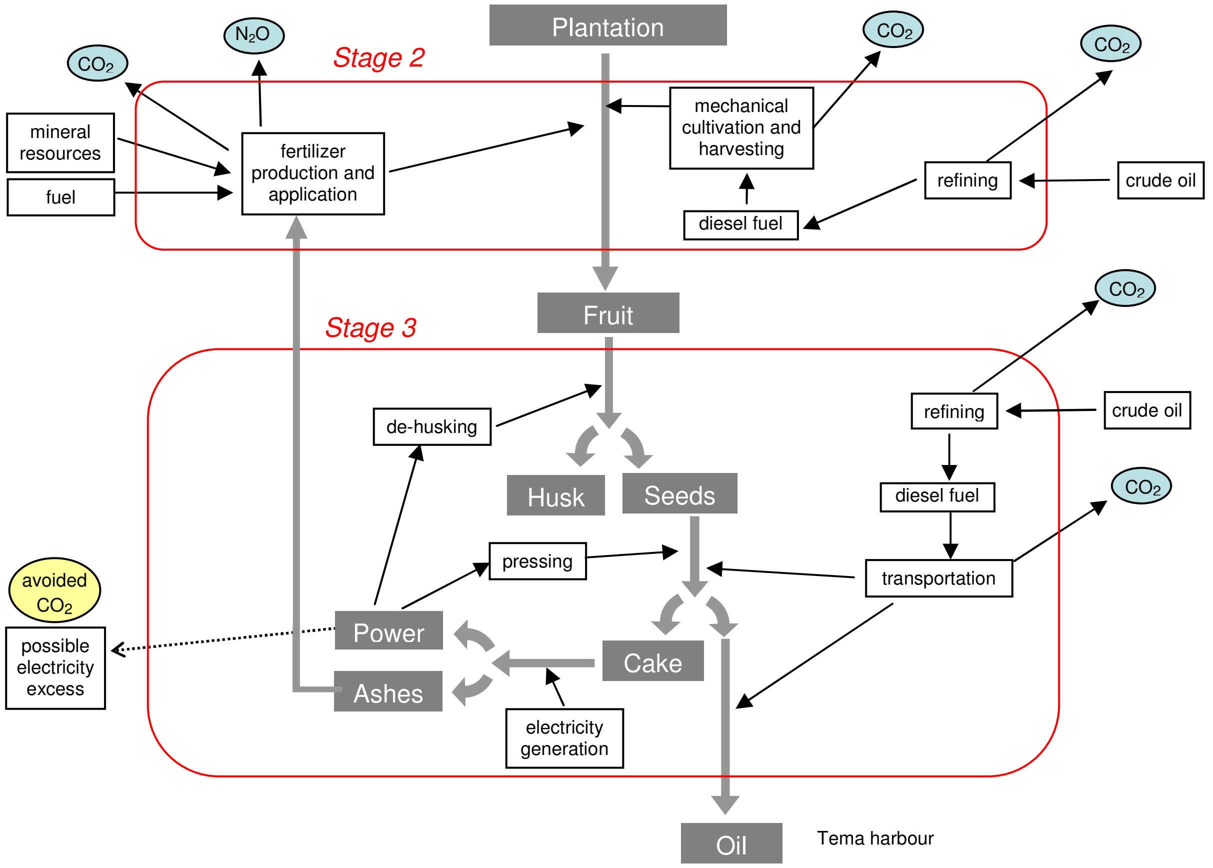

Figure 3 : System boundaries considered in the Jatropha oil production LCA : stages 2-3- option 1 (cakes are burned for power generation within a steam turbine; ashes are applied to the land)

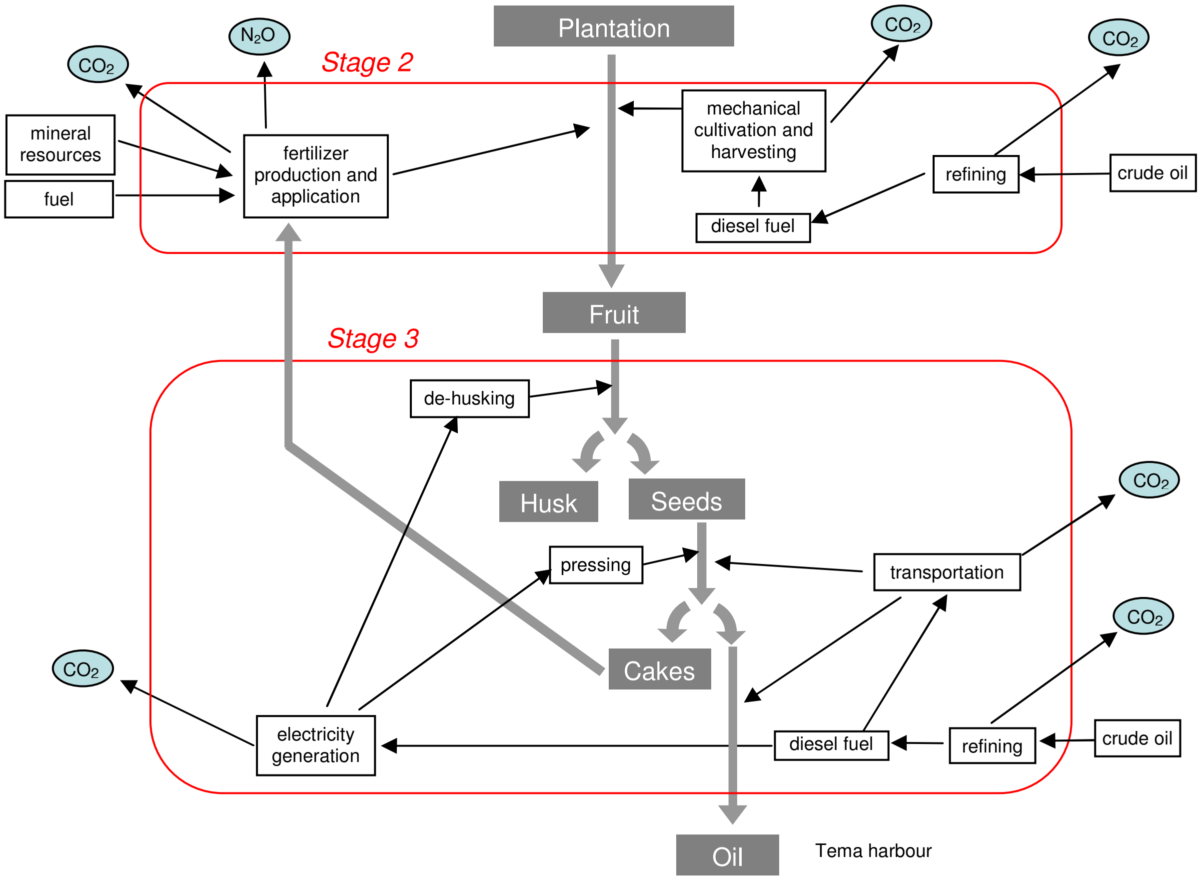

Figure 4 : System boundaries considered in the Jatropha oil production LCA : stages 2-3- option 2 (no own power generation; cakes are applied as such to the land)

6. Relevant green house gases

The GHG gases that have been considered is this study are the ones included in the ISO 14064 standard.

