Two-year old Jatropha plants at Sun Biofuels Mozambique SA (photo by Matthias Spöttle)

Report: **Greenhouse gas calculations Jatropha value chain Sun Biofuels Mozambique SA**

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Amsterdam, March 2011

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PREFACE

This report is prepared on the basis of the data provided by Sun Biofuel Mozambique SA and information gathered in the field visits and by desk research.

A first version was prepared on 18 October 2010 and discussed with Sun Biofuels Mozambique SA on 25 and 26 October 2010 during the visit at site. A second version was prepared on 4 November 2010. The present version is the third version that takes account of the remarks of the third party review carried out in January 2011.

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ABBREVIATIONS

CHVO	Co-processed Vegetable Oil
DAP	Di ammonium Phosphate
dLUC	Direct Land Use Change
EC	European Commission
ECPT	Ecosystem Carbon Payback Time
EU	European Union
GHG	Greenhouse gas
HVO	Hydrotreated Vegetable Oil
iLUC	Indirect Land Use Change
LAN	Lime Ammonium Nitrate
LCA	Life Cycle Analysis
ME	Methyl Ester
RED	Renewable Energy Directive
RFA	Renewable Fuels Agency (UK)
RTFO	Renewable Transport Fuel Obligation
SBF	Sun Biofuel Mozambique SA
SOC	Soil organic carbon

EXECUTIVE SUMMARY

Background

The project "*Towards Sustainability Certification of Jatropha Biofuels in Mozambique*" aims to build up knowledge for future certification of Jatropha biofuels through a benchmark pilot sustainability assessment of three Jatropha producers using existing sustainability criteria frameworks.

This report

This report presents the Greenhouse gas (GHG) calculations that Partners for Innovation carried out of the Jatropha chain of Sun Biofuel Mozambique SA (SBF). It uses the EC methodology and guidance for GHG calculations.

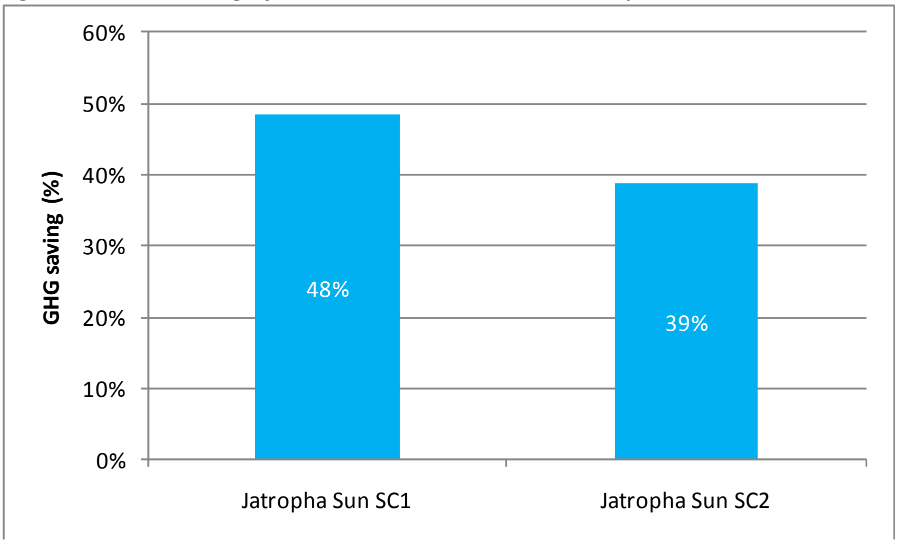
A number of policy and market developments make GHG performance an important parameter in the biofuel market. One of them is the Renewable Energy Directive (RED) that sets a minimum requirement of 35% in 2011 for GHG savings to biofuels in the EU. This'll be 50% in 2017 and 60% in 2018. Meeting the EU thresholds will hence translate into a higher biofuel value. This makes the GHG performance an important parameter for the market value of Jatropha oil and biodiesel.

This report is prepared on the basis of the data provided by Sun Biofuel Mozambique SA and information gathered in the field visits and by desk research. A first version was prepared on 18 October 2010 and discussed with Sun Biofuels Mozambique SA on 25 and 26 October 2010 during the visit at site. A second version was prepared on 4 November 2010. The present version is the third version that takes account of the remarks of the third party review carried out in January 2011.

Preliminary calculations show GHG savings of 48% and 39%

The calculations demonstrate that the Jatropha chain of SBF will create GHG savings: on the basis of the data provided, the GHG savings are estimated at 48% (scenario 1) for biodiesel produced and used in Mozambique, and 39% (scenario 2) for biodiesel produced and used in the UK. This hence meets the EU threshold of 35%. Carbon stock changes caused by land use change are assumed to be zero in these scenarios.

Figure 1: GHG saving of the two scenarios under study



Note: base case scenarios (SC1 use in Mozambique, SC2 use in UK) with land use change excluded

These GHG savings should be confirmed, and can be further optimised

These figures will have to be confirmed as underlying data are still uncertain: the calculations are for a large part based upon assumptions because Jatropha harvesting has only just begun and the first experiences with processing are to follow. There is also a high potential for optimisation: the project team has demonstrated that parameters such as seed yield, oil yield and nitrogen fertiliser input have a significant impact on the GHG performance of the Jatropha chain; GHG savings **range from 15% to 73%** around the base case of 48% in the case of the Mozambican scenario.

Land use change can have a large impact, but is assumed zero to positive in the case of SBF

Carbon stock changes caused by land use change can have a large impact on the GHG saving. This impact is positive if land with annual crops (such as tobacco) or grassland is converted to Jatropha land because of the carbon build-up of Jatropha as a perennial crop. The impact is negative if mature bush or forestland is converted into Jatropha land because of the high carbon stocks of these land types.

In the case of SBF, empiric data on the impact of land use change on the carbon stock is not available at present. For the SBF situation, the project team assumes that the impact of land use change is neutral (no impact) or positive (resulting in additional GHG savings). The impact is neutral if is considered that the land use change is from young savannah bush land, which was able to grow for about 4 to 8 years when the tobacco land was abandoned, to mature Jatropha land, that grew for 20 years. It is positive if is considered that the land use change is from mature tobacco land to mature Jatropha land, since the build-up is 17,5 tC/ha for the carbon stocked in the above and below ground Jatropha vegetation, according to the EC default value for mature Jatropha land[1].

Recommendations and suggestions

At company level, the project team would recommend the following next steps:

1. *Create a good understanding at plant management level*. In our view it is crucial to understand the mechanisms of the GHG saving of the Jatropha chain, because GHG performance is likely to become an important parameter for the market value of Jatropha oil and biodiesel. Key parameters are seed yield, oil yield, nitrogen fertiliser inputs, carbon stock of acquired land, carbon build-up at the plantation, and the use of by-products;

2. *Define SBF's GHG policy*. In the view of the project team this policy should include:
   a. *Guidance on the areas that SBF considers as no-go areas for carbon considerations*: translate RED requirements into SBF's practice;
   b. *Guidance for land acquisition:* establish how the carbon stock of land is documented before it is acquired and converted;
   c. *Guidance for monitoring:* put in place a monitoring programme of the parameters that significantly influence the GHG emissions of the chain: (i) seed yield, (ii) oil yield, (iii) fertiliser inputs, (iv) diesel use at the farm, (v) use of by-products, (vi) carbon stock at the time of the land acquisition, and (vii) carbon build-up in the Jatropha operations.
   d. *Guidance for building up information:* consider whether the present study is sufficient as a first step for SBF in this stage. Consider how to use the results of the study, only

[1] EC 2010a

internally or also externally (publish on the Internet). Determine the research needs of SBF (e.g. methodology to determine carbon stocks at the time of land acquisition and to monitor carbon build-up in the Jatropha operations, GHG calculations of pure plant oil applications).

At Jatropha sector level, the project team would recommend:

1. *Stimulate members to carry out GHG calculations.* Carrying out GHG calculations is an excellent way to gain profound understanding of the GHG performance of the Jatropha chain and of the issues at stake. As said above, this is crucial in our view because GHG performance is likely to become an important parameter for the market value of Jatropha oil and biodiesel.

2. *Lead and feed the debate.* The RED has provided a reference for GHG accounting of biofuels. It is clear that its mechanisms and its GHG accounting methodology will continue to evolve in the next years. The Jatropha sector and its companies will be greatly helped if knowledge gained on GHG calculations and on complying with the RED is circulated abundantly. They will also be advanced if research provides additional input and empirical data on for instance the carbon stocks that are built up at Jatropha plantations, and on GHG emissions of pure plant oil applications.

3. *Be involved in establishing default values for the Jatropha chains.* The RED includes default values for many biofuel chains but not for Jatropha. It is in the interest of the Jatropha industry to use default values, as this facilitates compliance with the RED. The project team suggests that the Jatropha Alliance, as sector organisation, seeks for industry support and for finance to be involved in the data collection and GHG calculation that determine the Jatropha default values. The EU agency to contact is the EU research centre JRC.

1. INTRODUCTION

>> This chapter provides background information on the project and explains the set-up of this report.

Background

The project "Towards Sustainability Certification of Jatropha Biofuels in Mozambique" aims to build up knowledge for future certification of Jatropha biofuels through a benchmark pilot sustainability assessment using existing sustainability criteria frameworks.

The project started in October 2009 with a review of the available sustainability criteria frameworks and certification schemes. On the basis of this review, a practical methodology was developed for the sustainability assessments of the Jatropha plantations, on the basis of the sustainability standard of the Roundtable on Sustainable Biofuels (RSB). Three Jatropha plantations in Mozambique were chosen for the assessments. These were visited in March 2010 and revisited in October 2010. In March 2011 the project results were disseminated within the Jatropha industry and fed into relevant international forums.

This report

This report presents the greenhouse gas (GHG) calculations that Partners for Innovation carried out of the Jatropha chain of Sun Biofuel Mozambique SA (SBF), and provides preliminary insights in the carbon intensity of this chain. It is based upon input provided by SBF and uses the EC methodology and guidance for GHG calculations.

The report is one of the outputs of activity 4 'Sustainability assessment'. It aims to provide input for further research and build-up of knowledge on factors determining the carbon intensity of the Jatropha chain, at company and sector level.

Other outputs in activity 4 are assessment reports evaluating the data and evidence provided by the participating companies against the principles and criteria of the Roundtable on Sustainable Biofuels, and identifying gaps in these data and evidence.

This report is prepared on the basis of the data provided by Sun Biofuel Mozambique SA and information gathered in the field visits and by desk research.

Why GHG calculations are important

A number of policy and market developments make GHG performance an important and valuable parameter in the biofuel market. The project team would like to mention the Renewable Energy Directive (RED) that sets a minimum requirement of 35% for GHG savings to biofuels in the EU in 2011. This will rise to 50% in 2017 and 60% in 2018. It is believed that other markets will follow. The draft sustainability criteria for biofuels of the Mozambican government require that biofuel production and processing shall contribute to the reduction of GHG-emissions as compared to fossil fuels.

This means that GHG performance above the thresholds will translate into a higher biofuel value. This makes the absolute GHG performance of Jatropha biodiesel an important parameter for the market value of Jatropha oil and biodiesel.

2. METHODOLOGY

>> This chapter explains the methodology applied for the GHG calculations.

Methodology and guidance

In line with the methodological choices made in an earlier stage in the project[2], the project team has used the methodology and guidance used within the Renewable Transport Fuel Obligation (RTFO)[3] to calculate GHG emissions of the Jatropha chain of SBF. This methodology is "RED ready" and calculates the GHG savings for the biofuel chain with a time horizon of 20 years. For the calculation of land carbon stocks, the project team has used the EC guidelines issued to complement the RED[4].

The RFA carbon calculator

The project team has opted for a relatively simple calculation using the carbon calculator (version 1.1) of the Renewable Fuels Agency (RFA) in the United Kingdom (UK), because such a calculation is sufficient to obtain meaningful results for knowledge and capacity building within the frame of the project, and because it fits within the available resources.

The RFA carbon calculator allows fuel suppliers to calculate the carbon saved on biofuels as an alternative to using default values and emission factors. The calculator applies the lifecycle analysis (LCA) methodology laid out in the RED. The calculator is freely available on the Internet[5] and includes full guidance, so that interested biofuel companies can use the tool in their practices. A dedicated Excel sheet was developed for the land use change calculations following the EC methodology.

