Carbon Footprint of Biodiesel from El Cimarrón, Colombia

Draft Report

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March 14, 2017

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PROJECT INFORMATION

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Contracting organization	Prestige Colombia SAS
Liability statement	Information contained in this report has been compiled from and/or computed from sources believed to be credible. Application of the data is strictly at the discretion and the responsibility of the reader. Quantis is not liable for any loss or damage arising from the use of the information in this document.
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Abbreviations and Acronym

AGB	Above Ground Biomass
AF	Allocation Factor
BGB	Below Ground Biomass
CO2	Carbon Dioxide
CF	Characterization Factor
CUE	Consortium CNPML, UPB and EMPA
CPO	Crude Palm Oil
m3	Cubic meter
DOM	Dead Organic Matter
EFB	Enmpty Fruit Bunch
EF	Environmental Factor
eq	Equivalents
FFA	Free Fatty Acids
FFB	Fresh Fruit Bunch
GWP	Global Warming Potential
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogram = 1,000 grams (g) = 2.2 pounds (lbs)
Kg CO2eq	Kilograms of carbon dioxide equivalents
kWh	Kilowatt-hour = 3,600,000 joules (j)
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
L	liter
MJ	Megajoule = 1,000,000 joules, (948 Btu)
CH4	Methane
POME	Palm Oil Mill Effluent
SMAPs	Sectorial Mitigation Action Plans
U	Unit Process
UNFCCC	United Nations Framework Convention on Climate Change
y	Year

EXECUTIVE SUMMARY

Carbon Footprint of Biodiesel from el Cimarrón | Colombia

CO_2 of palm based biodiesel

Context

- Prestige Colombia SAS is a Colombian **palm oil producer in Vichada** | Colombia
- **Oil palm cultivation:** Currently 650 ha | Expansion plan to 60.000 ha
- **Biodiesel production (future):** State-of-the art oil extraction, biodiesel production and treatment of by-products & **export** of palm oil or biodiesel **to Europe**

Objective

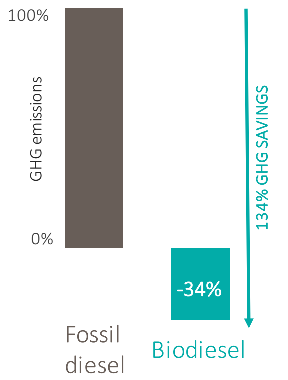
ASSESS the carbon footprint of the future large-scale biodiesel production of Prestige Colombia in Vichada

EVALUATE the compliance with the GHG criteria of the Renewable Energy Directive (RED)

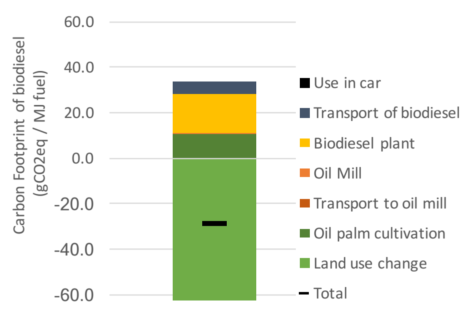
DESIGN the cultivation and processing facilities in a carbon friendly way.

Results

FOSSIL VS. BIODIESEL



ZOOM ON BIODIESEL



Biodiesel from el Cimarrón is projected to **fulfil the EU RED GHG criteria** by showing **134 %** less GHG emission as compared to fossil diesel.

If **oil palm plantations are established on low carbon land** (e.g. savannas in los Llanos) the carbon stock increases (negative values for land use change).

Economy of scale allows optimal use and treatment of by-products. Avoided methane emission due to proper treatment of POME and EFB.

Methodology

The GHG calculation follows the EU RED

1 Introduction

1.1 Background and problem statement

Prestige Colombia SAS (hereafter Prestige) is a Colombian palm oil producer in Vichada, Colombia. Currently 625 hectares (ha) are under cultivation and the first harvest is approaching. The oil will be extracted in a small mill in Vichada, which is currently under construction, and the crude palm oil is intended to be sold in Colombia. Prestige Colombia SAS has 13000 ha of land rights and are looking to further expand the cultivation area under the ZIDRES law (up to 60.000ha).