CO_2 and N_2O have been found to be the relevant GHG gases to consider in this study. CO2 emissions are involved in land use change (LUC) issues, in fuel combustion (directly) and electricity consumption (indirectly). N_2O emissions are involved in fertilizer production and use.

In a 100 year time horizon, N_2O Global Warming Potential (GWP) is 310, according to UNFCCC reference dataset (United Nations Framework Convention on Climate Change[4]). So 1 kg N_2O is 310 kg CO_2 eq.

CH4 emissions have not be found to be significant in the Jatropha life cycle analysis. Some CH4 is produced by the decomposition of any organic matter but it is difficult to predict if the emissions from Jatropha plantations will be higher or lower than the emissions from bush/savannah. Fluxes are expected to be insignificant (compared to other GHG), because of dry conditions, with very little anoxic decomposition of organic matter.

Other GHG defined in the GHG Protocol (HFC, HFE, PFC) are not relevant in this study.

---

[4] http://unfccc.int/2860.php

7. Operational units for GHG calculation

Under ISO 14064, the operational unit is ton CO2 eq. / year. However, this is in the perspective of assessing GHG emission from an organization (ISO 14064-1) or from an project (ISO 14064-2). In this case, we are interested in assessing the GHG footprint of a product throughout its life cycle. Another unit is thus more appropriate here: kg CO2 eq. / ton product i.e. in this case **kg CO2 eq. / ton Jatropha oil**.

However, each stage of the process has a different operational unit. Some hypotheses were necessary to convert each of them in a common operational unit which is kg CO_2 eq. / ton oil:

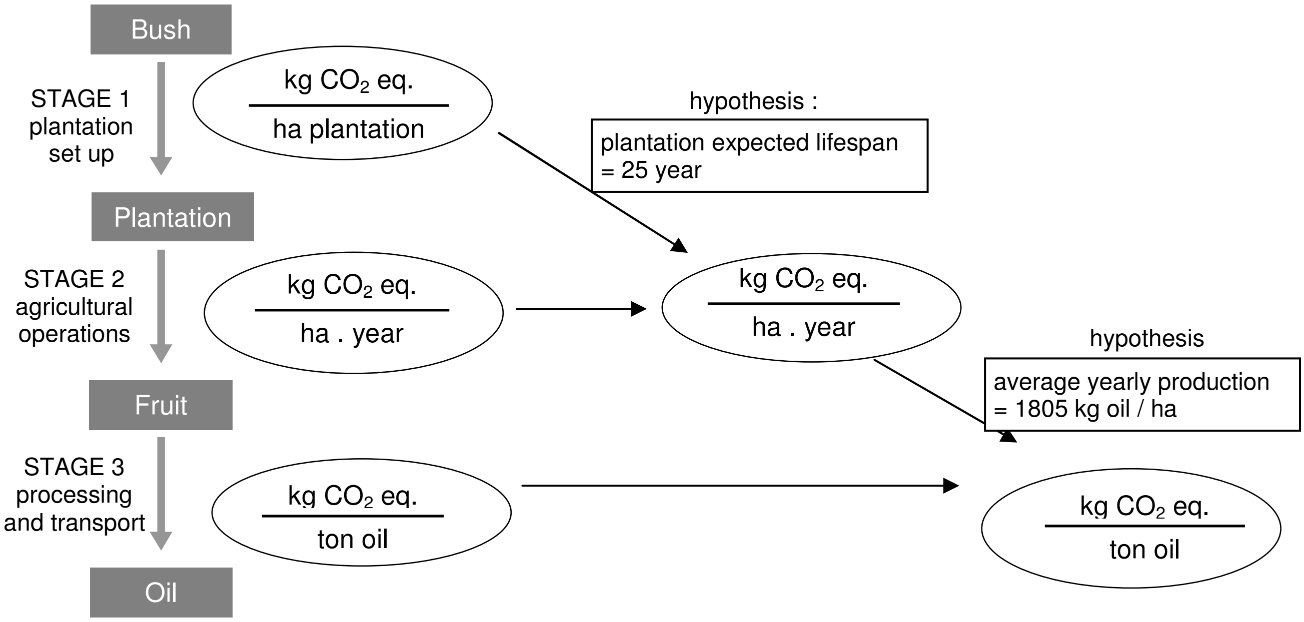

Figure 5 : Operational unit for each stage of the production and conversion to a single unit

Two hypotheses are necessary:

- expected lifespan of the plantation : 25 years. If the plantation keeps on working for a longer period, the specific carbon emissions will decrease.
- expected yearly oil production : 1805 kg / ha on average. This is a very critical point. If the production achieved is lower than expected, specific CO_2 emissions of stages 1 and 2 will increase.

8. Emission factors

8.1. *Emissions from diesel oil life cycle*

8.1.1. Direct emissions

Direct emissions are due to the combustion of diesel fuel. From the GIEC data (2006) we have the following figures :

LHV: 43.0 TJ / Gg
emission : 74.0 ton CO_2 / TJ
=> specific emission :
3182 ton CO_2 / Gg
= 3.182 kg CO_2 / kg diesel
= 2.673 kg CO_2 / liter diesel

8.1.2. Indirect emissions

Indirect emissions are caused by crude oil exploitation, transport and refining. From the dataset gathered by the “European Platform on Life Cycle Assessment”, we have the following figure on CO2 emission for diesel life cycle up to the refinery stage :

0.354 kg CO_2 / kg diesel
= 0.297 kg CO_2 / liter diesel

8.1.3. Total

Total for direct and indirect emissions

3.536 kg CO_2 / kg diesel
= 2.970 kg CO_2 / liter diesel

This figure does not include GHG emissions related to transportation of biofuel from refinery to the place of final use.

8.2. *Emissions from fertilizers life cycle*

8.2.1. Direct emissions

Direct emissions from fertilization are due to denitrification process (production and emissions of N_2O into the atmosphere from the nitrate released in soil by nitrogen fertilizer application). Although the release of N_2O is a natural process of the nitrogen cycle in any ecosystem, any fertilizer application (organic or mineral) causes an increase in N_2O release.

Following the publication of Bouwman, Boumans, and Batjes (2002), the IPCC (2006) adopted a default parameter for N_2O release from fertilizer application : 0.01 kg N20-N / kg N. In other words, 1% of the applied N2O is expected to be released as N2O. A wide range of variation is however expected beside this value : a range of 0.3% to 3% is expected.