Set-up of calculations and scenarios

The project team has modelled the Jatropha biodiesel chain in ten stages, from Jatropha cultivation to fuel filling at the fuel station. The project team has used company-specific data whenever available. If not available, default RTFO values were used. The project team has included a sensitivity analysis in order to demonstrate to which parameters the GHG performance is most sensitive.

Validation and review

Validation of input data and assumptions has taken place during the visit of the project team to the site of Sun Biofuels Mozambique in October 2010.

In order to validate the results, the project team has also compared the outcome of the calculations with four other GHG studies of Jatropha chains. Throughout this report, the project team has named these studies '*Jatropha RTFO default*', '*Jatropha D1 Oils*', '*Jatropha Daimler' and 'Jatropha jet fuel*'[6].

As part of Partner for Innovation's standard quality procedures, this report was furthermore internally reviewed by a third person not being part of the project team. This was done by Emiel Hanekamp. The report was then submitted to Robert Bailis and Ignacio Perez for an external review.

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[2] Partners for Innovation (2010)
[3] RFA (2010)
[4] EC (2010a)
[5] http://www.renewablefuelsagency.gov.uk/carboncalculator
[6] Sources are respectively RFA (2010), Ecofys (2008), IFEU (2007/2008) and Bailis (2010).

3. INPUT DATA AND ASSUMPTIONS

>> This chapter presents the scenarios and the data used for the GHG emission calculations.

3.1 Information about Sun Biofuels Mozambique SA

Established in 2005, Sun Biofuels Ltd is a UK-based biofuels company operating in Mozambique and Tanzania. Sun Biofuels' strategy is to cover all areas of the biofuels value chain from cultivation and harvest to oil extraction and marketing. Sun Biofuels is backed by Trading Emissions PLC, a carbon investment company listed on the London Stock Exchange.

Sun Biofuels Mozambique SA (SBF) operates the Jatropha plantation at Chimoio in the Manica Province of Mozambique. The site is situated on the Beira corridor which is the transport link between the port of Beira and the land-locked countries of Zimbabwe, Zambia and Malawi.

In 2007, SBF bought 4,900 hectares of land that belonged to a tobacco company and started restoring the infrastructure of the farms and preparing the land for plantation. One thousand hectares were planted with Jatropha Curcas in January 2009, another thousand hectares early 2010. Aim is to have 10,000 hectares planted with Jatropha in 2015. The first Jatropha fruit was harvested in April 2010 and the first oil extracted. Optimum yield is expected from 2012. Following its biodiversity policy, SBF has set aside land identified as wetlands, riparian buffer zones and woodland conservation areas.

SBF currently employs up to 1,500 people of the local communities. SBF also grows maize, soya, sugar beans and sunflower. The area for food crops was about 450 hectares in 2010.

3.2 Description of scenarios

The project team has calculated the GHG performance of two different scenarios starting from Jatropha cultivated at the facilities of SBF, a first one for use as biodiesel Methyl Ester (ME) in Mozambique, a second one for use as biodiesel ME in the United Kingdom (UK).

These scenarios consist of the following steps:

a. *Scenario 1: Mozambican Jatropha for biodiesel use in Mozambique.* This scenario is based upon cultivation of Jatropha at the SBF facilities in Chimoio in Mozambique and crushing in the direct vicinity of these facilities, then transport of the oil by train to Beira. Subsequently transport by ship to Maputo, processing to biodiesel ME in Maputo, and then blending with diesel for use in Mozambique.
b. *Scenario 2: Mozambican Jatropha for biodiesel use in UK.* The same scenario as 1 but instead of transport to Maputo, the oil is transported from Beira to the UK by ship for processing to biodiesel ME in the UK and blending with diesel for use in the UK.

Initially it was considered to include a scenario for local use as pure plant oil in the direct vicinity of the SBF facilities, e.g. in electricity generators in surrounding local communities. However, as reliable default values for such a scenario are not readily available, the project team did not pursue this calculation within the frame of this project.

For the processing step, several technologies are possible: transesterification generating biodiesel ME or hydrotreatment generating either Hydrotreated Vegetable Oil (HVO) or Co-processed Hydrotreated Vegetable Oil (CHVO). The energetic performance of these technologies varies but the GHG emissions are similar at chain level[7]. In the current project, the project team has chosen to model transesterification because this is the most likely technology to be used in the case of processing in Mozambique.

3.3 Data used

For the modelling of the two scenarios, the project team has used actual and estimated data provided by SBF whenever such data was readily available. These data is included in column 3 of Table 2. For a number of stages (stages 3, 5, 7 and 9) the project team has used default values available in the RFA carbon calculator for the Jatropha RTFO default chain. These values are included in column 4 of Table 2. Choices are explained in the texts after the Table.

Table 2 Input data and assumptions used in the GHG calculations of the Jatropha biodiesel chain

Stage	Parameter /Assumption	Actual and estimated input data	Defaults and assumptions
1. Jatropha cultivation	Fertilizer input Diesel use Pesticide input Crop yield	100 kg LAN/ha/yr (28%N) 90 kg DAP/ha/yr (18%N, 46%P_2O_5) 48 liters/ha/yr 156 g/ha/yr 3 t seeds/ha/yr (estimate)	
2. Seed transport	Truck or tractor	0 km	
3. Crushing of Jatropha seeds	Plant yield Electricity used		0.240 t oil/t seed 170 MJ/t oil No energetic use of hulls, shells and seedcake
4. Oil transport	Rail Ship Ship	250 km (Chimoio to Beira) 845 km (Beira to Maputo) (SC1) 13,264 km (Beira to UK) (SC2)	
5. Transesterification	Biodiesel yield Electricity used Natural gas Methanol addition KOH addition Glycerol Potassium Sulphate		0.950 t biodiesel/t oil 335 MJ/t biodiesel 1,690 MJ/t biodiesel 113 kg/t biodiesel 26 kg/t biodiesel 0.1 t/t biodiesel 0.04 t/t biodiesel
6. Biodiesel transport	Truck	100 km (SC1 and SC2)	
7. Blending depot	Electricity used		31.2 MJ/t
8. Blended biodiesel transport	Truck	100 km (SC1 and SC2)	
9. Fuel filling station	Electricity used		126.5 MJ/t
10. Land Use Change	Cropland to cropland	No change in carbon stock	

Note: the project team has used the emission factors available in the RFA carbon calculator. Energy-based allocation of by-products is used, following the EC RED methodology. A conservative factor of 1.4 was applied in order to account for the use of default values in stages 3 and 5, following the RFA carbon calculator.

1. Jatropha cultivation

Actual input data were obtained for *fertiliser input* (100 kg Lime Ammonium Nitrate (LAN – 28%N) and 90 kg Diammonium Phosphate (DAP – 18%N, 46%P_2O_5) per hectare per year[8]), *diesel use* (48 litre per hectare

[7] The GHG savings of the Jatropha default value chains are 63%, 61% and 63% for Biodiesel ME, HVO and CHVO respectively (RFA 2010).

[8] SBF expects to use 125 kg LAN/ha/yr at 80% of its productive land over the 20-year period, and 450 kg DAP/ha/yr at 20% of its productive land. LAN: 28%N. DAP: 18%N, 46%P_2O_5.

per year[9]) and *pesticide input* (156 gram active ingredient per hectare per year[10]). Inputs vary significantly in the other reports about the GHG reduction of Jatropha chains:

- *Jatropha RTFO default:* the default values are based upon a limited use of Urea as Nitrogen fertiliser combined with Phosphate and Potassium fertilisers: Urea 12 kg N/ha/yr, Single Super Phosphate 27 kg P_2O_5/ha/yr, Rock Phosphate 4.75 kg P_2O_5/ha/yr, Potassium Chloride 13.25 kg K_2O /ha/yr. No use at all of diesel and pesticides;
- *Jatropha D1 Oils*: use of organic manure, which is applied once. Amounts are not specified as they do not count in GHG emission calculation. No pesticides and diesel use.
- *Jatropha Daimler*: the modelling uses three theoretical cultivation scenarios ('today', 'optimised' and 'best') and assumes that the loss of nutrients resulting from the harvest should be replenished by fertiliser inputs. Nitrogen inputs used are 48, 81 and 141 N kg per hectare per year, respectively. Phosphate input is 19, 31 and 56 kg P_2O_5 per hectare per year, respectively. Potassium input is 53, 89 and 139 kg K_2O per hectare per year, respectively.
- *Jatropha jet fuel*: the modelling also uses three theoretical scenarios (low, medium and high yield) and also assumes that the loss of nutrients resulting from harvest should be replenished. Nitrogen inputs (urea) are 42, 84 and 126 kg N per hectare per year. Phosphate input is 17, 34 and 51 kg P_2O_5 per hectare per year. Potassium input is 47, 94 and 141 kg K_2O per hectare per year.

The project team has not obtained actual data for *seed yield* because SBF has no stable harvesting data yet. The project team therefore used a conservative value: 3 t seed per hectare per year. SBF considers this value as the bottom-line of what is realistic. Other studies use the following yields:

- *Jatropha RTFO default:* uses 2.27 t/ha/yr.
- *Jatropha D1 Oils*: this study uses 4.5 t/ha/yr seed yield, as an average harvested yield over 20 years plantation. A high yield scenario of 6.3 t/ha/yr seed yield was also defined[11].
- *Jatropha Daimler*: this study uses three cultivation scenarios: today, optimised and best. Seed yields referred to are on poor soils: 1.4, 2.3 and 4.4 t/ha/yr respectively[12].
- *Jatropha jet fuel*: this study uses three scenarios with low, medium and high yields of 2, 4 and 6 t seeds/ha/yr respectively. Base case is 4 t seeds/ha/yr.

Drying is done by the sun without additional energy inputs.

2. Seed transport

For seed transport SBF plans to crush in the direct vicinity of the plantation of SBF. The project team has hence used 'zero' transport kilometres. Other studies include transport kilometres as follows:

- *Jatropha RTFO default*: 50 km. Transport per truck in India.
- *Jatropha D1 Oils*: 150 km. Transport per truck in India.
- *Jatropha Daimler*: ranging from 9 to 38 km in India.
- *Jatropha jet fuel:* 1,439 km by truck in Brazil in the base case, 200 km in the high yield scenario.

[9] Diesel is used in a number of activities on the farms, including land preparation, sowing, application of fertilizer, emergency electricity generation, car and tractor use. Diesel use is calculated as the diesel used for all land (25 liter/ha/yr) divided by the part of land planted with Jatropha (52%). Most of the remaining land is not used, a small part is used for food production.

[10] Sum of the quantity used per hectare multiplied by the concentration of the active ingredient in each pesticide: 250 g/ha/yr Benomyl (50%), 48 g/ha/yr Chlorpyrifos (48%) and 40 g/ha/yr Cipermethrina (20%) = 250*50% + 48*48% + 40*20% = 156 g/ha/yr.

[11] Ecofys 2008, pages 8 and 39

[12] IFEU 2007, page 12

3. Crushing

SBF just started experimenting with crushing and has no actual data yet. The project team therefore took the values of the Jatropha RTFO default chain: *oil expelling yield* is set at 0.24 t oil/t seed, *use of electricity* at 170 MJ/t oil[13]. It is unknown whether these values relate to cold-pressing or whether heat is applied. The other studies use similar yields, but very different data for electricity use:

- *Jatropha D1 Oils*: yield of 0.25 t oil/t seed using a mechanical expeller. Electricity use was modelled with 22 MJ/t oil. This was considered rather low[14].
- *Jatropha Daimler*: yields range from 0.28 to 0.31 t oil/t seed. No info about electricity use.
- *Jatropha jet fuel:* yield of 0.25 t oil/t seed for a mechanical expeller. Energy use: 1,4 MJ electricity/t oil and 0,015 kg fuel oil/t oil.

During the crushing stages large quantities of by-products arise, such as hulls, shells and seedcake. There are several possibilities for these by-products: they may not be used at all, be used as fertiliser or be used for energy purposes (e.g. seedcake can be pressed into briquettes that can replace heavy duty oil in boilers of industrial applications). Another possibility is use as animal food: research is currently going on to detoxify the seedcake. As SBF are only experimenting with oil processing and do not know yet what will happen with the by-products, the project team assumed that by-products are not used for energy purposes which is a conservative assumption.