Prestige Colombia SAS is evaluating the feasibility of exporting palm oil or biodiesel to Europe. To receive government support or count towards national renewable energy targets the biofuels have to comply with the EU sustainability criteria. The renewable energy directive (RED) criteria for greenhouse gas (GHG) emissions states that "from 1 January 2018 greenhouse gas emission savings shall be at least 60%[1] for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017" (EU-Commission, 2008) Article 17 paragraph 2.

According to the EU, the default greenhouse emission savings of palm oil biodiesel do not fulfil the sustainability criteria of 60% GHG reduction compared to fossil fuels. Several previous studies however underlined the substantial GHG saving potential of Colombian biodiesel from palm oil (Castanheira & Freire, 2016; CUE, 2012) and thus the default values provided by the EU, which are mainly based on data from South-East Asia, do not reflect the conditions of biodiesel production in Colombia.

1.2 Goal of this study

The main goal of the proposed project is to assess the carbon footprint of the future large-scale biodiesel production of Prestige Colombia in Vichada and to evaluate the compliance with the GHG criteria of the RED.

The prospective study will be based on realistic assumptions from similar production and processing systems.

Further, the carbon footprint hot spots will be highlighted and measures to reduce the carbon footprint are proposed. The results of the study will be used to design the cultivation and processing facilities in a carbon friendly way.

The project report is intended to provide results in a clear and useful manner to support communication of the carbon footprint to internal and external audiences (clients, providers, policy makers, shareholders, etc.). When disclosing the results it has to be clearly stated that

[1] On 30 November 2016, the Commission published a proposal for a revised Renewable Energy Directive to ensure that the 2030 targets are met. The proposed changes includes e.g. that the GHG savings of least 70 % for biofuels and bioliquids produced in installations starting operation after 1 January 2021. (EU-Commission, 2008) Article 17 paragraph 2.

the carbon footprint study is prospective, since the system is yet to be build, and has the character of a screening study with relatively high uncertainties.

2 Carbon Footprint Methodology

2.1 Overview about carbon footprint standards for biofuels

Carbon footprinting is an internationally recognized approach that evaluates the carbon impacts associated with products and services throughout their life cycle, beginning with raw material extraction and including all aspects of transportation, production, use, and end-of-life treatment. Among other uses, carbon footprinting can identify opportunities to improve the environmental performance of products at various points in the life cycle, inform decision-making, and support marketing, communication, and educational efforts. It is important to note that, rather than direct measurements of real impacts, the impacts described are estimates of relative, potential impacts with limitations that are clearly indicated and accepted by the guidelines.

Different principles, standards and norms exist about how to assess the carbon footprint of a product or service:

- **Generic:** A set of international and national guidelines and principles about how to assess the carbon footprint of products and services are available. Among the most widely used are the ISO 14067 (ISO, 2013), GHG protocol (Penny, Fisher, & Collins, 2012) and PAS 2050 (BSI, 2011). They slightly differ in the goal & scope, modeling principles, level of detail and whether the standard is certifiable.
- **Biofuel specific:** Over the last decade a set of biofuel specific standards has emerged. They are mainly linked to policies (e.g. Renewable energy directive RED, Swiss tax exemption) or voluntary schemes (e.g. Roundtable of Sustainable biofuels, RSB) which might also be crop specific (e.g. Roundtable of Sustainable Palm Oil, RSPO) (EU-Commission, 2008; Leuenberger & Huber-Hotz, 2006; RSB, 2008; RSPO, 2005).

All of the carbon footprint approaches are based on the life cycle perspective, as defined in ISO 14040/44 (ISO, 2006a, 2006b). The most significant differences include whether they allow comparison with products fulfilling the same function (e.g. biofuels and fossil fuels), how they allocate by-products and how the land use change is considered.

In this study the RED method was used. The RED method is also recognized by RSB, is integral part of ISCC and partially compliant with RSPO certification.