So we will use the following figures for direct emissions from fertilizer application:
10 g N_2O / kg N = 3.1 kg CO_2 eq. / kg N

8.2.2. Indirect emissions

Indirect emissions from fertilizer are due to energy needed for the production and to N_2O emissions into the atmosphere happening when nitrogen fertilizers are generated. We have worked with the following figures, based on the work of Wind, Wallender (1997) and Sheehan et al (1998), cited in University of New South Wales (Recycled Organics Unit, 2003):

N : CO_2 emissions : 3.96 kg CO_2 / kg N
N_2O emissions : 0.0177 kg N_2O / kg N = 5.49 kg CO_2 eq. / kg N
total emissions : 9.45 kg CO_2 eq. / kg N

P : CO_2 emissions : 1.76 kg CO_2 / kg P

K : CO_2 emissions : 1.36 kg CO_2 / kg K

Those emission levels can vary according to the technique used to produce the fertilizer. If the nitrogen fertilizer to be considered is urea instead of nitrate, no N_2O emission is generated. So urea production leads to a level of GHG reported to be as low as 2.5 kg CO_2 eq. / kg N (Bentrup, 2008).

Moreover, it is interesting to note, however, that new technologies for nitrogen production are being developed, with systems of N_2O capture on the production site (de-N_2O catalyst). Data communicated by Yara (fertilizer producer) suggest that this technology can reduce GHG emission down to 3 kg CO_2 eq. / kg N (Bentrup, 2008).

At this stage, we don't have evidences attesting what technology is going to be applied for the production of nitrogen fertilizer, so we will use 5.49 kg CO_2 eq. / kg N as conservative emission factor in the base case. We will keep in mind, however, that GHG emissions from nitrogen production can be reduced if appropriate modern production technologies are applied. The influence of the use of such techniques on the general GHG balance will be assessed as an alternative.

8.2.3. Total

N : 12.55 kg CO_2 eq / kg N
P : 1.76 kg CO_2 eq / kg P
K : 1.36 kg CO_2 eq / kg K

8.3. Emissions from electricity generation

The emission factor to be considered for electricity generation in Ghana is a complex question. Even no accurate statistics have been found on this topic, Ghana is reported to produce a large majority of its power from hydroelectric power plant, mostly in a large dam on the Volta river and also in smaller facilities. So the average emission factor is currently very low.

However, as electricity consumption in the country increases and no further hydro facilities are being developed, marginal power generation rely mostly on fossil fuel. In the framework of the development of a new project, an emission factor reflecting typical power generation based on fossil fuel is the most realistic and conservative approach.

So, in the framework of this project, we will use an emission factor based on diesel genset power generation. It remains however difficult to assess, CO_2 emissions from genset vary according to the power of the genset, and also with the operating load. For large gensets (> 35 MW), available data suggests that 0.31 kg diesel / kWhe would be a realistic figure (Retscreen International dataset, http://www.retscreen.net). This is an efficiency of about 27 %. With a life cycle emission factor of 3.536 kg CO_2 / kg diesel, it leads to a specific CO_2 emission of about 1.1 kg CO_2 / kWhe.

We consider this figure as relevant both for the avoided CO_2 if green electricity is exported from the system and if electricity is needed by the system to operate the production process.

9. Results for the base case

9.1. *Stage 1: plantation set up*

9.1.1. Mechanical operations for land clearing

The use of specific machinery for land clearing has been assessed by Biofuel Africa, based on specific consumptions and hours of operation for each ha of cleared land.

Table 1 : GHG emissions from mechanical operations for land clearing

	l diesel/ha	kg CO_2/ha
machinery for vegetation removal (bulldozer)	80.6	239.4
land preparation (vegetation collecting harrowing, ridge making)	42.0	125.4
total	122.6	364.7

9.1.2. Land use change: carbon pool in living vegetation

When living trees and vegetation are cut, the carbon contained in living matter is released into the atmosphere. The wood is used to produce charcoal, sold to the locals. Since the savannah vegetation is removed in the land use change (LUC) process, this can not be seen as renewable biomass.

However, if we consider that permanent savannah is converted into permanent Jatropha plantation, the carbon released in the atmosphere is the difference between initial carbon stock in savannah vegetation and carbon stock in Jatropha trees. The estimation for savannah is based on the weight of woody biomass removed from 1ha test surface, and of literature data (Xiaoyong, Hutley and Eamus, 2003).

Table 2 : GHG emissions from savannah vegetation removal

	kg C/ha	kg CO_2/ha
living woody biomass (assessed from field test)	1382	5066
living tree foliage (assumed to be 1/40 of woody biomass)	35	127
living grasses (typical savannah)	6500	23833
living roots (assuming 1/3 vegetation underground, 1/3 above ground)	3941	14450
total	11857	43476

Table 3 : Carbon storage in a Jatropha plantation

	kg C/ha	kg CO_2/ha
Jatropha living biomass, assuming: 4200 trees/ha, 7.5 kg dry matter / tree, 3.0 kg C / tree (C = 40% dry matter)	12600	46200

As can be seen in the tables above, the estimation leads to the conclusion that the carbon stock in vegetation is about the same in both cases. So we will consider that the switch in vegetation does not lead to any carbon release in the atmosphere, from the moment when the Jatropha plantation has reached a significant development.

9.1.3. Land use change: carbon pool in soil organic matter (SOM)

The carbon pool in soil is larger than in living vegetation. From 40 soil analysis (performed in 2008 by the Savanna Research Institute, Tamale) the following figures have been calculated, considering only a topsoil layer:

- the average C content in topsoil (0-0.2 m) is estimated to be 1.9 % i.e. 19 g C / kg dry soil
- assuming 1.4 kg/dm^3 bulk density, it leads to 5320 g C / m^2 within the topsoil (0-0.2 m)

Table 4 : Carbon pool in soil organic matter

	kg C/ha	kg CO_2/ha
soil organic carbon	53200	195067

It is very difficult to predict what will happen to this carbon pool when the savannah will be converted to Jatropha plantation. Some part of this stock might be released in the early stage of plantation set up. However, if suitable agricultural practices are applied, it can be expected to see the SOM increase. Fire will be avoided. Mulch will be applied (weeds, husks and product from pruning). Cover crops and catch crops between the lanes will be planted so that bare soil (leading to carbon losses) will be reduced.

There are evidences that Jatropha cultivation can help increasing SOM, and that African soils make up, on a global scale, a significant opportunity to act as carbon sinks. In the framework of this project, SOM should be very carefully monitored along the years, because any depletion can have a very important impact on the overall CO_2 balance.

In our base case, we have considered that the evolution of SOM throughout the years will be neutral. In the “sensitivity analysis” section, we have calculated what can be the consequences on the carbon footprint of Jatropha if SOM happens to increase or decrease under Jatropha cultivation.

9.1.4. Nursery operations for providing young trees to plantation

The GHG emissions within the nursery are: emissions due to land use change and agricultural operations (land preparation, sowing, fertilizing, harvesting).

An irrigation system in the nursery is necessary. It is assumed at this stage that a gravitary irrigation network (fed by a dam) can be used, so that the irrigation process do not necessitate any significant energy consumption.

It is assumed that the vegetation in a (permanent) nursery in negligible compared with vegetation to be cleared, so the removal of the initial vegetation will be the major contribution to GHG emissions from nursery set up and management.