4. Oil transport

Oil transport is defined by the scenarios: the oil is transported by rail from Chimoio to Beira (250 km). From there, it is either transported by ship to Maputo where processing to biodiesel takes place (845 km - scenario 1), or to the UK for processing (13,264 km[15] - scenario 2). In comparison:

- *Jatropha RTFO default:* 1,500 km by rail in India, and 12,000 km by ship to the UK.
- *Jatropha D1 Oils*: 750 km by truck in India to the harbour, and 14,500 km by ship to the UK
- *Jatropha Daimler:* oil was for domestic use in India.
- *Jatropha jet fuel:* 700 km by truck in Brazil to the port, and 15,000 km by ship to the US west coast

5. Transesterification

The project team has used the values of the Jatropha RTFO default chain for transesterification. In comparison:

- *Jatropha D1 Oils*: they also use the RTFO default values except for the yield where they use a slightly lower yield (0.91 instead of 0.95 t biodiesel/t oil).
- *Jatropha Daimler:* no information.
- *Jatropha jet fuel:* modelled with hydroprocessing using the data of refiner OUP.

6. Biodiesel transport, 7. Blending, 8. Blended biodiesel transport, 9. Fuel filling

The project team has used the values of the Jatropha RTFO default chain for these stages, with exception of the transport distances where we have assumed that biodiesel transport is 100 km in both scenarios 1 and 2, and that the transport distance is 100 km too for blended biodiesel transport. In comparison:

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13 RFA (2010)

14 Ecofys 2008, page 26

15 Estimation of shipping distances using www.portworld.com.

- *Jatropha D1 Oils*: this study considers these stages outside of the system boundaries
- *Jatropha Daimler:* no information.
- *Jatropha jet fuel:* estimate on the basis of conventional jet fuel – emission factor of 0.9 kg CO2-e per kg jet fuel.

10 Land use change

SBF bought the 4,900 ha property of the former tobacco farm in 2007. About 1,000 hectares were planted with Jatropha early 2009, another 1,000 hectares early 2010. All Jatropha areas were formerly used as tobacco land. Most of the tobacco land was abandoned in 2004/2005 but parts of it already since 2002. Lands lay fallow between abandoning from tobacco and planting of Jatropha. In this period of minimum 4 to maximum 8 years these lands progressively evolved into young savannah bush land with vegetation composed of plants and woody plants essentially lower than 5 meters. This was cleared before the planting of Jatropha.

The EU RED requires that land use changes are taken into account. Feedstock may not originate from land that had the following status in January 2008[16]:

a. Primary forest and (primary) other wooded land;
b. Areas designated by law for nature protection;
c. Other biodiverse areas that the EC chooses to recognise (no areas recognised yet);
d. Highly biodiverse grassland (to be defined in the EC comitology);
e. Wetland;
f. Forest with a canopy cover of more than 30% (not clear yet how to measure this)[17];
g. Forest with a canopy cover between 10 and 30% (except if evidence can be provided that the GHG saving including land use change meets the GHG thresholds);
h. Undrained peatland.

The reference is the status of the land in January 2008. Evidence of compliance with the land related criteria of the RED can take many forms, including aerial photographs, satellite images, maps and land register entries. The use of earlier evidence than January 2008 is not ruled out. For example, if it is shown that land was cropland a little earlier than 2008, e.g. in 2005, this may be enough to show compliance with some or all of the land related criteria. The EC intends to publish more guidance[18].

The project team has taken account of direct Land Use Change (LUC) in two ways.

i. *No land use change in scenarios 1 and 2.* In the base case scenarios 1 and 2 the project team has assumed that there is no change in land use and thus no change in related carbon stock. A change from one crop to another is not considered as land use change by the RED. In the case of Sun Biofuels Mozambique, the change is first from tobacco land (annual crop) to abandoned cropland evolving in 4 to 8 years to young savannah bush, and then to land with perennial Jatropha;
ii. *Provisional calculations of land use change impact in sensitivity analysis.* In the sensitivity analysis, the project team has calculated the impact of land use changes on the GHG saving of base case

[16] For exact definitions: see Annex III.
[17] The EC includes a notion of land spanning area and of tree height in the definition of forest *"continuously forested areas, namely land spanning more than one hectare with trees higher than five meters, or trees able to reach those thresholds in situ"*
[18] EC 2010b, pages 9 and 10

scenario 1. The project team has used EC guidelines[19] to calculate the carbon stock change when converting towards Jatropha land of a number of land use types: (i) crop land being tobacco, (ii) grassland or savannah, (iii) scrubland, (iv) forestland with a canopy cover < 30%, and (v) forestland with a canopy cover > 30%.

The impact of indirect Land Use Change (iLUC) was not assessed as, in the case of SBF, Jatropha did not displace existing cultivation of tobacco.

Other studies and reports have chosen to address land use change as follows:

- *Jatropha RTFO default.* Did not take GHG emissions from land use change into account.
- *Jatropha D1 Oils.* This study calculated a base case with and without carbon stock impacts from land use change. Its calculations showed that land use change from grassland to Jatropha land had a limited negative impact of 2% GHG saving (-1 t C/ha), using the IPCC Tier 1 approach. The study also indicated that the actual situation may be more positive because of the carbon build-up of Jatropha as a perennial crop, which was estimated at a positive impact of about 20% in GHG saving. The recommendation was to provide actual data for this. The study also made calculations on land use change from forest to Jatropha and demonstrated that any forestland conversion is highly disadvantageous to GHG performance.
- *Jatropha Daimler*: this study used three different values for the impact of land use change on the carbon stock. Changing from scarce vegetation to Jatropha was set at having no impact: 0 t C/ha. Changing from no vegetation to Jatropha was set at having a limited positive impact: 5 t C/ha. Changing from medium vegetation was set at having a significant negative impact: -20 t C/ha.
- *Jatropha jet fuel*: the base case assumes no impact by direct land use change (dLUC). In the sensitivity analysis the impact of direct land use changes was modelled for a number of typical land use changes. Land use change was assessed having a significant negative impact for Jatropha land converted from forest and shrubland, a slight negative or slight positive impact when converted from grassland, and a positive impact when converted from pasture, degraded pasture or annual cropland. The impact of indirect land use change (iLUC) was not assessed, although its potential impact was acknowledged, and iLUC quantification methods were discussed.

3.4 Allocation methodology

The project team has chosen to use the energy-based allocation methodology as this is the methodology adopted by the RED. The impact of using other allocation methods is briefly discussed in the sensitivity analysis.

[19] EC 2010a

4. FINDINGS

>> This chapter presents the GHG emission calculations, the outcome of the sensitivity analysis, a comparison with other reports and the discussion of the results.

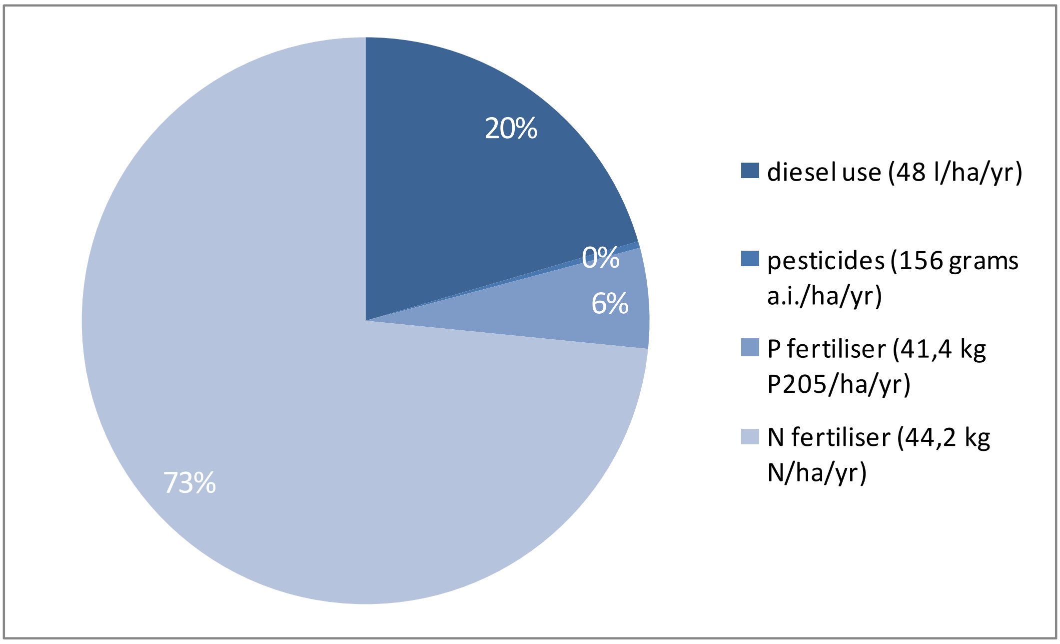
4.1 GHG emission contributors

Main contributor: the nitrogen fertilisers in crop cultivation

The main cause for the CO2-e emissions of the biodiesel chains of SBF is the crop cultivation stage which results in 27.7 g CO2-e/MJ fuel (see Figure 4).

Within the crop cultivation step, the nitrogen in the fertilisers is responsible for the biggest GHG emission: 73% (see Figure 3). About half of this is related to the production of the nitrogen fertilisers, the other half to the nitrous oxide emissions from soil as a consequence of the application of the fertiliser. Diesel use comes next (20%), followed by the use of phosphate fertiliser (6%). The pesticides input of 156 gram active ingredient/ha/yr is a minor contributor (0.4%).

Figure 3: GHG emission contributors in the Jatropha crop production stage



Another significant contributor is the transesterification

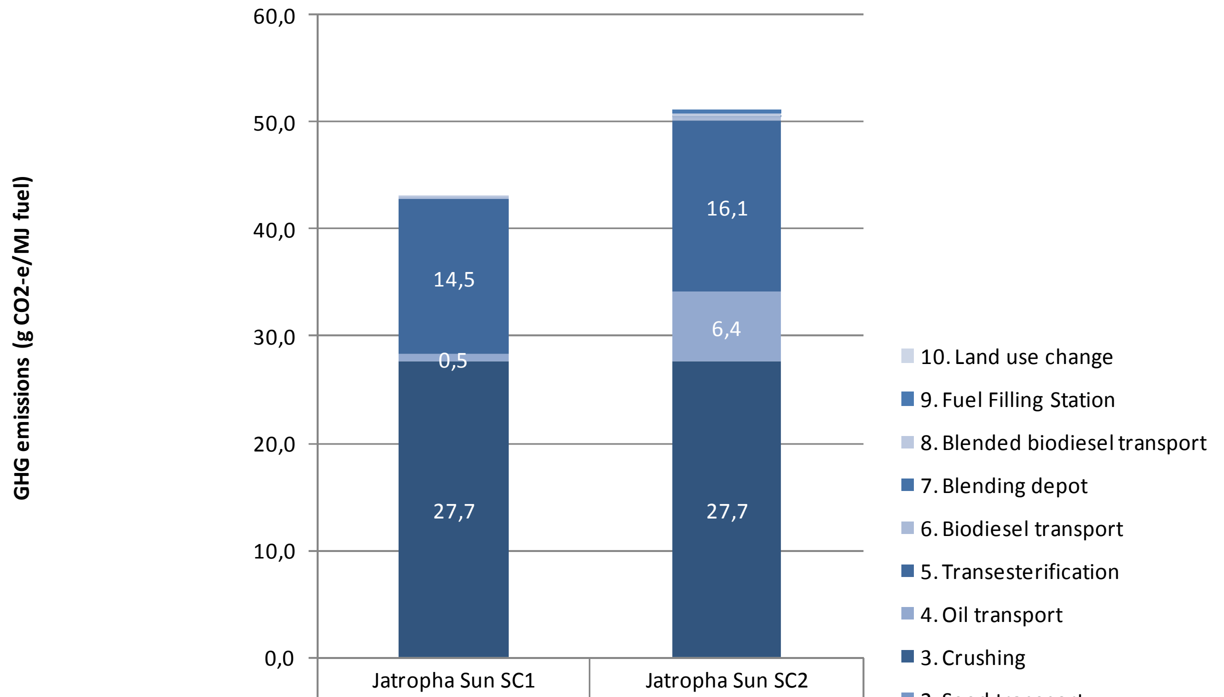
Transesterification is another significant contributor to GHG emissions: 14.5 g CO2-e/MJ fuel in scenario 1 and 16.1 in scenario 2 (see Figure 4). The difference is due to the lower GHG emissions of electricity in Mozambique, compared to the UK: electricity in Mozambique has a lower GHG emission because of the high portion of hydropower[20].

Oil transport is only a significant contributor in case of transport to the UK

Oil transport is a minor contributor in scenario 1 (0.5 g CO2-e/MJ fuel – see Figure 4) and a significant contributor in scenario 2 (6.4 g CO2-e/MJ fuel), basically because of the 13,364 km transport by ship to the UK.