2.2 Carbon footprint according to RED

RED specifies that GHG from the production and use of biofuels shall be calculated as:

$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$,

where

E: *total emissions from the use of the fuel;*

e_{ec}: *emissions from the extraction or cultivation of raw materials;*

e_l: *annualised emissions from carbon stock changes caused by land-use change (see chapter 2.4.4 of this report);*

e_p: *emissions from processing;*

e_{td}: *emissions from transport and distribution;*

e_u: *emissions from the fuel in use;*

e_{sca}: *emission saving from soil carbon accumulation via improved agricultural management;*

e_{ccs}: *emission saving from carbon capture and geological storage;*

e_{ccr}: *emission saving from carbon capture and replacement; and*

e_{ee}: *emission saving from excess electricity from cogeneration.*

Within this study the emission savings (e_{sca}, e_{ccs}, e_{ccr} and e_{ee}) are not considered as relevant, since:

- The soil carbon accumulation via agricultural management is considered in the e_l. No bonus for E_{sca} is attributed, since the oil palm plantations are no established on severely degraded nor on heavily contaminated land (RED Annex V, C.8).
- No carbon is captured and geologicaly stored (e_{ccs}) or used to replace fossil derived CO2 used in commercial products and services (e_{ccr}). The savings of replacing fossil diesel is considered (see below).
- No excess electricity is produced by the biofuel system, since all the electricity generated is consumed for palm oil cultivation and processing. Consequently e_{ee} is set to zero.

The emission savings are calculated as:

$SAVING = (E_F - E_B)/E_F$, where

E_B: *total emissions from the biofuel or bioliquid; and*

E_F: *total emissions from the fossil fuel comparator.*

2.3 Scope of the study

2.3.1 General description of the product systems

The oil palm cultivation and processing plant are located close to Nueva Antioquia, Primavera municipality, Vichada department, Colombia. The map below illustrates the current area under cultivation, the 13.000 ha and the planned expansion of 80.000ha (of which 60.000ha are used for oil palm plantation).

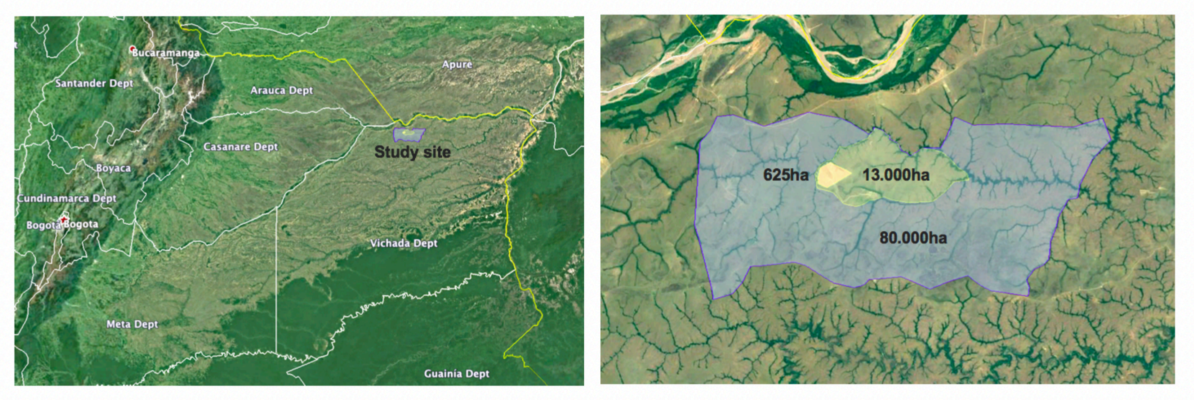


Figure 1: Location of Prestige Colombia SAS oil palm plantation. The area currently under cultivation (yellow), the land title (green) and the potential expansion (blue).

Oil palm plantations were established in 2011 and 2012 (yellow area, 625ha) and the oil extraction plant which is currently under construction is planned to be operational in April 2017.

Within this study we the carbon footprint of large scale biodiesel production in Primavera, Nueva Antioquia. The analysed system consists of an oil palm cultivation area of 60.000ha on the total land area of 80.000ha[2], 5 oil extraction mills and a state of the art biodiesel production plant. The residues from oil extraction are used to generate electricity and compost. The biodiesel will be transported to Europe in two potential routs (via Venezuela and Cartagena).

2.3.2 Functional unit

Product carbon footprints rely on a "functional unit" as a reference for evaluating the components within a single system or among multiple systems on a common basis. It is therefore critical that this parameter is clearly defined and measurable. To fulfil the functional unit, different quantities and types of materials are required for each product. These are known as reference flows. The reference flow for comparing biodiesel with fossil diesel used in this study is **1 MJ of fuel combusted in a standard passenger car** and the GHG emissions from fuels are expressed in terms of grams of CO2 equivalent per MJ of fuel, gCO2eq/MJ.