As one hectare nursery supports more than 100 ha plantation, GHG emissions in kg CO_2 eq / ha nursery need to be divided by 100, in order to get GHG emissions in kg CO_2 eq / ha plantation. One fertilizer application is involved : NPK (36kg - 214kg - 107 kg).

Table 5 : GHG emissions from Jatropha nursery

	l diesel /ha nursery	kg CO_2 eq. /ha nursery	kg CO_2 eq. /ha plantation
land use change nursery (as in Table 2)		43476	435
total emissions for land clearing (as in Table 1)	122.6	364.7	3.6
sowing	7.6	22.7	0.2
fertilizer application	2.8	8.3	0.1
mechanical harvesting of plants	3.3	9.7	0.1
fertilizer life cycle for the nursery N (36kg/ha)		451.8	4.5
fertilizer life cycle for the nursery P (214kg/ha)		376.6	3.8
fertilizer life cycle for the nursery K (107 kg/ha)		145.5	1.5
total	136.3	44855.4	448.8

9.1.5. Land preparation and plantation of young trees

In this category we have a set of agricultural operations occurring only once in the plantation lifetime, during the initial plantation set up.

Table 6 : GHG emissions from land preparation and plantation of young trees

	l diesel/ha	kg CO_2 eq. /ha
transportation from nursery full load 200k plants (for 48ha)	0.5	1.4
Jatropha planting machine and first fertilizer application	3.4	10.2
applying additional fertilizer when needed	2.8	8.2
weed/grass cutting with tractor mounted lawnmower 1st round	3.1	9.1
light duty harrowing/mulching 1.8 m between Jatropha rows	2.0	6.0
weed/grass cutting with tractor mounted lawnmower 2nd round	3.1	9.1
pest spraying (Neen oil) 1st round	0.7	2.0
pest spraying (Neen oil) 2nd round	0.7	2.0
intercrop legume planting	2.2	6.6
fertilizer life cycle N (36kg/ha)		451.8
fertilizer life cycle P (214kg/ha)		376.6
fertilizer life cycle K (107 kg/ha)		145.5
total	18.4	1028.6

9.1.6. Total

The total of the above established values is hereunder. About half of the GHG emissions for plantation set up is due to fertilizer life cycle.

Considering the expected life cycle of the entire plantation, the initial emissions of 1842.1 kg CO_2 / ha can be distributed into 25 years:

1842.1 / 25 = 73.7 kg CO_2 eq. / ha year

In accordance with the expected average yield of 1805 kg oil / year, the following figure can be computed:

73.7 / 1.805 = 40.8 kg CO_2 eq. /ton oil.

Table 7 : Total GHG emissions from plantation set up

	kg CO_2 eq. / ha	kg CO_2 eq. / ha-an	kg CO_2 eq. / ton oil
GHG from mechanical operations for land clearing	364.7	14.6	8.1
GHG from land use change: release from carbon pool in living vegetation (assumed)	~ 0	~ 0	~ 0
GHG from land use change: release from carbon pool in soil organic matter (assumed)	~ 0	~ 0	~ 0
GHG from Jatropha nursery	448.8	18.0	9.9
GHG from land preparation and plantation of young trees	1028.6	41.1	22.8
TOTAL STAGE 1: plantation set up	1842.1	73.7	40.8

9.2. Stage 2: agricultural operations

9.2.1. Introduction

The agricultural operations include:

- pruning
- pesticide application
- fertilization
- weeding cutting / harrowing
- harvesting and transportation to drying / dehulling site.

The appropriate nitrogen fertilization is expected to be 233 kg/ha. Two options are considered in this study:

- 233 kg/ha can be applied as organic fertilizer if press cakes are applied on land without being burnt (**option 2**).
- if some of the cakes are burnt (**option 1**) an additional dose of mineral N fertilizer will be needed.

We assume that the denitrification rate of the applied N fertilizer do not depend on whether the nitrogen is under mineral of organic form. So the denitrification is the same for option 1 and option 2.

No mineral fertilizer is expected for P and K.

The other agricultural operations mentioned are unchanged whatever the selected option (1 or 2).

9.2.2. Option 1 (cakes are fired for own electricity production)

The dose of mineral N fertilizer to apply depends on the amount of cakes fired in the steam turbine (see stage 3). We will use the hypothesis that 86% of the cakes are burnt and only the ashes of those cakes are applied on the land (with unchanged P and K content but with very little N). On the other hand, 14% of the cakes are applied to the land as such (with 33 kg N / ha out of the required 233 kg N/ha).

So the requested mineral fertilizer dose is : 200 kg mineral N / ha = 111 kg mineral N / ton oil.

Table 8 : GHG emissions from agricultural operations: option 1 (cakes are fired for own electricity production)

	l diesel / ha	kg CO_2 eq./ ha
pruning and mulching	7.4	21.8
fertilizer application	2.8	8.1
pesticide application (if any)	2.3	6.9
weed cutting / harrowing	3.1	9.0
mineral fertilizer production (200 kg mineral N / ha needed)	0.0	1893.4
N_2O emissions on field (denitrification of 233 kg N/ha)	0.0	722.0
Joonas harvester (expect 4km/h)	19.2	56.9
transporting tractor with trailer	6.9	20.4
tractor trailer 6 metric ton/9m3	6.2	18.4
trailer empty return	3.3	9.7
TOTAL STAGE 2: agricultural operations	51.1	2767.2
	=> 1533.1 kg CO_2 eq. / ton oil.	

With an expected yield of 1.805 ton oil / ha, the GHG emission are calculated as follows:
2767.2/ 1.805 = 1533.1 kg CO_2 eq. / ton oil.

9.2.3. Option 2 (no own electricity production)

No mineral fertilizer is needed in this option since the cakes are not burnt and applied on the land with their full nitrogen content.

Table 9 : GHG emissions from agricultural operations: option 2 (no own electricity production)

	l diesel / ha	kg CO_2 eq./ha
pruning and mulching	7.4	21.8
fertilizer application	2.8	8.1
pesticide application (if any)	2.3	6.9
weed cutting / harrowing	3.1	9.0
mineral fertilizer production (0 kg mineral N / ha needed)	0.0	0.0
N_2O emissions on field (denitrification of 233 kg N/ha)	0.0	722.0
Joonas harvester (expect 4km/h)	19.2	56.9
transporting tractor with trailer on neightboring row	6.9	20.4
tractor trailer 6 metric ton/9m3	6.2	18.4
trailer empty return	3.3	9.7
TOTAL STAGE 2: agricultural operations	51.1	873.8
	=> 484.1 kg CO_2 eq. / ton oil.	

With an expected yield of 1.805 ton oil / ha, the GHG emission are calculated as follows:
873.8 / 1.805 = 484.1 kg CO_2 eq. / ton oil.

9.3. Stage 3: processing and transportation

9.3.1. Option 1 (cakes are fired for own electricity production)

The expected power production from the steam turbine is computed hereunder, assuming a 10 MW turbine.