[20] The electricity emission factor in Mozambique is 0.0009 kg CO2-e/MJ electricity. In the UK this is 0.131 kgCO2-e/MJ electricity.

Figure 4. GHG emission contributors in the complete Jatropha chain



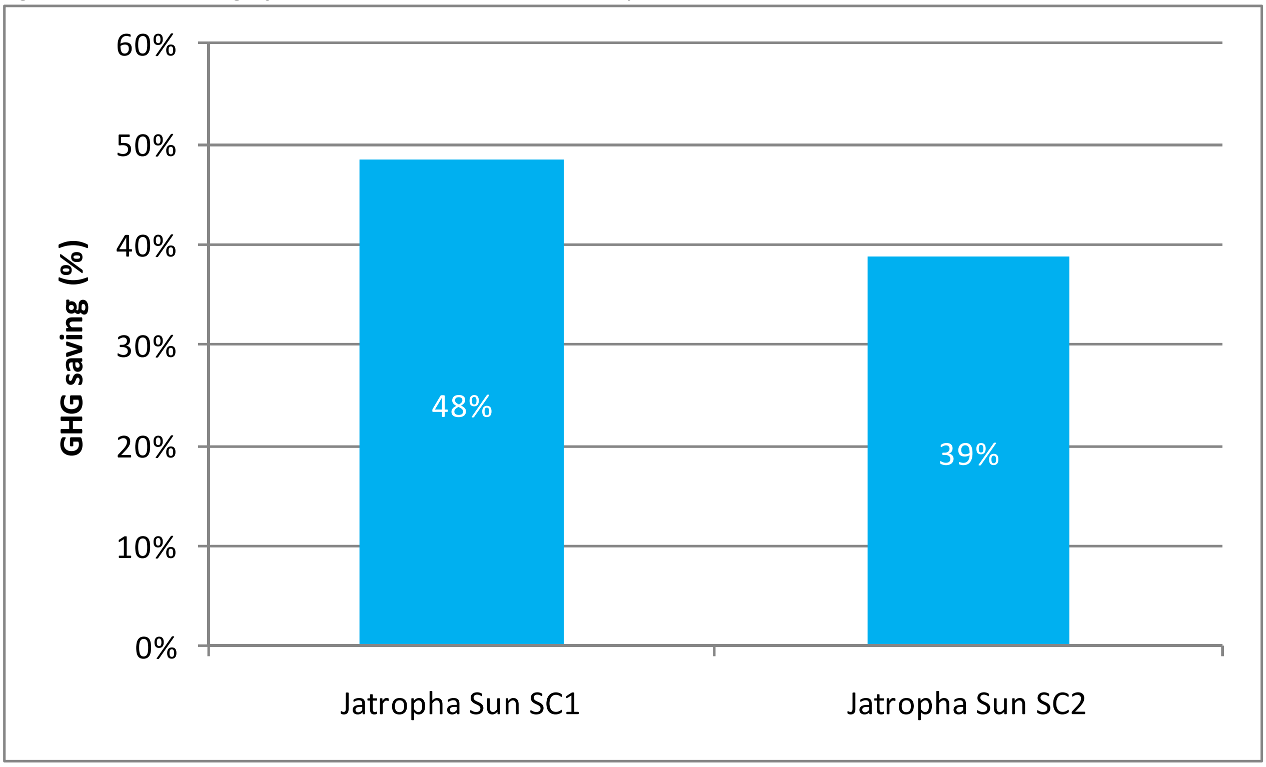
	Jatropha Sun SC1	Jatropha Sun SC2
10. Land use change	0,0	0,0
9. Fuel Filling Station	0,0	0,5
8. Blended biodiesel transport	0,2	0,2
7. Blending depot	0,0	0,1
6. Biodiesel transport	0,2	0,2
5. Transesterification	14,5	16,1
4. Oil transport	0,5	6,4
3. Crushing	0,0	0,0
2. Seed transport	0,0	0,0
1. Jatropha cultivation	27,7	27,7

4.2 GHG saving of scenarios 1 and 2

The GHG emission savings are 48% and 39% compared to fossil diesel for scenario 1 and 2 respectively (see Figure 5). The GHG performance for scenario 1 is 43.2 g CO2-e per MJ fuel and 51.2 for scenario 2. For fossil diesel this is 83.8 g CO2-e per MJ fuel[21].

Scenario 1 is doing better than scenario 2 basically because it has no transport to the UK, and thus no related GHG emissions.

Figure 5: GHG saving of the two scenarios under study



Note: base case scenarios (SC1 use in Mozambique, SC2 use in UK) with land use change excluded

4.3 Sensitivity: variation of selected growing and processing parameters

The project team has carried out a sensitivity analysis on the basis of scenario 1, in order to demonstrate to which parameters the GHG performance is most sensitive. This was only done for scenario 1, not for scenario 2, as the outcome is very similar.

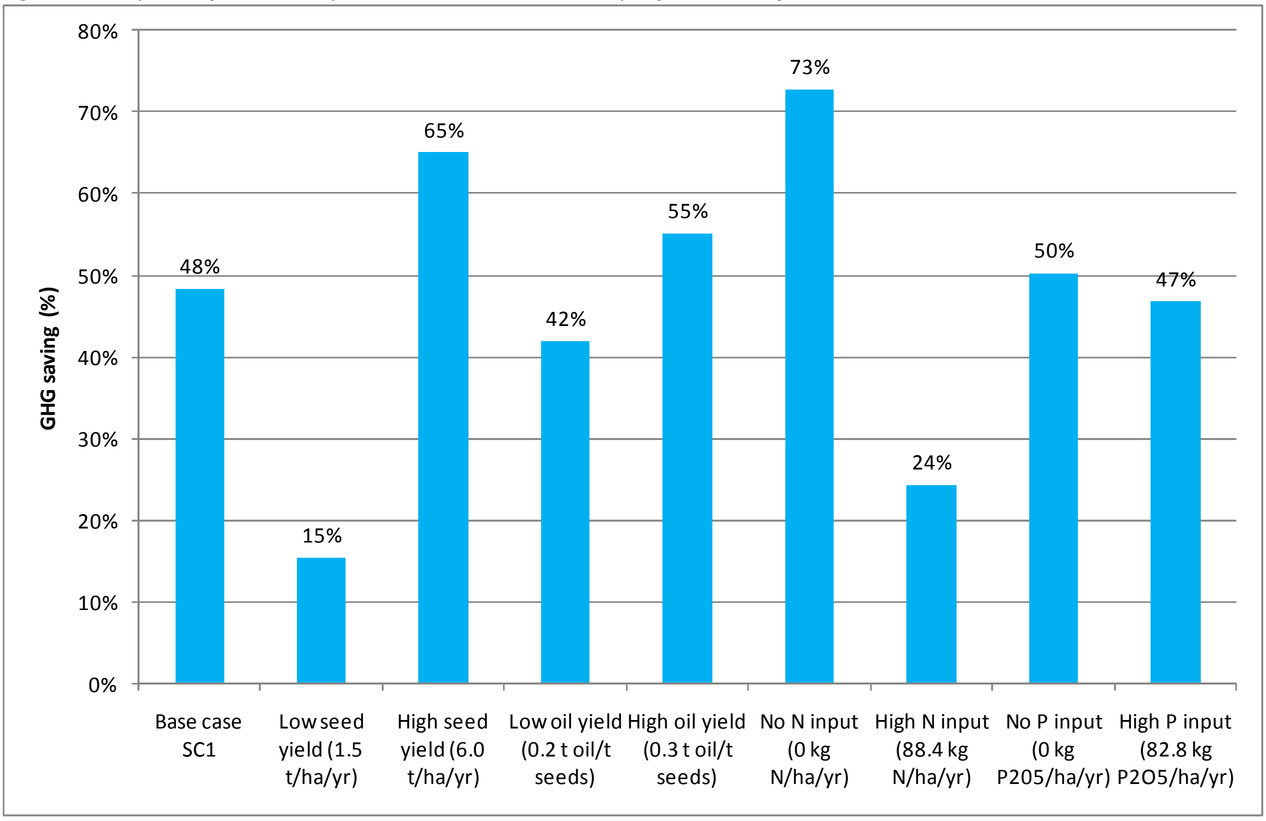
This sensitivity analysis is first done on a selection of growing and processing parameters, as follows:

- Seed yield (from 1.5 to 6 t seed per hectare per year, base 3);
- Oil expelling yield (from 0.2 to 0.3 t oil per t seed, base 0.24);
- Nitrogen fertiliser (from 0 to 88.4 kg N per ha per year, base 44.2);
- Phosphate fertiliser (from 0 to 82.8 kg P2O5 per ha per year, base 41.4).

[21] EC (2010)

Figure 6 below shows the results. It is clear that seed yield, oil yield and the input of nitrogen fertiliser have a significant impact on the GHG saving. Better seed yield and better oil expelling yield lead to higher GHG savings. Higher use of nitrogen fertiliser leads to a significant lower GHG saving. The GHG saving is less sensitive to phosphate fertiliser.

Figure 6: Impact of selected parameters on the GHG performance for scenario 1



Another parameter that has a significant impact is the energetic use of by-products such as hulls, shells and seedcake. As said before, the project team has assumed that these by-products are not used for energy purposes in the base case scenarios 1 and 2 and that the related GHG emissions are negligible. This is a conservative assumption: the GHG saving of the Jatropha chain can significantly increase if these by-products are used for energy purposes; their energy content is considerable, particularly of the seedcake.

The allocation methodology used also has a significant impact on the outcome of the calculations. The project team has used energy-based allocation conform the RED. Other allocation methodologies are market value-based allocation, mass-based allocation and system expansion. Market value-based allocation is difficult to apply since there is no valid information available on the market value of Jatropha by-products. Bailis (2010) reports on the sensitivity of the other allocation methods. In this study, mass-based allocation lead to 17% lower GHG emissions compared to energy-based allocation in the base case. System expansion showed very different results whether by-products were not used (60% increase of GHG emissions compared to energy-based allocation), used as fertiliser (no impact) or pressed into briquettes and used to replace heavy fuel oil in industrial boiler applications (negative GHG emissions further to the large credit from displaced heavy fuel oil).

4.4 Sensitivity: variations in former land use

Estimating the impact of land use change by using default values

Land use change can have a big impact on the carbon calculations. As said before, the project team has used the EC methodology (EC 2010a) based on default values and correction factors to calculate carbon stocks changes caused by land use change. Table 7 below shows the carbon stock of Jatropha land and of other land types, when applying this EC methodology to the local situation. Full calculations and assumptions are included in Annex II.3.

Table 7: Carbon stock of Jatropha land and other land types, according to EC default values

Land use	Carbon stock in vegetation (tC/ha)	Soil organic carbon in top layer (tC/ha)	Total carbon stock (tC/ha)
Perennial Jatropha	18	47	65
Annual cropland (tobacco)	0	26	26
Grassland savannah	8	46	54
Forestland (canopy cover <30%)	30	47	77
Scrubland	46	46	92
Forestland (canopy cover >30%)	156	47	203

Note: default values of EC 2010a were applied. Climate: tropical moist. Soil: low activity clay. Detail in Annex IIC.

Carbon stocks are highest in forest and scrubland, mainly because of the carbon stocked in above and below ground vegetation (30, 46 and 156 tC/ha). A mature Jatropha plantation also has considerable carbon stocked in above and below ground vegetation (estimated as 17.5 tC/ha in EC 2010a). This is less the case in grassland savannah (8 tC/ha) while assumed to zero for land with annual crops (0 tC/ha).

The EC methodology models soil organic carbon (SOC) by applying a number of correction factors to standard SOC values for a specific soil type. When this methodology is applied to the local conditions, SOC does not deviate significantly from the standard value of 47 tC/ha in the local conditions (see Table 7), except for annual cropland that has a much lower SOC than the standard value of low activity clay in tropical moist climate (26 instead of 47 tC/ha).

Table 8 below presents the impact of land use change on carbon stocks and GHG saving. Changing annual cropland or grassland savannah into Jatropha evolves into a net build-up of carbon and hence additional GHG savings. Changing low density forest, mature scrubland or high density forest into Jatropha leads to significant losses of carbon, which result in negative GHG savings. This means that the positive effect of fuel substitution is negated over the 20-year lifetimes used for the calculations on GHG savings.