[2] The area might be divided into different sections (not just one plot) and combined with other crop and animal production.

This implies that we will measure the GHG emissions from the life biodiesel cycle transformed to CO2 equivalents and then compared to the emissions from fossil fuels for the same amount of energy. The MJ refers to the lower heating value of the fuel.

2.3.3 System boundaries

The system boundaries identify the life cycle stages, processes, and flows considered in the LCA and should include all activities relevant for attaining the above-mentioned study objectives.

In this study the GHG emissions from cradle-to-grave are quantified, starting with the feedstock production up to the combustion of the biodiesel. In the following section, the general life cycle stages are described, while the detailed description of each stage is provided in chapter 3.

Oil palm cultivation: The oil palm cultivation starts with the land provision and includes all direct and indirect emissions related to cultivation, as well as the harvesting and transportation of the fresh fruit bunches (FFB) to the oil mill. Emissions from the cultivation of raw materials (e_{ec}) shall include emissions from the cultivation process itself; from the collection of raw materials; from waste and leakages; and from the production of chemicals or products used in cultivation (includes value chain emissions).

Oil extraction and biodiesel production: Emissions from processing (e_p) shall include emissions from the processing itself; from waste and leakages; and from the production of chemicals or products used in processing. The CPO is extracted from the FFB. The by products such as kernel oil and meal are sold. The palm oil mill effluents (POME) and the empty fruit bunch (EFB) are composted. The raw materials are refined and trans-esterified to produce biodiesel and glycerine.

Transport to filling station: Emissions from transport and distribution (e_{td}) shall include emissions from the transport and storage of raw and semi-finished materials and from the storage and distribution of finished materials.

The biodiesel is blended with fossil diesel produced and transported to the filling stations before it is combusted in the diesel engines of vehicles.

2.3.3.1 Temporal and geographic boundaries

This is a prospective study, since the system under study is not yet implemented. Data and assumptions are intended to reflect current equipment, processes, and market conditions.

2.3.3.2 Cut-off criteria

All product components and production processes are included when the necessary information is readily available or a reasonable estimate can be made. In accordance with the EU RED methodology the following flows are excluded from this study:

- **Capital goods:** Emissions from the manufacture of machinery and equipment are not be taken into account (RED guidelines). It should be noted that the capital equipment and infrastructure available in the ecoinvent database is included in the background data. The inclusion leads to a slight overestimation which can be considered as insignificant, since capital goods of background processes typically show low contributions.

- **Human energy inputs** (e.g. the food of the employees).
- **Transport of consumers** to and from the point of retail purchase (e.g. transport to the filling station).
- **Transport of employees** to and from their normal place of work.

Further processes and flows that are cut-off are described in the respective chapters.

2.4 Data collection and modelling

2.4.1 Data types and sources

As far as possible conservative but realistic values for the system under are collected based on expert interviews, questionnaires or from relevant literature.

Oil palm plantations: Primary data from the 625 ha under cultivation was collected. The data collection was based on a questionnaire filled out by personal from Prestige. The primary data was compared to literature value and a conservative value for each flow was considered. Secondary data was used for the background processes and the carbon stock values of the different land uses.

Palm oil extraction: Estimated data from the oil mill which is currently under construction is collected based on a questionnaire filled out by personnel from Prestige. The data was compared to literature value and a conservative value for each flow was considered.

Biodiesel production: Default values from EU RED were used.

Biodiesel transport and distribution: We analysed four different transportation routes, considering the specific transportation distances and transportation means. The energy consumption from the fuel depot and filling station are based on EU RED default values.

Biodiesel use: The EU RED default values (zero) are used.

Fossil diesel: The EU RED default values are used.

Background data are not specifically related to the product system and are usually derived from generic inventory databases. Typical examples are transport datasets and datasets related to material production and electricity generation. Such background data is derived from literature and from the Ecoinvent v 3.2 database[3]. Ecoinvent is internationally recognized by many experts in the field as one of the most complete LCI databases available, from a quantitative (number of included processes) and a qualitative (quality of the validation processes, data completeness, etc.) perspective.

[3] http://www.ecoinvent.org/

For fuels and electricity the Colombian specific emission factors of Fecoc[4] 2016 were used for the fuel combustion (AMELL ARRIETA, CHEJNE JANNA, LOPEZ LÓPEZ, FORERO, & HERRERA, 2016) and completed with Ecoinvent background processes for the fuel production.