Table 10 : Power generation from press cakes: expected production data for a 10 MW turbine

cakes weight (1681 + 461 kg cakes / ha)	2142	kg cakes / ha year
	1187	kg cakes / ton oil
heating value of the cakes	22.42	MJ/kg
total energy in cakes	26606	MJ in cakes / processed ton oil
maximum possible power generation with a 10 MW turbine (80% load)	70080	MWh e /year
	2284	kWh e / ton processed oil
primary energy needed to operate the turbine at 80% load	194667	MWh/year
	700800000	MJ/year
weight cakes needed to feed electricity production	31258	tons cakes/ year
available cakes/year for 17000 ha	36414	tons cakes/ year
proportion of the cakes actually burnt for power generation	86	%

Since a lot of excess power is produced by this turbine and since only electricity is expected to be used as energy source for the processing, we can consider that the processing do not lead to any GHG production under the conditions of option 1. Electric consumption for de-hulling is not known at this stage, since the appropriate machinery is not available yet.

Table 11 : GHG emissions from processing: option 1 (cakes are fired for own electricity production)

	kWh e /ton oil	kg CO_2/ton oil
expected electricity consumption for de-hulling	No data available	
expected electricity consumption for oil extraction	385	0
max. power generation (10 MW turbine, 80% load) : 70080 MWhe/year	-2284	0
Total	0	0

In option 1 we consider that no electricity from external source will be needed, so the GHG emissions from this process are considered to be zero.

Since de-hulling will probably take place in different locations than the place where pressing and power generation will take place (decentralised activities), gensets will probably be needed. So de-hulling activities will require diesel oil instead of electricity from own power generation, and some additional CO_2 emissions will probably have to be additionally considered. They can not be assessed at this time.

9.3.2. Option 2 (no own electricity production)

In option 2, no own power generation is operated, so only the electricity use will rely on the public network and/or on diesel gensets. Because power supply in Northern Ghana is not reliable all year through, diesel gensets will be needed as back up anyway. As described above, the emission factor used as reference for electricity production is based on a diesel genset: 1.1 kg CO_2/kWhe.

Electric consumption for de-hulling is not known at this stage, since the appropriate machinery is not available yet. Expected consumption is probably low in comparison with energy necessary for pressing.

Table 12 : GHG emissions from processing: option 2 (no own electricity production)

	kWh e /ton oil	kg CO_2/ton oil
expected electricity consumption for de-hulling	No data available	
expected electricity consumption for oil extraction	385	423.5
max. power generation (10 MW turbine, 80% load) : 70080 MWhe/year	0	0
Total	385	423.5

9.3.3. Oil transportation to Tema harbour

In the base case, the transportation scheme includes:

- ⇨ transport of seeds to the processing plant
  - o transport of the dried, de-hulled seeds from farms to extraction facilities (60 km);
  - o travel back, empty or transporting ashes/cakes back to the farms (60 km),

- ⇨ transport of oil to Tema harbour
  - o road transportation to a river harbour on the White Volta (110 km),
  - o river transportation on river boats down to Akosodo dam (420 km),
  - o road transportation from Akosodo dam to Tema sea harbour (80 km).

It is assumed that barges do not return empty, so only a single travel is accounted for. An empty return is supposed for trucks.

Table 13 : GHG emissions related to seed transportation (from de-hulling site to pressing)

	l diesel / ton oil	kg CO_2/ton oil
Transport from collection point to oil extraction facility full load	5.34	15.87
Transport from extraction facility to collection point (empty /cakes/ashes)	2.85	8.46
Total for transport seeds from de-hulling to pressing	8.19	24.33

Table 14 : GHG emissions related to oil transportation to Tema harbour

	l diesel / ton oil	kg CO_2/ton oil
Transport of Jatropha crude oil from extraction facility to Black Volta harbour, full load 22MT (24m3)	2.44	7.2
Transport back from Black Volta harbour to oil extraction facility, empty load	1.54	4.6
Barges from Black Volta to Akosombo dam (700 tons)	3.24	9.6
Transport of Jatropha crude oil from Black Volta harbour to Akosombo dam, full load 22MT (24m3)	1.77	5.3
Transport back to Black Volta harbour, empty load	1.12	3.3
Total for transport oil to Tema harbour	10.10	30.0

The following specific emission factor has been considered for the 700 tons barges (Ademe 2006): 0.007710195 l/ton km.

9.3.4. Total

Table 15 : Total GHG emissions from processing and transport

	option 1	option 2
	kg CO_2 / ton oil	kg CO_2 / ton oil
Processing	0	423.5
Transport seeds from de-hulling to pressing	24.3	24.3
Transport oil to Tema harbour	30.0	30.0
TOTAL STAGE 3: transport and processing	54.3	477.8

It is important to keep in mind that our assessment of the pressing facilities and process is based on the operations currently performed in the test farm. The scale of the test farm (700 ha) compared to the expected size of the project in Northern Ghana (17000, 23000 or even 40000 ha) is very different. Using the data from the test farm as far as the energy consumption for pressing is concerned leads to conservative figures, since it might be possible to reduce specific energy consumption in large scale facilities.

9.4. Total GHG emissions

The total through the entire LCA scope is calculated hereunder:

Table 16 : Total GHG emissions for the supply chain (from field to Tema harbour)

	option 1	option 2
	kg CO_2 eq. /ton oil	kg CO_2 eq. /ton oil
STAGE 1: plantation set up	40.8	40.8
STAGE 2: agricultural operations	1533.1	484.1
STAGE 3 : transport and processing	54.3	477.8
GRAND TOTAL	**1628.2**	**1002.7**

10. Avoided CO_2 from exported electricity

In the option 1, it is expected that Biofuel Africa will operate a steam turbine based on heat produced by press cakes firing. Our base case is that a 10 MW steam turbine will be used, in such a way that about 86 % of the press cakes will be burnt to produce yearly 70080 MWhe (2284 kWh e / ton processed oil).

Since the electricity needed for Jatropha seeds processing is estimated to 385 kWhe / ton oil, electricity excess will be available (1899 kWh/ton). It can be externally sold, to the Ghanaian public grid.

As this electricity is exported from the boundaries of the system, we can consider that it leads to the avoidance of CO_2 emissions. In order to compute a figure of avoided CO_2, we will refer again to a diesel genset, but of course if this evaluation had to be carried out in a formal context (e.g. CDM project) a deeper insight of the Ghanaian electric network will be needed in order to figure out what are the most relevant alternative power productions to consider. Of course if hydroelectricity production was included in the reference emission factor, the estimation of the avoided CO_2 would be considerably lower.

Table 17 : Avoided CO_2 due to exported electricity

expected power generation with a 10 MW turbine (80% load)	70 080	MWh e /year
	2 284	kWh e / ton processed oil
expected electricity use for pressing (17000 ha, 1.805 ton oil/ha)	385	kWh e / ton processed oil
	11 814	MWh e /year
expected electricity exiting the boundaries of the system	58 266	MWh e /year
avoided CO_2 due to exported electricity	64093	ton CO_2 / year
	2095	kg CO_2 / ton oil

The decision of Biofuel Africa might be to use a smaller turbine, so that a smaller proportion of the available press cakes will be burnt. The excess cakes could be applied to the land as such (instead of cake ashes), in such a way that more nitrogen is actually returned to the land. Avoided CO_2 due to green electricity exportation will be lower in this case, but nitrogen fertilizer requirements (and related GHG emissions) will also be lower (intermediate situation between option 1 and option 2).