Table 8: Impact of land use change on the GHG performance based on EC default values

Former land use	New land use	Loss of carbon stock (t C/ha)	GHG saving SC1 (base yield)
Perennial Jatropha	Perennial Jatropha	0	48%
Annual cropland (tobacco)	Perennial Jatropha	-39	380%
Grassland Savannah	Perennial Jatropha	-11	141%
Forestland (canopy cover <30%)	Perennial Jatropha	13	-59%
Scrubland	Perennial Jatropha	27	-184%
Forestland (canopy cover >30%)	Perennial Jatropha	139	-1142%

Note: the accuracy of the GHG saving calculations based on default values is questionable.

Discussing the outcome of default value calculations.
The accuracy of the calculations based on default values is questionable. Within a certain land use type, for example, the carbon stock can vary significantly around the default values depending on the local situation. In the case of Jatropha plantations, land preparation practices, tree spacing and residue management can have large impact on the carbon stock and are only roughly modelled in the default value method. In the case of land taken in, many gradations exist between land types for which default values are available. Savannah bush land, for example, may have low carbon stocks similar to grassland savannah if it is scarcely vegetated with bushes or much higher carbon stocks similar to scrubland if the bushes are dense.

The case of Sun Biofuels Mozambique.
Empiric data of SBF indicate a large variation of SOC over the different plots of the plantation. The SOC average of the empiric data is 26 tC/ha, which is near to the SOC value for annual cropland calculated for local conditions with the EC default value method, and well below the 47 tC/ha for mature Jatropha plantations calculated with the same EC method.

SBF has some empiric data of SOC of samples taken with a two-year interval: SOC values at the moment of planting were compared with SOC values after two years of operation. This data did not show build-up of soil organic carbon. It is however too early to draw conclusions on the build-up of SOC because the plantation is too young and the data too limited.

If, however, we assume that there is no difference in SOC between tobacco land and mature Jatropha land, Jatropha land will stock more carbon than annual cropland because of the build-up of carbon in above and below ground vegetation (17,5 tC/ha according to EC 2010a versus 0 tC/ha). The same applies to the comparison of mature Jatropha land with mature grassland savannah (17,5 versus 8 tC/ha) in local conditions.

The situation at SBF is that tobacco land was abandoned, that it lay fallow for minimum 4 and maximum 8 years, and that it evolved progressively into a type of savannah bush land. The actual carbon stock of such land may well be higher than 8 tC/ha of mature grassland savannah but is certainly well below mature low density forestland or mature scrubland with respectively 30 and 46 tC/ha of above and below ground vegetation. Because of the short period in which the land was abandoned and evolved into savannah bush, a better estimate is to half the carbon stock value of low density forestland or scrubland which leads to 15 and 23 tC/ha respectively. These are near to the 17.5 tC/ha for mature Jatropha land and should be considered as similar given the large error margins of the methodology based upon default values and because the data are not confirmed by empiric data.

In absence of valid empiric data, there are two options in the case of SBF. Either we consider that the land use change was from young savannah bush land, which was able to grow for about 4 to 8 year, to mature Jatropha land. In this case the carbon stock change should be assumed zero over the 20-year lifetime for the calculations, following the reasoning above. Or we consider that the land use change was from mature tobacco land to mature Jatropha land. In the latter case there is a build-up of 17.5 tC/ha for the carbon stocked in the above and below ground Jatropha vegetation, according to EC default values.

4.5 Comparison with other reports

The project team has compared the GHG emissions of scenarios 1 and 2 with various other calculations and reports. These are summarised hereafter and presented schematically in Figure 8.

Jatropha D1 Oils

This study reports GHG emissions of 25 g CO2-e/MJ fuel and 70% GHG saving. This is 28 g CO2-e/MJ fuel and 68% GHG saving if land use change from grassland to perennial cropland is taken into account.

The GHG savings of this chain are higher than the scenarios 1 and 2 of SBF. This is mainly related to the cultivation stage, where no GHG emissions are counted: the study assumes that there is no use of diesel and pesticides, and only use of manure as organic fertiliser that does not count for GHG emissions. An additional minor reason is that the study considers that biodiesel transport, blending and filling stages are out of the system boundaries[22].

Land use change is identified as the major parameter influencing the GHG savings of the chain. It is assumed that D1's plantations are on former grassland, and land use change consequently only has a minor impact. The study also demonstrates that conversion from forestland does have a major negative impact.

Jatropha RTFO default

This RTFO default chain is based upon Jatropha cultivation and crushing in India, transport of the oil to the UK (12,000 km by ship) for processing to biodiesel ME in UK and blending with diesel for use in the EU. GHG savings are 63%; the GHG emission is 31 g CO2-e/MJ fuel. Land use change is not taken into account.

The GHG savings of this chain are higher than the scenarios 1 and 2 of SBF. This is mainly related to the crop cultivation stage with low use of nitrogen fertiliser and no use of diesel at the plantation. The Jatropha RTFO default chain generates 4.9 g CO2-e/MJ fuel in the cultivation stage which is largely due to the nitrogen fertiliser Urea (12 kg N/ha/yr, 4.5 g CO2-e/MJ fuel).

Jatropha Daimler AG

This study was a screening lifecycle assessment to evaluate the environmental advantages and disadvantages of Jatropha biodiesel compared to conventional diesel fuel. One of the environmental aspects covered is the emission of GHG; the study estimated a GHG saving of 38% in the base case with centralised production. This GHG saving was calculated for land use change from scarce vegetation[23] to Jatropha; the assumption was that this conversion does not lead to carbon stock changes. The study recommended using Jatropha at poor or scarce vegetation as carbon payback times are more than hundred years in medium vegetation.

Jatropha jet fuel

The base case of this study estimated a GHG saving of 55% at the yield of 4 t seeds/ha/yr, without land use change. The impact of land use change was calculated for different land types. Changes from annual crops, degraded pasture and managed pasture, had a positive impact resulting in GHG savings of 81%, 85% and 83%. Changes from grassland (dry) and grassland (moist) had a slight negative or slight positive

[22] The project team has included these stages as the RED methodology requires to do so.
[23] IFEU (2008), page 39. Scarce vegetation is defined as tropical semi-arid grassland (page 13).

impact resulting in GHG savings of 59% and 37% respectively. Changes from shrubland (dry), forest (dry) and forest (moist) had a negative impact resulting in GHG savings of -60%, -288% and -426% respectively.

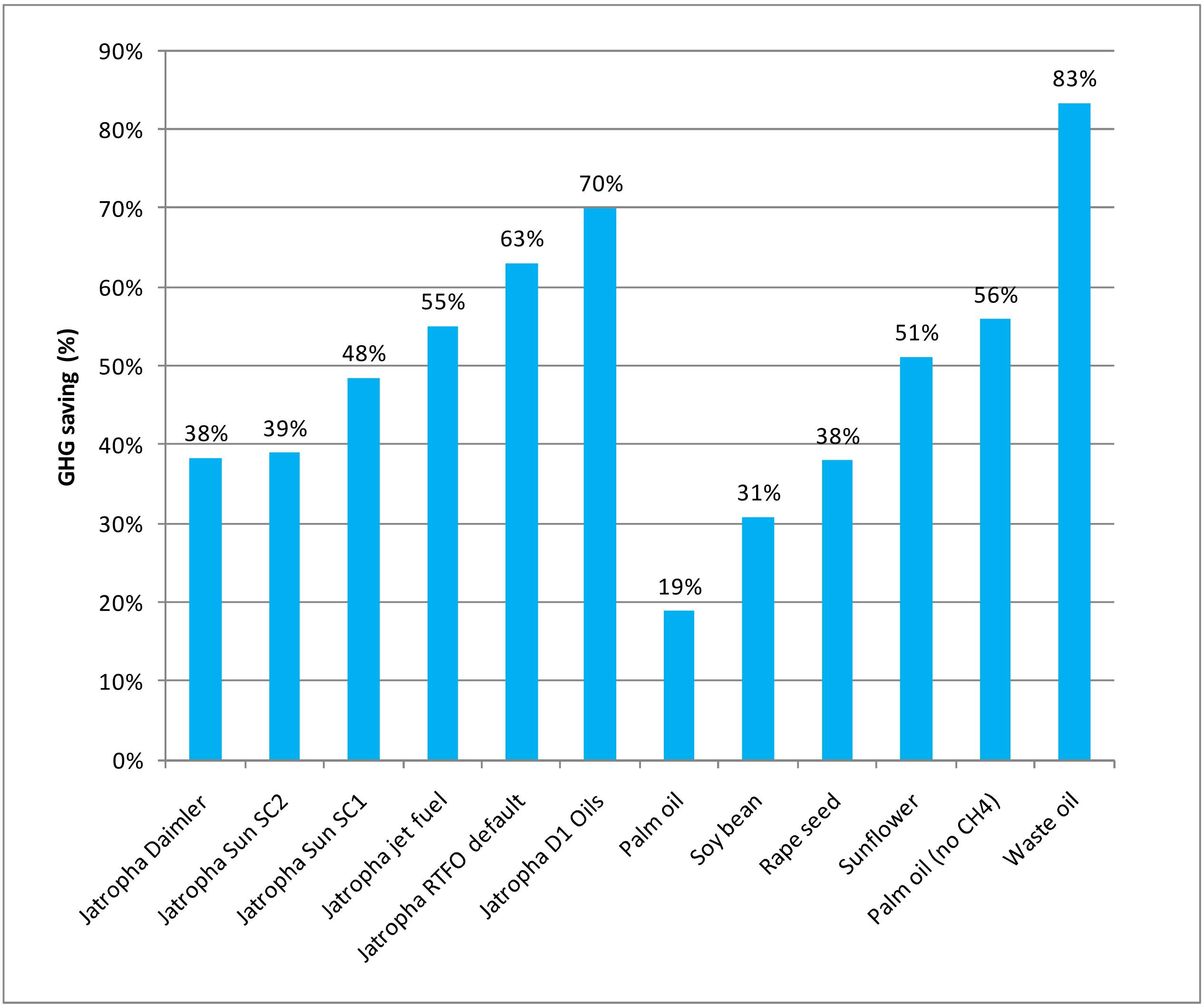
EC Default values

The project team has also compared with the default values of biodiesel from other feedstock as included in the RED (see Figure 8).

Waste vegetable or animal oil rank best with 83% GHG savings, followed by palm oil with a oil milling process where methane emissions are captured (56%), sunflower (51%) and rape seed (38%). Lower ranks are soy bean (31% GHG saving) and palm oil if the oil milling process is not specified (19%).

These values are conservative, and it must be noted that operators can decide to submit actual values instead of the default values. Note that none of the RED default values include the impact of carbon stock changes due to land conversion.

Figure 8: GHG emissions of scenarios 1 and 2 compared to other Jatropha chains and to other biodiesels (all assuming no impact on carbon stocks by land use change)



Discussion

Figure 8 shows that there is a large variation among the results of the different Jatropha studies, but also that the approach and issues highlighted are quite similar. The differences between the different results can furthermore be easily understood.

The Jatropha D1 Oils and RTFO default chains, for example, have better GHG saving than the scenarios of SBF mainly because of the higher amounts of nitrogen fertiliser used in the crop cultivation stage at SBF. The difference will be minimized if SBF is able to reduce nitrogen fertiliser inputs, e.g. by using seed cake as fertiliser, or by obtaining a higher seed yield and oil yield than those used for the base case. The other Jatropha examples, the Jatropha Daimler chain and Jatropha jet fuel study, present similar GHG savings.

All studies indicate that the lifecycle assessment calculations are dependent on a number of assumptions that can have an important impact on the final results.

There is consensus that carbon stock variations due to land use change have a high influence on the GHG performance of biofuel chains. Data on the influence of land use change in specific chains is rare until now. The Jatropha D1 Oils study, the Jatropha Daimler study and the Jatropha jet fuel study took account of land use change, but all in a very general way and on the basis of default values. It is anticipated that more specific information on land use change will become available with the requirement of the RED to take account of this aspect. It is also anticipated that empiric data on carbon build-up in Jatropha plantations will become available in the next years, when plantations will become mature.

The comparison with the EC default values of other feedstock does not present new information but compares the GHG performance of feedstock with which Jatropha biodiesel will have to compete on the market place. It must however be noted that the comparison with EC default values provides only a limited view of the GHG performance of other feedstock. First of all because default values do not include land carbon stock considerations, which is the parameter with the highest impact on the GHG performance. Second because default values are by definition conservative; operators will have an incentive to submit actual values if these values are much better than the default values. It is anticipated that most biodiesel operators will be able to meet the 35% EU threshold, as long as the GHG saving is not negatively impacted by land use change.