The data sources and assumptions are documented in the respective chapters. Inventory modelling and carbon footprint calculations are performed in Simapro 7.3[5].

2.4.2 Allocation method

We apply the energy allocation as defined in the EU RED: "Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value in the case of co-products other than electricity).

Wastes, agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials." EU RED, Annex V, chapter C.17.

2.4.3 Biogenic carbon emissions

Carbon dioxide is captured by the FFB and are typically released in the same year during the combustion of the fuel. Following the RED guidelines, we exclude the CO_2 uptake by FFB and the CO_2 emissions from the fuel in use *(e_u)*.

This assumption is based on the concept of "carbon neutrality", where the atmospheric carbon fixation and end-of-life carbon emissions occur in such a short period of time that they can be regarded as offsetting each other.

2.4.4 Land use change

The carbon emissions from direct land use change are calculated according to the Tier 1 approach proposed by Intergovernmental Panel on Climate Change (IPCC, 2006). The carbon change is calculated as the difference of the carbon in above ground biomass (AGB), below ground biomass (BGB), dead organic matter (DOM) and soil organic carbon (SOC) before and after oil palm plantation. The reference land use is set to 2008[6] and a discounting period of land use change is set to 20 years (annualized emissions).

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[4] La calculadora de **Factores de Emisión de los Combustibles Colombianos -FECOC-**. tiene como objeto facilitar el cálculo de emisiones de CO2 generados por el aprovechamiento energético de los combustibles que actualmente hacen parte importante de la canasta energética Colombiana. http://www.upme.gov.co/calculadora_emisiones/aplicacion/calculadora.html#

[5] http://www.pre-sustainability.com/

[6] 2008 is the cut-off year, which means that LUC occurred before 2008 are not accounted for. Within this study the reference year of 2008 is not relevant since the plantations are established later.

For the calculation of those emissions the following rule shall be applied (RED Annex V, C.7):

$$e_l = (CS_R - CS_A) * 3.664 * \frac{1}{20} * \frac{1}{P} - eB$$

where

e_l	annualised greenhouse gas emissions from carbon stock change due to land-use change (measured as mass of CO2-equivalent per unit biofuel energy);
CS_R	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;
CS_A	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 CS_A shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier;
P	the productivity of the crop (measured as biofuel or bioliquid energy (MJ) per unit area (ha) per year);
e_B	bonus of 29 gCO2eq/MJ biofuel or bioliquid if biomass is obtained from restored degraded land under the conditions provided for in point 8 of RED Annex V chapter C[7]. Not applicable in this study.
3.664	The quotient obtained by dividing the molecular weight of CO2 (44 g/mol) by the molecular weight of carbon (12 g/mol) is equal to 3,664.

Indirect land use change (iLUC) effects are not considered in accordance with the RED guidelines, but potential iLUC are discussed in chapter 4.4.

2.5 Greenhouse gases

Greenhouse gases (GHGs) are substances known to contribute to global warming and include carbon dioxide, methane, dinitrogen oxide and chlorofluorocarbons amongst other substances. The GHGs are weighted based on an identified global warming potential (GWP) expressed in grams of carbon dioxide (CO_2) equivalents.

The fraction of an initial CO_2 pulse that remains in the atmosphere at time t is based on the decay function of the Bern 2.5CC carbon cycle model. Since the decay and radiative efficiency of other GHG differs from CO_2, the characterization factors are dependent on the time horizon. The GWP of other GHG is commonly calculated over time horizon of 20, 100 and 500 years. Within this study the assessment period of modelling the emissions and the impact is set at 100 years. This time horizon is widely accepted and recommended by EU RED, PAS 2050, RSPO and the ILCD guidelines (BSI 2011; European Commission 2010).

The greenhouse gases taken into account are CO_2, N_2O (CO_2 equivalence of 296) and CH4 (CO_2 equivalence of 23). However, for the background database we use the full list of GHG substances as implemented in the GWP indicator (IPCC 2007) in SimaPro, which leads to a slight overestimation of the GHG emission.

[7] The bonus hall be attributed if evidence is provided that the land was not in use for agriculture or any other activity in January 2008; and the land is heavily contaminated or severely degraded. Severely degraded land' means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded.