11. Alternative options

11.1. Using Jatropha oil to operate farming, process and local transport

If we assume that (crude) Jatropha oil will be used instead of diesel in all agricultural machines, in gensets, and in trucks used for local transportation (from field to processing and from processing to Black Volta harbour), the GHG footprint of Jatropha will be reduced, but less oil will be available.

The following physical properties of the Jatropha oil were used to compute this alternative (de Oliveiraa et al., 2009):

- density: 0.92 g/cm3 (15 °C),
- calorific value: 40.3 MJ/kg.

Table 18 : Alternative option: using Jatropha oil to operate farming machines

	option 1	option 2
	kg CO_2 eq. /ton oil	kg CO_2 eq. /ton oil
STAGE 1: plantation set up	34.8	37.2
STAGE 2: agricultural operations	1374.4	357.6
STAGE 3 : Transport and processing	7.5	6.9
GRAND TOTAL with Jatropha used to operate production/transport	**1416.7**	**454.9**
Base case (for comparison)	*1628.2*	*1002.7*
Loss of Jatropha output	107 kg/ton	234 kg/ton
	10.7 %	23.4 %

Using crude Jatropha oil to operate production and transport makes the GHG footprint smaller for both options, but the difference is more significant with option 2 than option 1. The reason is that:

- little N fertilizer is used and gensets are used to produce power in option 2
- a lot of N fertilizer is used and no genset is operated in option 1.

Gensets GHG emissions are reduced when they are operated with biofuel, while GHG footprint of fertilizers remains the same anyway.

Since Jatropha oil is used to operate the gensets in option 2, the alternative leads to consume larger quantities of Jatropha oil within the supply chain for option 2 than for option 1.

11.2. Operating all transportation with truck (no river transport)

The alternative hereunder considers a full road transport from Tamale to Tema harbour, with 22 tons loaded trucks. The distance is 750 km. In the computation, we have considered that the trucks return empty from Tema to Tamale.

Table 19 : Alternative option: operating all transportation with truck (no river transport): stage 3

	option 1	option 2
	kg CO_2 / ton oil	kg CO_2 / ton oil
Processing	0	422
Transport seeds from de-hulling to pressing	24.3	24.3
Transport oil to Tema harbour	80.5	80.5
TOTAL STAGE 3: transport and processing	104.8	527.9
Base case (for comparison)	*54.3*	*477.8*

Table 20 : Alternative option: operating all transportation with truck (no river transport): grand total

	option 1	option 2
	kg CO_2 eq. /ton oil	kg CO_2 eq. /ton oil
STAGE 1: plantation set up	40.8	40.8
STAGE 2: agricultural operations	1533.1	484.1
STAGE 3 : Transport and processing	104.8	527.9
GRAND TOTAL	**1678.7**	**1052.8**
Base case (for comparison)	*1628.2*	*1002.7*

11.3. Producing nitrogen fertilizers with low GHG emission levels

As described in the section about emission factors, two modern technologies of nitrogen fertilizer production can lead to lower GHG emissions than the level used in our base case (9.45 kg CO_2 eq. / kg N) :

- urea production (2.5 kg CO_2 eq. / kg),
- nitrate production using de-N_2O catalyst (3.0 kg CO_2 eq. / kg).

The impact on the general balance would be as follows for a fertilizer with GHG emissions associated to production of 3 kg CO_2 eq. / kg N.

Table 21 : Alternative option: producing nitrogen fertilizers with low GHG emission levels

	option 1	option 2
	kg CO_2 eq. /ton oil	kg CO_2 eq. /ton oil
STAGE 1: plantation set up	35.6	35.6
STAGE 2: agricultural operations	817.1	484.1
STAGE 3 : Transport and processing	54.3	477.4
GRAND TOTAL	**907.0**	**997.1**
Base case (for comparison)	*1628.2*	*1002.7*

Of course the difference between option 1 and option 2 would fade out in this alternative, since GHG emissions due to nitrogen fertilizers production is a major part of the footprint under option 1.

The relevance of this alternative would need a deeper investigation of the fertilizer production facilities in Accra (Yara factory), since it is expected that fertilizers that will be used in the project would be produced there. The choice between urea and nitrate as fertilizer will be important as well.

11.4. Operating a smaller steam turbine

The hypothesis of operating a 10 MW turbine is based on the expected amount of press cakes available. A 10 MW turbine is obviously oversized for the electricity needs of the processing facilities and it would produce a lot of excess power (to be exported from the system boundaries).

It might be an option to operate a smaller turbine, enough to cover the electricity consumptions for the process but fed by the firing of a smaller part of the press cakes. In this case, less electricity will be exported from the system, and a smaller proportion of the cakes will be fired (so that a larger proportion of them can be applied on the land, reducing the need of producing mineral N fertilizer).

A power of 2-3 MW seems to be the minimum range for a small steam turbine. The operation all year through at 80 % load of a 2 MW turbine would produce enough electricity for the consumption of the processing facilities and would need to fire only 17 % of the cakes. Only little electricity is expected to be exported in this case (about 72 kWhe/ton, leading to CO_2 avoidance of 79 kg/ton oil). A large proportion of the cakes (83%) would be applied on the land, reducing the need of mineral N fertilizer application.

The GHG footprint associated to this alternative is shown in the table hereunder. This alternative refers only to option 1, since no turbine is operated in option 2.

Table 22 : Alternative option: operating a smaller steam turbine

	option 1	option 2
	kg CO_2 eq. / ton oil	kg CO_2 eq. / ton oil
STAGE 1: plantation set up	40.8	-
STAGE 2: agricultural operations	506.1	-
STAGE 3 : transport and processing	54.3	-
GRAND TOTAL	**601.2**	-
Base case (for comparison)	*1628.2*	*1002.7*

If we consider the GHG footprint of Jatropha oil only, using a smaller turbine leads to a reduction of the emissions, since more press cakes are available for direct application on the land and less mineral fertilizer needs to be produced. However, less excess electricity is made available for exportation outside the limit of the system, so it leads to less avoided CO_2 in this perspective.

11.5. Extracting oil with solvent

The use of solvent for the oil extraction process will reduce the electricity requirement for this step and increase oil recovery (more efficient extraction). Specific consumptions and performances for this alternative have been investigated by Biofuel Africa with the help of data from an equipment supplier. This is based on a plant processing 100 tons seeds / day. The installed power of the machinery is 262.3 kW. The expected oil recovery is expected to be 34% of dry seed (with 1% of dry seed being unextracted oil). It leads to an expected specific consumption of about 185 kWh / ton oil. The expected oil yield increases up to 2.192 ton / ha-year (instead of 1.805 ton / ha-year for the base case).