5. CONCLUSIONS AND RECOMMENDATIONS

>> This chapter presents our main conclusions and recommendations

Conclusions

The main purpose of carrying out the GHG calculations was to better understand the GHG performance and the issues at stake of the Jatropha value chain in general, and that of SBF in particular. The related purpose was to define which next steps are required, at company level and at Jatropha sector level, if possible.

The calculations clearly help to understand the main GHG issues at stake in the Jatropha chains of SBF. They demonstrate that the Jatropha chain of SBF will create GHG savings: on the basis of the data provided, the GHG savings are estimated at **48% (scenario 1 Mozambique)** for biodiesel produced and used in Mozambique, and **39% (scenario 2 UK)** for biodiesel produced and used in the UK. This hence meets the **EU threshold of 35%.** Carbon stock changes caused by land use change are assumed zero in these scenarios.

These figures will have to be confirmed as underlying data are still uncertain: the calculations are for a large part based upon assumptions because Jatropha harvesting has only just begun and the first experiences with processing are to follow. There is also a high potential for optimisation: the project team has demonstrated that parameters such as seed yield, oil yield and nitrogen fertiliser input have a significant impact on the GHG performance of the Jatropha chain resulting in GHG savings **ranging from 15% to 73%** around the base case of 48% in the case of the Mozambican scenario.

It was also demonstrated that carbon stock changes caused by land use change have a large impact on the GHG saving. This impact is positive if land with annual crops (as tobacco) or grassland is converted to Jatropha land because of the carbon build-up of Jatropha as a perennial crop. The impact is negative if mature bush or forestland is converted to Jatropha land because of the high carbon stocks of these land types.

In the case of SBF, empiric data on the impact of land use change on the carbon stock is not available at present. For the SBF situation, the project team assumes that the impact of land use change is either neutral (no impact) or positive (resulting in additional GHG savings). The impact is neutral if is considered that the land use change is from young savannah bush land, which was able to grow for about 4 to 8 years, to mature Jatropha land, that grew for 20 years. It is positive if is considered that the land use change is from mature tobacco land to mature Jatropha land, since the build-up is 17.5 tC/ha for the carbon stocked in the above and below ground Jatropha vegetation, following the EC default value for mature Jatropha land.

Suggestions and recommendations

At company level, the project team would recommend the following next steps:

1. *Create a good understanding at plant management level*. In our view it is crucial to understand the mechanisms of the GHG saving of the Jatropha chain, because GHG performance is likely to become an important parameter for the market value of Jatropha oil and biodiesel. Key parameters are seed yield, oil yield, nitrogen fertiliser inputs, carbon stock of acquired land,

carbon build-up at the plantation, and the use of by-products;

2. *Define SBF's GHG policy*. In the view of the project team this policy should include:
    a. *Guidance on the areas that SBF considers as no-go areas for carbon considerations*: translate RED requirements into SBF's practice;
    b. *Guidance for land acquisition:* establish how the carbon stock of land is documented before it is acquired and converted (measuring soil organic carbon, estimating above and below ground vegetation and dead organic matter);
    c. *Guidance for monitoring:* put in place a monitoring programme of the parameters that significantly influence the GHG emissions of the chain: (i) seed yield, (ii) oil yield, (iii) fertiliser inputs, (iv) diesel use at the farm, (v) use of by-products, (vi) carbon stock at the time of the land acquisition, and (vii) carbon build-up in the Jatropha operations.
    d. *Guidance for building up information:* consider whether the present study is sufficient as a first step for SBF in this stage. Consider how to use the results of the study, only internally or also externally (publish on the Internet). Determine the research needs of SBF (e.g. methodology to determine carbon stocks at the time of land acquisition and to monitor carbon build-up in the Jatropha operations, GHG calculations of pure plant oil applications).

At Jatropha sector level, the project team would recommend:

1. *Stimulate members to carry out GHG calculations.* Carrying out GHG calculations is an excellent way to gain profound understanding of the GHG performance of the Jatropha chain and of the issues at stake. As said above, this is crucial in our view because GHG performance is likely to become an important parameter for the market value of Jatropha oil and biodiesel.

2. *Lead and feed the debate.* The RED has provided a reference for GHG accounting of biofuels. It is clear that its mechanisms and its GHG accounting methodology will continue to evolve in the next years. The Jatropha sector and its companies will be greatly helped if knowledge gained on GHG calculations and on complying with the RED is circulated abundantly. They will also be advanced if research provides additional input and empirical data on for instance the carbon stocks that are built up at Jatropha plantations, and on GHG emissions of pure plant oil applications.

3. *Be involved in establishing default values for Jatropha chains.* The RED includes default values for many biofuel chains but not for Jatropha. It is in the interest of the Jatropha industry to use default values, as this facilitates compliance with the RED. The project team suggests that the Jatropha Alliance, as sector organisation, seeks for industry support and for finance to be involved in the data collection and GHG calculation that determine the Jatropha default values. The EU agency to contact is the EU research centre JRC.

ANNEXES

Annex I: Bibliographic references

>> This annex contains a selection of the references used for this report.

Literature (selection)

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SBF (2010b): GHG questionnaire filled in (versions of 4 and 27May 2010)

SBF (2010c): personal communications on 4-5 March, and 25-26 October 2010, during the site visits at Sun Biofuels Mozambique

SBF (2010d): “soil samples”. Soil sample reports 1 and 2 produced by BemLab, Somerset Mall, SouthAfrica, 20 and 21 July 2010. Additional soil sample reports 3, 4 and 5.

SBF (2011): email of Nico Strydom of 2 March 2011 providing answers to additional questions

External reviews

Bailis Robert (2011): review document and detailed comments on version 2 of this report, emails of 22 January 2011 and 8 April 2011

Pérez Domínguez Ignacio (2010, 2011): detailed review comments on version 2 of this report, emails of 22 December 2010 and 9 April 2011

Annex II: Data sets

Scenario 1: Jatropha grown in Mozambique, biodiesel ME production and use in Mozambique

>>See data sheets for this scenario attached.

Fuel chain Liquid

Jatropha Sun SC1
Crushing-transport to Beira-Transport to Maputo-Blend in Maputo-Local Use

Land use conversion: no carbon stock change assumed

Internal batch number (optional):	
Fuel type produced:	Biodiesel ME
Country:	Mozambique
Biofuel feedstock:	Jatropha
Quantity of fuel:	0 l
Quantity of fuel recorded in RTFO Operating System:	0 l
Fuel chain default value:	31 grams(CO2e)/MJ

Social and Environmental

Land use on 30 Nov 2005:	Cropland - non protected
Standard:	Roundtable on Sustainable Biofuels (RSB)
Social level:	None
Environmental level:	None

Fuel chain carbon intensity: **43,2 grams CO2e / MJ**

Crop production

Jatropha Production

Crop yield: 3 Tonnes(feedstock)/ha

Emissions from land use change and soils

Emissions from land use: 0 Tonnes(CO2e)/ha

subtotal **0 kg(CO2e)/t crop**

Rate of nitrous oxide emissions per hectare: 272 kg(CO2e)/ha

subtotal **90,8 kg(CO2e)/t crop**

Farming inputs

Type / Description	Application rate mass of nutrient per area	Emissions factor Mass CO2e per Mass of nutrient	Nitrogen content Mass of N per mass of product	Total emissions kg(CO2e)/t crop
Unspecified N fertiliser	28 kg/ha	6,07 kg/kg	1 kg/kg	56,6
Unspecified N fertiliser	16,2 kg/ha	6,07 kg/kg	1 kg/kg	32,8
Unspecified P fertiliser	41,4 kg/ha	1,02 kg/kg	0 kg/kg	14

subtotal **103 kg(CO2e)/t crop**

Pesticide application rates: 156 grams(active ingredient)/ha

Pesticide emissions factor: 17 kg(CO2e)/kg(active ingredient)

subtotal **0,884 kg(CO2e)/t crop**

Other inputs:

Type / Description	Use	Emissions factor	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t crop**

On-farm fuel use

Type / Description	Use Energy per area	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t crop
Diesel	48 l/ha	0,0876 kg/MJ	50,3

subtotal **50,3 kg(CO2e)/t crop**

Crop residues

Residue Use / Description	Yield mass of crop residue per area	Credit/debit Mass CO2e per mass of residue	Market Value value per mass of residue	Total emissions kg(CO2e)/t crop

Credit or debit for residue **0 kg(CO2e)/t crop**

Combined allocation factor for **1 kg(CO2e)/t crop**

Total for this module: **245 kg(CO2e)/t output**

Contribution of this module to fuel chain: **1030 kg(CO2e)/t biofuel**

Biofuel plant or oilseed crush / mill

Crushing of Jatropha Seeds
Vicinity of SunBiofuels

Country in which this processing step takes place: Mozambique
Product: Jatropha oil

Plant inputs

Plant yield: 0,24 Tonnes(output)/Tonnes(input)
Amount of electricity used: 170 MJ(Electricity)/Tonnes(output)
Electricity emissions factor: 0,0009 kg(CO2e)/MJ(electricity)

subtotal **0,153 kg(CO2e)/t output**

Conservative factor: 1,4

Fuel used per tonne of output:

Type / Description	Use Energy of fuel per mass of biofuel	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t output**

Chemical inputs:

Type / Description	Use mass of chemical per mass of biofuel	Emissions factor mass of CO2e per mass of chemical	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t output**

Coproducts:

Name / Description	Use	Yield Mass of coproduct per mass	Credit/debit Mass of CO2eq per mass of coproduct	Energy content value per mass of coproduct	Total credit kg(CO2e)/t

Credit or debit for residue **0**
Combined allocation factor for **1**

Total for this module: **0,214 kg(CO2e)/t output**
Contribution of this module to fuel chain: **0 kg(CO2e)/t biofuel**

Feedstock transport

Transport to Beira (rail)

Transport country of origin: Mozambique
Transport mode: Rail - Africa

Distance transported: 250 km
Energy intensity of transport: 0,24 MJ(Fuel)/t-km

Module Efficiency: 1 Tonnes(input)/Tonnes(output)

Fuel information

Type / Description	Use Energy of fuel per mass	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Diesel		0,0876 kg/MJ	5,25

subtotal **5,25 kg(CO2e)/t output**

Total for this module: **5,25 kg(CO2e)/t output**
Contribution of this module to fuel chain: **5 kg(CO2e)/t biofuel**

Feedstock transport

Transport to Maputo (ship)
portwolrd.com

Transport country of origin: Mozambique
Transport mode: Shipping - Inland bulk carrier

Distance transported: 845 km
Energy intensity of transport: 0,32 MJ(Fuel)/t-km

Module Efficiency: 1 Tonnes(input)/Tonnes(output)

Fuel information

Type / Description	Use Energy of fuel per mass	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Heavy fuel oil		0,0872 kg/MJ	14

subtotal **14 kg(CO2e)/t output**

Total for this module: **14 kg(CO2e)/t output**
Contribution of this module to fuel chain: **14 kg(CO2e)/t biofuel**

Biofuel plant or oilseed crush / mill

Transesterification

Country in which this processing step takes place: Mozambique
Product: Biodiesel ME

Plant inputs

Plant yield: 0,95 Tonnes(output)/Tonnes(input)
Amount of electricity used: 335 MJ(Electricity)/Tonnes(output)
Electricity emissions factor: 0,0009 kg(CO2e)/MJ(electricity)

subtotal **0,301 kg(CO2e)/t output**

Conservative factor: 1,4

Fuel used per tonne of output:

Type / Description	Use Energy of fuel per mass of biofuel	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Natural gas	1690 MJ/Tonnes(output)	0,0677 kg/MJ	114

subtotal **114 kg(CO2e)/t output**

Chemical inputs:

Type / Description	Use mass of chemical per mass of biofuel	Emissions factor mass of CO2e per mass of chemical	Total emissions kg(CO2e)/t
Methanol	113 kg/Tonnes	1,98 kg/kg	224
Potassium hydroxide	26 kg/Tonnes	2,43 kg/kg	63,2

subtotal **287 kg(CO2e)/t output**

Coproducts:

Name / Description	Use	Yield Mass of coproduct per mass	Credit/debit Mass of CO2eq per mass of coproduct	Energy content value per mass of coproduct	Total credit kg(CO2e)/t
Glycerol		0,1 Tonnes/Tonnes	0 kg/Tonnes	16 MJ/Kg(coproduct)	0
Potassium sulphate		0,04 Tonnes/Tonnes	0 kg/Tonnes	0 MJ/Kg(coproduct)	0