As mentioned in chapter 2.4.3 the biogenic CO_2 and monoxide emissions are excluded from the study. However, the GWP factor for non-CO_2 emissions originating from biogenic carbon sources (e.g. CO_2 removed from the atmosphere and subsequently emitted as CH_4) are considered and the emission factor is corrected in order into account the removal of the CO_2 that gave rise to the biogenic carbon source. For biogenic methane the GWP_{100} is 23 kg CO2-eq per kg biogenic methane (EU RED).

Further, no weighting factor for delayed emissions (e.g. time delay between vegetable oil production and combustion of the biodiesel) is not considered in accordance with EU RED (assumed that the uptake and the emissions are taking place in the same period).

2.6 Sensitivity analyses

The parameters, methodological choices and assumptions used when modeling the systems present a certain degree of uncertainty and variability. It is important to evaluate whether the choice of parameters, methods, and assumptions significantly influences the study's conclusions and to what extent the findings are dependent upon certain sets of conditions. Sensitivity analyses are used to study the influence of the uncertainty and variability of modeling assumptions and data on the results and conclusions, thereby evaluating their robustness and reliability. Sensitivity analyses help in the interpretation phase to understand the uncertainty of results and identify limitations. The following sensitivity analyses are conducted in this study:

- **Land use change:** on the amount of land changed & the carbon stock values used (including or excluding LUC as a sensitivity result)
- **Electricity generation at oil mill:** The biomass based electricity generation using craft engine operates on an organic ranking cycle is compared to diesel electricity generation.
- **Transportation routes:** Two different export scenarios of the biodiesel (via Venezuela and Cartagena) are calculated.

2.7 Limitations of the study

The GHG study provides a comprehensive overview about the carbon emissions along the biodiesel value chain and about the GHG savings compared to fossil diesel. However, while interpreting the results following limitations have to be considered:

Prospective study: The systems analysed are not yet established. The study estimates the realistic GHG reduction potential, but in case the system is established different than assumed the results will change. Consequently the GHG study needs to be updated frequently in order to reflect the actual palm oil cultivation, processing and use.

Inventory data: The assessment of environmental impacts in the life cycle usually requires a large set of data and model assumptions. These assumptions have to be considered while interpreting the results.

The uncertainties related to the inventory data were not quantified. However, the sensitivity of results on different inventory assumptions was tackled by the evaluation of different scenarios.

Due to limited access to primary data, some secondary and tertiary inventory datasets had to be used. Some of the implemented LCI data represent European operations, implying that the study here may not be 100% representative of processes related to Colombia or geographic locations of Prestiges supply chain and customers. However, a database of equivalent quality, transparency, and robustness is not yet available for the Colombia.

Overall sustainability: Although the carbon footprinting methodology is adequate to assess a key aspect of environmental sustainability, it is capturing neither other environmental impacts (e.g. acidification, eutrophication, toxicity, biodiversity, etc.) nor the socio-economic impacts they generate. In order to obtain a complete view of sustainability, the results of the CF study should be interpreted together with other assessments, i.e. twin study describing socio-economic and environmental conditions at El Cimarron commissioned by Prestige (Wiig, 2017)

3 Palm oil supply chain

3.1 Overview about the assed value chains

In the following chapter the biodiesel value chain is described in detail and the inventory data generated is provided. Figure 2 provides an overview about the structure and about selected key aspects relevant for conducting the biodiesel carbon footprint calculation.