Since de recovery of oil is higher, specific GHG emissions related to stages 1 and 2 are reduced. In stage 3, indirect GHG emissions due to electricity consumption are reduced for option 2. Emissions from crude oil transportation are unaffected.

Table 23 : Alternative option: solvent extraction

	option 1	option 2
	kg CO_2 eq. / ton oil	kg CO_2 eq. / ton oil
STAGE 1: plantation set up	33.6	33.6
STAGE 2: agricultural operations	1401.2	398.1
STAGE 3 : transport and processing	54.3	257.8
GRAND TOTAL	**1489.2**	**689.6**
Base case (for comparison)	*1628.2*	*1002.7*

As can be seen in the table, solvent extraction leads to a significant reduction of GHG emissions for option 1, and a very significant reduction for option 2.

A higher recovery of oil will has an impact on the calorific value of the press cakes, as well as on the available amount of the cakes. This has complex consequences on option 1: all the press cakes need to be burnt to operate a 10 MW turbine at 65% load. It means than less cakes can be applied on the field than in the base case and so more mineral fertilizer is needed (with more indirect GHG emissions). Less electricity will be produced: 56 700 MWhe / year (instead of 70 080 MWhe / year in the base case) since the turbine will operate at a 65 % load instead of 80%. Even though specific electricity consumption is smaller than for the base case, there will be less electricity in excess: 1334 kWh e /ton oil (instead of 1899 kWh e /ton oil for the base case).

Beside the change in energy consumption and extraction rates, the GHG balance of the solvent life cycle needs to be addressed, particularly the way it would be produced / transported / disposed of. This information is not available at this time.

12. Sensitivity analysis

12.1. Introduction

Some input used in the GHG assessment is based on assumptions or expectations: particularly the future evolution of the organic matter in soil and the prospective Jatropha oil yield. At this early stage of the process realisation, it is of course not possible to have certitudes on those parameters.

It is hence useful to assess what would be the consequence on the entire GHG balance if those parameters happen to differ from what is expected today. That's the purpose of the sensitivity analysis.

12.2. Organic matter in soil

In the GHG calculation, it has been assumed that organic mater in soil (SOM) will not deplete after land clearing and Jatropha plantation and throughout the plantation life cycle. SOM is estimated to be about 53 ton C / ha in the initial situation, so this is an enormous carbon pool. We have insisted on the need of an appropriate agricultural techniques aiming at the maintenance and improvement of soil organic matter.

The following table shows how the GHG balance might be altered by oil organic matter increase or depletion throughout the years.

Table 24 : Influence of soil organic matter evolution on the GHG balance

SOM evolution	initial C content (before set up)	final C content (after 25 years)	CO_2 release from C in soil		general GHG balance	
					option 1	option 2
	ton C / ha	ton C / ha	ton CO_2 / ha	kg CO_2 / ton oil	kg CO_2 eq. / ton oil	kg CO_2 eq. / ton oil
50% depletion	53	27	97	2153	3781	3156
25% depletion	53	40	49	1077	2705	2080
10% depletion	53	48	19	431	2059	1434
no change in SOM (base case)	53	53	0	0	1628	1003
10% increase	53	58	-19	-431	1198	572
25% increase	53	73	-73	-1615	13	-612
50% increase	53	109	-206	-4576	-2948	-3573
100% increase	53	219	-607	-13458	-11830	-12455

As can be seen in this table, any significant evolution of SOM throughout the plantation lifecycle will have an enormous impact on the GHG balance. If 50% of the soil organic matter is released into the atmosphere, Jatropha oil production during 25 years will not lead to any avoidance of GHG emission in comparison with fossil diesel, it might even be worse (GHG emissions for diesel oil life cycle are 3536 kg CO2 eq. / ton). On the other hand, if a good management of soil organic carbon is operated through appropriate agricultural practices, the benefits in GHG avoidance can be considerable.

12.3. Expected oil yield

Biofuel Africa has some reasons to believe that the following yield can be expected:
30 000 kg fresh fruit / ha-year = 6400 kg dry seeds / ha-year = 1805 kg oil / ha-year.

If we refer to available literature references, this expectation may seem rather optimistic since reported yields are usually lower:

- 15 625 kg fresh fruit / ha-year can be computed from a case study in Thailand (Prueksakorn and Gheewala, 2006) ;
- between 1000 and 5000 kg dry seed / ha-year on the 4th year after plantation establishment is given for plantations in South America (Achtena et al., 2008).

However, Biofuel Africa Ltd points out that the estimation of 1805 kg oil is based on local data (extrapolation of the yield from Jatropha edges in Tamale) and that these figures are seen as realistic by Yara company in Accra (fertilizer producer and consultant with experience with Jatropha). The climate in Ghana is particularly favourable for reaching high oil yield, compared to some other places in the world where Jatropha has been cultivated. That's why we have used the 1805 kg oil / ha-year figure in our base case.

Unexpected reasons, including pests or adverse climatic conditions, might lead to failure in reaching the expected oil yield. It is important to be aware of the potential impact of a lower yield on the overall GHG balance, as shown in the table hereunder.

Table 25 : Influence of Jatropha oil yield on the GHG balance

achieved yield	option1	option2
ton oil / ha-year	kg CO_2 eq. / ton oil	kg CO_2 eq. /ton oil
1.0	1900	1103
1.5	1825	1028
1.805 (base case)	1628	1003
2.0	1512	990
2.5	1301	968

In the computation, the application of nitrogen fertilizer has been considered as proportional to the oil output (since the calculation of this dose was initially computed using the exported nitrogen). It must be noted that the avoided CO_2 due to green energy exportation in option 1 is also affected by the variation in oil yield (and available press cakes), even though this computation is kept out of the carbon footprint of the product.

13. Conclusions

The life-cycle analysis (LCA) realized in this study covers the production of Jatropha oil in Northern Ghana considering the stages from the Jatropha plantation up to the Jatropha oil storage tank in Tema (Ghanaian harbour) including the inland transportation. The base case considered in this assessment leads to the following specific GHG emissions for Jatropha oil life cycle from the plantation to Tema harbour:

- 1628.2 kg CO_2 eq./ton oil if cakes are fired to produce electricity in a steam turbine (option 1),
- 1002.7 kg CO_2 eq./ton oil if cakes are applied to land, reducing the need of fertilization (option 2).

The largest contributions to those emissions are:

- production of nitrogen fertilizer and denitrification (particularly for option 1),
- power generation for processing (particularly for option 2).

Option 1 offers the opportunity to produce excess electricity to be exported from the system. It leads to a CO_2 avoidance which can not be integrated in the carbon footprint of the product. If we use diesel genset as reference, the avoided CO_2 is 64093 ton / year.

The production considered as reference is currently medium scale (about 700 ha in the test farm) while it is expected to operate large scale production in Tamale (first target being to start cultivation on 17 000 ha, with currently 23 000 ha being contracted and 40 000 ha being a long term objective). The way some stages of the supply chain are operated today (particularly pressing techniques) differ from what can be expected in possible large-scale facilities in the future.