Credit or debit for residue **0**
Combined allocation factor for **0,959**

Total for this module: **539 kg(CO2e)/t output**
Contribution of this module to fuel chain: **539 kg(CO2e)/t biofuel**

Liquid fuel transport

Transport country of origin: Mozambique
Transport mode: Truck - Liquid Fuel

Distance transported: 100 km
Energy intensity of transport: 0,94 MJ(Fuel)/t-km

Module Efficiency: 1 Tonnes(input)/Tonnes(output)

Fuel information

Type / Description	Use Energy of fuel per mass	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Diesel		0,0876 kg/MJ	8,23

subtotal **8,23 kg(CO2e)/t output**

Total for this module: **8,23 kg(CO2e)/t output**
Contribution of this module to fuel chain: **8 kg(CO2e)/t biofuel**

Biofuel Blending Depot

Country in which this processing step takes place: Mozambique

Amount of electricity used: 31,2 MJ(Electricity)/Tonnes(output)
Electricity emissions factor: 0,0009 kg(CO2e)/MJ(electricity)

subtotal **0,0281 kg(CO2e)/t output**

Fuel used per tonne of output:

Type / Description	Use Energy of fuel per mass of biofuel	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t output**

Total for this module: **0,03 kg(CO2e)/t output**
Contribution of this module to fuel chain: **0 kg(CO2e)/t biofuel**

Liquid fuel transport

Transport country of origin: Mozambique
Transport mode: Truck - Liquid Fuel

Distance transported: 100 km
Energy intensity of transport: 0,94 MJ(Fuel)/t-km

Module Efficiency: 1 Tonnes(input)/Tonnes(output)

Fuel information

Type / Description	Use Energy of fuel per mass	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Diesel		0,0876 kg/MJ	8,23

subtotal **8,23 kg(CO2e)/t output**

Total for this module: **8,23 kg(CO2e)/t output**
Contribution of this module to fuel chain: **8 kg(CO2e)/t biofuel**

Fuel filling station

Country in which this processing step takes place: Mozambique

Amount of electricity used: 126 MJ(Electricity)/Tonnes(output)
Electricity emissions factor: 0,0009 kg(CO2e)/MJ(electricity)

subtotal **0,114 kg(CO2e)/t output**

Fuel used per tonne of output:

Type / Description	Use Energy of fuel per mass of biofuel	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t output**

Total for this module: **0,11 kg(CO2e)/t output**
Contribution of this module to fuel chain: **0 kg(CO2e)/t biofuel**

Scenario 2: Jatropha grown in Mozambique, biodiesel ME production and use in the UK

>>See data sheets for this scenario attached.

Fuel chain Liquid

Jatropha Sun SC2
Crushing-transport to Beira-International Transport to UK-Blend in UK-EU Use

Land use conversion: no charbon stock change assumed

Internal batch number (optional):	
Fuel type produced:	Biodiesel ME
Country:	Mozambique
Biofuel feedstock:	Jatropha
Quantity of fuel:	0 l
Quantity of fuel recorded in RTFO Operating System:	0 l
Fuel chain default value:	31 grams(CO2e)/MJ

Social and Environmental

Land use on 30 Nov 2005:	Cropland - non protected
Standard:	Roundtable on Sustainable Biofuels (RSB)
Social level:	None
Environmental level:	None

Fuel chain carbon intensity: **51,2 grams CO2e / MJ**

Crop production

Jatropha Production

Crop yield: 3 Tonnes(feedstock)/ha

Emissions from land use change and soils

Emissions from land use: 0 kg(CO2e)/ha

subtotal **0 kg(CO2e)/t crop**

Rate of nitrous oxide emissions per hectare: 272 kg(CO2e)/ha

subtotal **90,8 kg(CO2e)/t crop**

Farming inputs

Type / Description	Application rate mass of nutrient per area	Emissions factor Mass CO2e per Mass of nutrient	Nitrogen content Mass of N per mass of product	Total emissions kg(CO2e)/t crop
Unspecified N fertiliser	16,2 kg/ha	6,07 kg/kg	1 kg/kg	32,8
Unspecified N fertiliser	28 kg/ha	6,07 kg/kg	1 kg/kg	56,6
Unspecified P fertiliser	41,4 kg/ha	1,02 kg/kg	0 kg/kg	14

subtotal **103 kg(CO2e)/t crop**

Pesticide application rates: 156 grams(active ingredient)/ha

Pesticide emissions factor: 17 kg(CO2e)/kg(active ingredient)

subtotal **0,884 kg(CO2e)/t crop**

Other inputs:

Type / Description	Use	Emissions factor	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t crop**

On-farm fuel use

Type / Description	Use Energy per area	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t crop
Diesel	48 l/ha	0,0876 kg/MJ	50,3

subtotal **50,3 kg(CO2e)/t crop**

Crop residues

Residue Use / Description	Yield mass of crop residue per area	Credit/debit Mass CO2e per mass of residue	Market Value value per mass of residue	Total emissions kg(CO2e)/t crop

Credit or debit for residue **0 kg(CO2e)/t crop**

Combined allocation factor for **1 kg(CO2e)/t crop**

Total for this module: **245 kg(CO2e)/t output**

Contribution of this module to fuel chain: **1030 kg(CO2e)/t biofuel**

Biofuel plant or oilseed crush / mill

Crushing of Jatropha Seeds
Vicinity of SunBiofuels

Country in which this processing step takes place: Mozambique
Product: Jatropha oil

Plant inputs

Plant yield: 0,24 Tonnes(output)/Tonnes(input)
Amount of electricity used: 170 MJ(Electricity)/Tonnes(output)
Electricity emissions factor: 0,0009 kg(CO2e)/MJ(electricity)

subtotal **0,153 kg(CO2e)/t output**

Conservative factor: 1,4

Fuel used per tonne of output:

Type / Description	Use Energy of fuel per mass of biofuel	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t output**

Chemical inputs:

Type / Description	Use mass of chemical per mass of biofuel	Emissions factor mass of CO2e per mass of chemical	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t output**

Coproducts:

Name / Description	Use	Yield Mass of coproduct per mass	Credit/debit Mass of CO2eq per mass of coproduct	Energy content value per mass of coproduct	Total credit kg(CO2e)/t

Credit or debit for residue **0**
Combined allocation factor for **1**

Total for this module: **0,214 kg(CO2e)/t output**
Contribution of this module to fuel chain: **0 kg(CO2e)/t biofuel**

Feedstock transport

Transport to Beira (rail)

Transport country of origin:	Mozambique
Transport mode:	Rail - Africa
Distance transported:	250 km
Energy intensity of transport:	0,24 MJ(Fuel)/t-km
Module Efficiency:	1 Tonnes(input)/Tonnes(output)

Fuel information

Type / Description	Use Energy of fuel per mass	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Diesel		0,0876 kg/MJ	5,25

subtotal **5,25 kg(CO2e)/t output**

Total for this module: **5,25 kg(CO2e)/t output**

Contribution of this module to fuel chain: **5 kg(CO2e)/t biofuel**

Feedstock transport

Transport to UK (ship)
Maputo - Falmouth UK (portworld.com)

Transport country of origin:	Mozambique
Transport mode:	International shipping
Distance transported:	13300 km
Energy intensity of transport:	0,2 MJ(Fuel)/t-km
Module Efficiency:	1 Tonnes(input)/Tonnes(output)

Fuel information

Type / Description	Use Energy of fuel per mass	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Heavy fuel oil		0,0872 kg/MJ	231

subtotal **231 kg(CO2e)/t output**

Total for this module:	**231 kg(CO2e)/t output**
Contribution of this module to fuel chain:	**233 kg(CO2e)/t biofuel**

Biofuel plant or oilseed crush / mill

Transesterification

Country in which this processing step takes place: United Kingdom
Product: Biodiesel ME

Plant inputs

Plant yield: 0,95 Tonnes(output)/Tonnes(input)
Amount of electricity used: 335 MJ(Electricity)/Tonnes(output)
Electricity emissions factor: 0,131 kg(CO2e)/MJ(electricity)

subtotal **43,9 kg(CO2e)/t output**

Conservative factor: 1,4

Fuel used per tonne of output:

Type / Description	Use Energy of fuel per mass of biofuel	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Natural gas	1690 MJ/Tonnes(output)	0,0677 kg/MJ	114

subtotal **114 kg(CO2e)/t output**

Chemical inputs:

Type / Description	Use mass of chemical per mass of biofuel	Emissions factor mass of CO2e per mass of chemical	Total emissions kg(CO2e)/t
Methanol	113 kg/Tonnes	1,98 kg/kg	224
Potassium hydroxide	26 kg/Tonnes	2,43 kg/kg	63,2

subtotal **287 kg(CO2e)/t output**

Coproducts:

Name / Description	Use	Yield Mass of coproduct per mass	Credit/debit Mass of CO2eq per mass of coproduct	Energy content value per mass of coproduct	Total credit kg(CO2e)/t
Glycerol		0,1 Tonnes/Tonnes	0 kg/Tonnes	16 MJ/Kg(coproduct)	0
Potassium sulphate		0,04 Tonnes/Tonnes	0 kg/Tonnes	0 MJ/Kg(coproduct)	0

Credit or debit for residue **0**

Combined allocation factor for **0,959**

Total for this module: **598 kg(CO2e)/t output**

Contribution of this module to fuel chain: **598 kg(CO2e)/t biofuel**

Liquid fuel transport

Transport country of origin: United Kingdom
Transport mode: Truck - Liquid Fuel

Distance transported: 100 km
Energy intensity of transport: 0,94 MJ(Fuel)/t-km

Module Efficiency: 1 Tonnes(input)/Tonnes(output)

Fuel information

Type / Description	Use Energy of fuel per mass	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Diesel		0,0876 kg/MJ	8,23

subtotal **8,23 kg(CO2e)/t output**

Total for this module: **8,23 kg(CO2e)/t output**
Contribution of this module to fuel chain: **8 kg(CO2e)/t biofuel**

Biofuel Blending Depot

Country in which this processing step takes place: United Kingdom

Amount of electricity used: 31,2 MJ(Electricity)/Tonnes(output)
Electricity emissions factor: 0,131 kg(CO2e)/MJ(electricity)

subtotal **4,09 kg(CO2e)/t output**

Fuel used per tonne of output:

Type / Description	Use Energy of fuel per mass of biofuel	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t

subtotal **0 kg(CO2e)/t output**

Total for this module: **4,09 kg(CO2e)/t output**
Contribution of this module to fuel chain: **4 kg(CO2e)/t biofuel**

Liquid fuel transport

Transport country of origin: United Kingdom
Transport mode: Truck - Liquid Fuel

Distance transported: 100 km
Energy intensity of transport: 0,94 MJ(Fuel)/t-km

Module Efficiency: 1 Tonnes(input)/Tonnes(output)

Fuel information

Type / Description	Use Energy of fuel per mass	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t
Diesel		0,0876 kg/MJ	8,23

subtotal **8,23 kg(CO2e)/t output**

Total for this module: **8,23 kg(CO2e)/t output**
Contribution of this module to fuel chain: **8 kg(CO2e)/t biofuel**

Fuel filling station

Country in which this processing step takes place: United Kingdom

Amount of electricity used: 126 MJ(Electricity)/Tonnes(output)
Electricity emissions factor: 0,131 kg(CO2e)/MJ(electricity)

subtotal 16,6 kg(CO2e)/t output

Fuel used per tonne of output:

Type / Description	Use Energy of fuel per mass of biofuel	Emissions factor Mass CO2e per Energy	Total emissions kg(CO2e)/t

subtotal 0 kg(CO2e)/t output

Total for this module: 16,6 kg(CO2e)/t output
Contribution of this module to fuel chain: 17 kg(CO2e)/t biofuel

Carbon stock calculations: data and assumptions

Calculation carbon stocks

The calculation used is as follows: $CS = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I + C_{VEG}$ (Source: EC 2010a)

Parameter	Unit	Explanation
CS	t C/ha	The carbon stock per unit area associated with the land use
SOC_{ST}	t C/ha	Standard soil organic carbon in the 0-30 centimeter topsoil layer.
F_{LU}	-	Land use factor reflecting the difference in soil organic carbon associated with the type of land use compared to the standard soil organic carbon.
F_{MG}	-	Management factor reflecting the difference in soil organic carbon associated with the principle management practice compared to the standard soil organic carbon.
F_I	-	Input factor reflecting the difference in soil organic carbon associated with different levels of carbon input to soil compared to the standard soil organic carbon.
C_{VEG}	t C/ha	Above and below ground vegetation carbon stock.

Perennial Jatropha

Parameter	Value	Unit	Explanation
CS	65	t C/ha	Calculation using the formula above. Choice: use standard value for C_{VEG}
SOC_{ST}	47	t C/ha	Table 1 (mineral soils): value for tropical moist, low activity clay soils
F_{LU}	1	-	Table 4 (factors for perennial crops): value for perennial crops
F_{MG}	1	-	Table 4 (factors for perennial crops): value for tropical moist, full tillage[24]
F_I	1	-	Table 4 (factors for perennial crops): value for medium input[25]
C_{VEG}	17.5	t C/ha	Table 12 (values for specific perennial crops): standard value determined for Jatropha in EC 2010a

[24] Full tillage was assumed as there was substantial soil disturbance when preparing the land for Jatropha planting with little of the surface covered by residues. The definitions used in the EC methodology are as follows: full-tillage >> substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g. < 30 %) of the surface is covered by residues. Reduced tillage >> primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion) and normally leaves surface with > 30 % coverage by residues at planting. No till >> direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.

[25] Medium carbon input was assumed because plant residues of Jatropha trees and grass that is cleaned between the trees remains for a large part in the field. The definitions used in the EC methodology are as follows: low (carbon) input >> low residue return occurs when there is due to removal of residues (via collection or burning), frequent bare-fallowing, production of crops yielding low residues (e.g. vegetables, tobacco, cotton), no mineral fertilisation or nitrogen-fixing crops. Medium (carbon) input >> representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g. manure) is added. Also requires mineral fertilisation or nitrogen-fixing crop in rotation. High (carbon) input with manure >> represents significantly higher carbon input over medium carbon input cropping systems due to an additional practice of regular addition of animal manure. High (carbon) input without manure >> represents significantly greater crop residue inputs over medium carbon input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied.

Tobacco cropland

Parameter	Value	Unit	Explanation
CS	26	t C/ha	Calculation using the formula above. Choice: use standard value for C_{VEG}
SOC_{ST}	47	t C/ha	Table 1 (mineral soils): value for tropical moist, low activity clay soils
F_{LU}	0.48	-	Table 2 (factors for annual cropland): value for tropical moist
F_{MG}	1.15	-	Table 2 (factors for annual cropland): value for tropical moist, reduced tillage[26]
F_I	1	-	Table 2 (factors for annual cropland): value for tropical moist, medium input[27]
C_{VEG}	0	t C/ha	Table 9 (values for annual cropland): standard value

Grassland (Savannah)

Parameter	Value	Unit	Explanation
CS	54	t C/ha	Calculation using the formula above. Choice: use standard value for C_{VEG}
SOC_{ST}	47	t C/ha	Table 1 (mineral soils): value for tropical moist, low activity clay soils
F_{LU}	1	-	Table 5 (factors for grassland): value for grassland
F_{MG}	0.97	-	Table 5 (factors for grassland): value for tropical moist, moderately degraded[28]
F_I	1	-	Table 5 (factors for grassland): value for medium input[29]
C_{VEG}	8.1	t C/ha	Table 13 (values for grassland): standard value for tropical, Moist & Wet

Forestland (canopy cover between 10% and 30%)

Parameter	Value	Unit	Explanation
CS	77	t C/ha	Calculation using the formula above. Choice: use standard value for C_{VEG}
SOC_{ST}	47	t C/ha	Table 1 (mineral soils): value for tropical moist, low activity clay soils
F_{LU}	1	-	Table 7 (factors for forestland): value for native forest (non degraded)
F_{MG}	1	-	Table 7 (factors for forestland): not applicable
F_I	1	-	Table 7 (factors for forestland): not applicable
C_{VEG}	30	t C/ha	Table 16 (values for forestland 10-30% canopy cover): standard value for tropical moist forest, Africa

[26] Together with SBF plant management we assumed reduced tillage for the tobacco period. For definitions see footnote 24.
[27] Together with SBF plant management we assumed medium input for the tobacco period. For definitions see footnote 25.
[28] Definitions used for management: improved management >> represents grassland which is sustainably managed with moderate grazing pressure and that receive at least one improvement (e.g. fertilisation, species improvement, irrigation). Nominally managed >> represents non-degraded and sustainably managed grassland, but without significant management improvements. Moderately degraded >> represents overgrazed or moderately degraded grassland, with somewhat reduced productivity (relative to the native or nominally managed grassland) and receiving no management inputs. Severely degraded >> implies major long-term loss of productivity and vegetation cover, due to severe mechanical damage to the vegetation and/or severe soil erosion.
[29] Definitions used for input: medium input >> applies where no additional management inputs have been used. High input >> applies to improved grassland where one or more additional management inputs/improvements have been used (beyond that is required to be classified as improved grassland).

Scrubland

Parameter	Value	Unit	Explanation
CS	92	t C/ha	Calculation using the formula above. Choice: use standard value for C_{VEG}
SOC_{ST}	47	t C/ha	Table 1 (mineral soils): value for tropical moist, low activity clay soils
F_{LU}	1	-	Table 5 (factors for grassland): value for grassland
F_{MG}	0.97	-	Table 5 (factors for grassland): value for tropical moist, moderately degraded[30]
F_I	1	-	Table 5 (factors for grassland): value for medium input[31]
C_{VEG}	46	t C/ha	Table 15 (values for scrubland): standard value for tropical, Africa

Forestland (canopy cover more than 30%)

Parameter	Value	Unit	Explanation
CS	203	t C/ha	Calculation using the formula above. Choice: use standard value for C_{VEG}
SOC_{ST}	47	t C/ha	Table 1 (mineral soils): value for tropical moist, low activity clay soils
F_{LU}	1	-	Table 7 (factors for forestland): value for native forest (non degraded)
F_{MG}	1	-	Table 7 (factors for forestland): not applicable
F_I	1	-	Table 7 (factors for forestland): not applicable
C_{VEG}	156	t C/ha	Table 17 (values for forestland >30% canopy cover): standard value for tropical moist deciduous forest, Africa

[30] Definitions used for management: see footnote 28
[31] Definitions used for input: see footnote 33

GHG savings taking land use into account

The calculation formulas are as follows:

$GHG\ saving = 1 – E_B/E_F$ (Source: RED)

Parameter	Unit	Explanation
E_B	g CO2-e/MJ	Total emissions from the biofuel or bioliquid
E_F	g CO2-e/MJ	total emissions from the fossil fuel comparator (=83.8 g CO2-e/MJ for biodiesel).

$E_B = e_l + e_{ec} + e_p + e_{td} + e_u – e_{sca} – e_{ccs} – e_{ccr} – e_{ee}$ (Source: RED)

Parameter	Unit	Explanation
e_l	g CO2-e/MJ	Annualised emissions from carbon stock changes caused by land-use change *>> calculated on the basis of EC guidance, specified in the present section*
e_{ec} e_p e_{td} e_u	g CO2-e/MJ g CO2-e/MJ g CO2-e/MJ g CO2-e/MJ	Emissions from the extraction or cultivation of raw materials Emissions from processing Emissions from transport and distribution Emissions from the fuel in use *>> all calculated in the RFA carbon calculator*
e_{sca} e_{ccs} e_{ccr} e_{ee}	g CO2-e/MJ g CO2-e/MJ g CO2-e/MJ g CO2-e/MJ	Emission saving from soil carbon accumulation via improved agricultural management Emission saving from carbon capture and geological storage Emission saving from carbon capture and replacement Emission saving from excess electricity from cogeneration *>> all set to zero in the case of Sun Biofuels Mozambique*

$e_l = (CS_R – CS_A) * 3.664 * 1/20 * 1/P – e_B$ (Source: RED)

Parameter	Unit	Explanation
CS_R	t C/ha	The carbon stock per unit area associated with the reference land use (measured as mass of carbon per unit area, including both soil and vegetation). The reference land use shall be the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later.
CS_A	t C/ha	The carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation). In cases where the carbon stock accumulates over more than one year, the value attributed to CSA shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier.
P	MJ/ha/yr	The productivity of the crop (in terms of energy from biofuel produced per ha-yr) *>> 37,2 MJ/kg biodiesel (source: RFA 2010)*
e_B	g CO2-e/MJ	Bonus of 29 gCO2eq/MJ if biomass is obtained from restored degraded land under the conditions provided for in the RED point 8. *>> bonus not applied in the case of Sun Biofuels Mozambique*

$ECPT = e_l * 1/(E_F - E_B + e_l) * 20$ (Sources: RFA 2010 Annex H and Gibbs 2008)

ECPT = Ecosystem Carbon Payback Time (in years)

GHG saving SC1 including GHG loss - base yield									
CSr	CSa	CSr (tC/ha)	CSa (tC/ha)	P (MJ/ha/yr)	el (g CO2-e/MJ)	eec+ep+etd+eu (g CO2-e/MJ)	EB (g CO2-e/MJ)	GHG saving (%)	ECPT (yr)
Perennial Jatropha	Perennial Jatropha	65	65	25445	0	43	43	48%	0
Cropland Tobacco	Perennial Jatropha	26	65	25445	-278	43	-234	380%	-137
Grassland Savannah	Perennial Jatropha	54	65	25445	-78	43	-35	141%	-38
Forestland (canopy cover <30%)	Perennial Jatropha	77	65	25445	90	43	133	-59%	44
Scrubland	Perennial Jatropha	92	65	25445	195	43	238	-184%	96
Forestland (canopy cover >30%)	Perennial Jatropha	203	65	25445	997	43	1040	-1142%	491

GHG saving SC1 including GHG loss - high yield									
CSr	CSa	CSr (tC/ha)	CSa (tC/ha)	P (MJ/ha/yr)	el (g CO2-e/MJ)	eec+ep+etd+eu (g CO2-e/MJ)	EB (g CO2-e/MJ)	GHG saving (%)	ECPT (yr)
Perennial Jatropha	Perennial Jatropha	65	65	50890	0	29	29	65%	0
Cropland Tobacco	Perennial Jatropha	26	65	50890	-139	29	-110	231%	-51
Grassland Savannah	Perennial Jatropha	54	65	50890	-39	29	-10	112%	-14
Forestland (canopy cover <30%)	Perennial Jatropha	77	65	50890	45	29	74	11%	17
Scrubland	Perennial Jatropha	92	65	50890	98	29	127	-51%	36
Forestland (canopy cover >30%)	Perennial Jatropha	203	65	50890	499	29	528	-530%	183

Note: the biodiesel energy content used to calculated the productivity (P) of the crop is 37,2 MJ/kg biodiesel (source: RFA 2010).

Annex III: land use type definitions of the EU Renewable Energy Directive

(Excerpts of articles 17.3, 17.4 and 17.5 of the RED)

17.3 Biofuels and bioliquids (…) shall not be made from raw material obtained from **land with high biodiversity value**, namely land that had one of the following statuses in or after January 2008, whether or not the land continues to have that status:

a. **primary forest and other wooded land**, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;

b. **areas designated**: (i) by law or by the relevant competent authority **for nature protection** purposes; or (ii) for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature (…);

unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

c. **highly biodiverse grassland** that is: (i) natural, namely grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes; or (ii) non-natural, namely grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded, unless evidence is provided that the harvesting of the raw material is necessary to preserve its grassland status[32].

17.4. Biofuels and bioliquids (…) shall not be made from raw material obtained from **land with high carbon stock**, namely land that had one of the following statuses in January 2008 and no longer has that status:

a. **wetlands**, namely land that is covered with or saturated by water permanently or for a significant part of the year;

b. **continuously forested areas**, namely land spanning more than one hectare with trees higher than five meters and a **canopy cover of more than 30%**, or trees able to reach those thresholds in situ;

c. land spanning more than one hectare with trees higher than five meters and a **canopy cover of between 10% and 30%**, or trees able to reach those thresholds in situ, unless evidence is provided that the carbon stock of the area before and after conversion is such that (…) the conditions laid down in paragraph 2 of this Article would be fulfilled[33].

17.5. Biofuels and bioliquids (…) shall not be made from raw material obtained from land that was **peatland** in January 2008, unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously undrained soil.

[32] To be defined in the EC comitology.
[33] I.e. the EU thresholds are met.