Several alternatives are still open for some supply chain steps, so their possible impact on the GHG footprint has been investigated:

- Using Jatropha oil to operate farming, process and local transport might lead to a very significant abatement of the specific GHG emissions (reaching a reduction of 548 kg CO_2 eq./ton oil for option 2, but the amount of Jatropha oil necessary is not negligible at all (up to 23% of the available oil for option 2).
- Operating all transportation with truck instead of boats leads to increase GHG emissions, even though transport remains a minor contributor to the overall balance.
- Producing nitrogen fertilizers with low GHG emission levels can a very significant impact on Jatropha oil footprint (reaching a reduction of 721 kg CO_2 eq./ton oil for option 1). The feasibility of this alternative depends on the technologies available in the Ghanaian fertilizer plant from which fertilizer are expected to be bought.
- Operating a smaller steam turbine (2-3 MW instead of 10 MW) can improve the GHG balance of option 1, since less mineral fertilizer would be necessary. However, this option would make use of only a small part of the energy resource available within press cakes, and the avoided CO_2 from the exportation of green electricity outside the system boundaries will be less.
- Extracting oil with solvents is a likely alternative in large-scale facilities, and will lead to a significant reduction of the specific GHG emissions (because of higher oil recovery and lower electricity consumptions). The impact of the solvent life cycle on the general GHG balance will have to be checked as well.

Some input used in the GHG assessment is based on assumptions or expectations: particularly the future evolution of soil organic matter and prospective Jatropha oil yield. We have reasons to expect that SOM will remain stable or increase thanks to appropriate agricultural practices (including avoidance of fire, mulching, cover crops…). However, it is important to keep in mind that a depletion of the carbon pool in soil would lead to a very detrimental GHG balance. Similarly, if the Jatropha oil yield turns out to be less than expected, it will lead to higher specific emissions.

The further steps in the life cycle of the Jatropha oil (including international sea transportation and refining) are not in the scope of this report. Taking those steps into account would be essential before comparing the result with the GHG emissions in fossil diesel life cycle (which is 3 536 kg CO_2 / ton diesel for the entire life cycle, or 3 182 kg CO_2 / ton diesel considering only direct emissions).

14. Recommendations

As any significant SOM increase or depletion would have an important impact on the overall CO2 balance, an intensive monitoring of soil organic matter (SOM) is essential. This should include the assessment of the initial situation (before land clearing) and a yearly analysis of the evolution. It is advisable to analyse SOM in a deeper profile than 20 cm, since mechanical work on the land will affect the distribution of carbon through the different soil horizons.

Even though the production of electricity with a steam turbine leads to more mineral fertilizer use and hence to higher GHG emissions, it seems a very interesting option. It is not appropriate to consider the avoided CO_2 (due to exported green power) as part of the Jatropha oil carbon footprint, but this avoided CO_2 can be reported separately and it can possibly lead to benefits in the framework of a CDM project or possibly in another framework.

Since fertilizer production can be a large source of GHG, it is essential for Biofuel Africa that the choice of the fertilization scheme will take this aspect into account and that mineral fertilizer will be product according the modern techniques entailing low GHG emission.

Using Jatropha oil as fuel in the supply chain instead of fossil diesel or not is more an economic choice than a technical choice. As far as GHG abatement is concerned, this alternative means that (for a given surface of land available) a smaller amount of oil with lower GHG footprint will be produced. The decision will depend on market opportunities, cost considerations, and possibly on legal frameworks in the lands where Jatropha based bio-diesel will be commercialised in the future.

In order to compute the realistic “well-to-wheel” GHG balance, the LCA should be extended in the future in such a way that it will include the international sea transportation and the refining process.

15. References

Achtena, Verchotb, Frankenc, Mathijsd, Singhe, Aertsa, and Muysa, 2008, *Jatropha bio-diesel production and use*, Biomass and bioenergy nr 32 (2008)pp 1063–1084.

Ademe 2006, *Etude sur le niveau de consommation de carburant des unités fluviales françaises : efficacité énergétique et émissions unitaires de* CO_2 *du transport fluvial de marchandises* ; TL & Associés consulting.

Bentrup, 2008, *Fertilizer, Biomass and CO2 Emissions*, IFA Technical Symposium : Food, Fuel and Climate Change: Challenges for the Fertilizer Industry, 10-14 March 2008 - Sao Paulo, Brazil

Bouwman, Boumans, and Batjes, 2002, *Emissions of N2O and NO from fertilised fields: summary of available measurement data*. Glob. Biogeochem. Cycles, 16(4), art. no. 1058.

Bouwman, Boumans, and Batjes, 2002, *Modeling global annual N2O and NO emissions from fertilised fields*. Glob. Biogeochem. Cycles, 16(4), art. no. 1080.

de Oliveiraa, Leitea, de Souzaa, Melloa, Silvab, Rubima, Meneghettib and Suarez, 2009, *Characteristics and composition of Jatropha gossypiifoliaand Jatropha curcas L. oils and application for biodiesel production,* Volume 33, Issue 3, March 2009, Pages 449-453.

Ernesto S. Elefan, 2008, *Biofertilizers for Jatropha curcas L. (Euphorbiaceae) Grown in Different Planting Media*, International Conference on Environmental Research and Technology (ICERT)

IPCC, 2006, *IPCC Guidelines for National Greenhouse Gas Inventories*, prepared by the National Greenhouse Gas Inventories Programme.

JRC (Joint Research Center), 2006, *Well-to-wheels analysis of future automotive fuels and powertrains in the European context*, report of JRC/EUCAR/CONCAWE

Prueksakorn and Gheewala, 2006, *Energy and Greenhouse Gas Implications of Biodiesel Production from Jatropha curcas L.*, The 2nd Joint International Conference on “Sustainable Energy and Environment (SEE 2006)”, 21-23 November 2006, Bangkok, Thailand

Sheehan, Camobreco, Duffield, Graboski, Shapouri, 1998. *Life cycle inventory for biodiesel and petroleum diesel for use in an urban bus*, NREL/SR-580-24089 UC Category 1503, National Renewable Energy Laboratory, Colorado, USA. Prepared for U.S. Department of Energy and U.S. Department of Agriculture.

University of New South Wales, Recycled Organics Unit (2003). *Life Cycle Inventory and Life Cycle Assessment for Windrow CompostingSystems,* Report prepared for NSW Department of Environment and Conservation (Sustainability ProgramsDivision), Published by Recycled Organics Unit, The University of New South Wales, Sydney

Wind, Wallender, 1997, *Fossil-fuel carbon emission control in irrigated maize production*, Energy 22: 827-846.

World Business Council for Sustainable Development, World Resources Institute, 2004, *The Greenhouse Gas Protocol, a corporate accounting and reporting standard,* revised version March 2004.

Xiaoyong, Hutley and Eamus, *Carbon balance of a tropical savannah of northern Australia*, Oecologia, Volume 137, Number 3 / November 2003