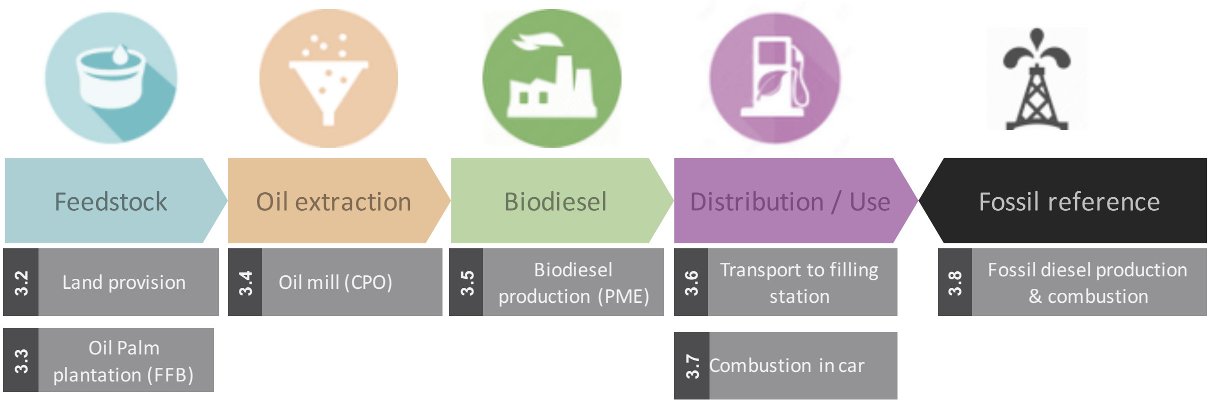

Figure 2: Overview on the biodiesel value chain. The numbers indicate the chapters describing the inventory of the corresponding process.

3.2 Land provision (e_l)

3.2.1 Previous land use categories

There are two dominant land cover in the study site, which are savannas and gallery forest along the surface water bodies. Oil palm plantations will only be established on natural grassland or on land under use (e.g. pasture or agricultural land), leaving a buffer area of at 50m[8] to the next water body, as indicated in Figure 3.

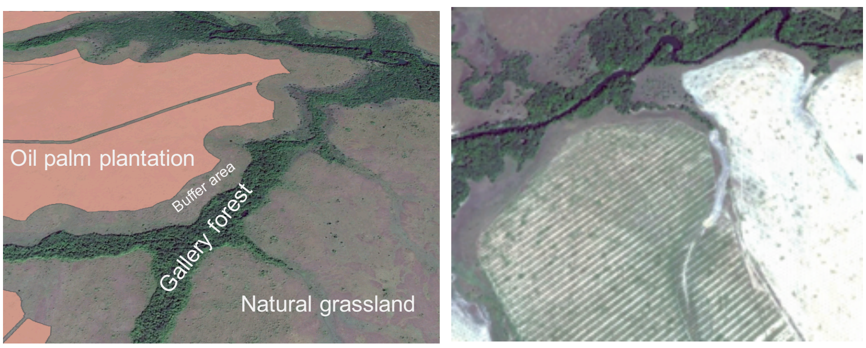

Figure 3: Predominant land use types in the study area (left) and the google image from 2016 of the currently established plantation (right, google maps)

According *IPCC "grasslands vary greatly in their degree and intensity of management, from extensively managed rangelands and savannahs – where animal stocking rates and fire regimes are the main management variables – to intensively managed (e.g., with*

[8] For the new plantations a buffer area of 150m will be implemented.

fertilization, irrigation, species changes) continuous pasture and hay land. Grasslands generally have vegetation dominated by perennial grasses, and grazing is the predominant land use." (IPCC 2006, Chapter 6).

Within this study we assume extensively managed savannahs as the previous land use, where grazing and fire are common perturbations.

3.2.2 Biomass carbon stock change

The direct carbon emissions caused by the direct land use change (LUC) are calculated according to the Tier 1 methodology by IPCC. The above and below ground biomass values of the different ecosystem are taken from literature and are listed in Table 1. The carbon stock of oil palm is the average carbon stock about the whole crop.

Table 1: Living biomass and dead organic matter of different land use systems in Colombia, in tC / ha.

Category	Land use	Biomass carbon stock (tC/ha)	Source
Forest	Gallery Forest	180	From IDEAM 2011 &WWF, 2014
Scrubland	Tropical scrubland – South America	53	European commission, table 15 (EC, 2010).
Annual crop	Annual cropland - rice	0	IPCC 2006
Oil palm	Perennial crop - Oil Palm	60	European commission, table 12 (EC, 2010).
Grassland & savanna	Grassland – tropical moist	8.1	European commission, table 13 (EC, 2010).
	Savanna	15.75	21 Mg AGB / ha (Anaya, Chuvieco, & Palacios-Orueta, 2009), 0.48 tC / t BM, ratio BGB/AGB = 0.5 (IPCC, 2006)
	Open grassland	7.64	Etter et al. 2010
	Sandy grassland	4.46	Etter et al. 2010

In this study we use the value of 8.1 tC/ha for previous land use (grassland), as specified in (EC, 2010), to model the biomass carbon stock change. The difference in average carbon stock of grassland to oil palm plantations is illustrated in Figure 4.

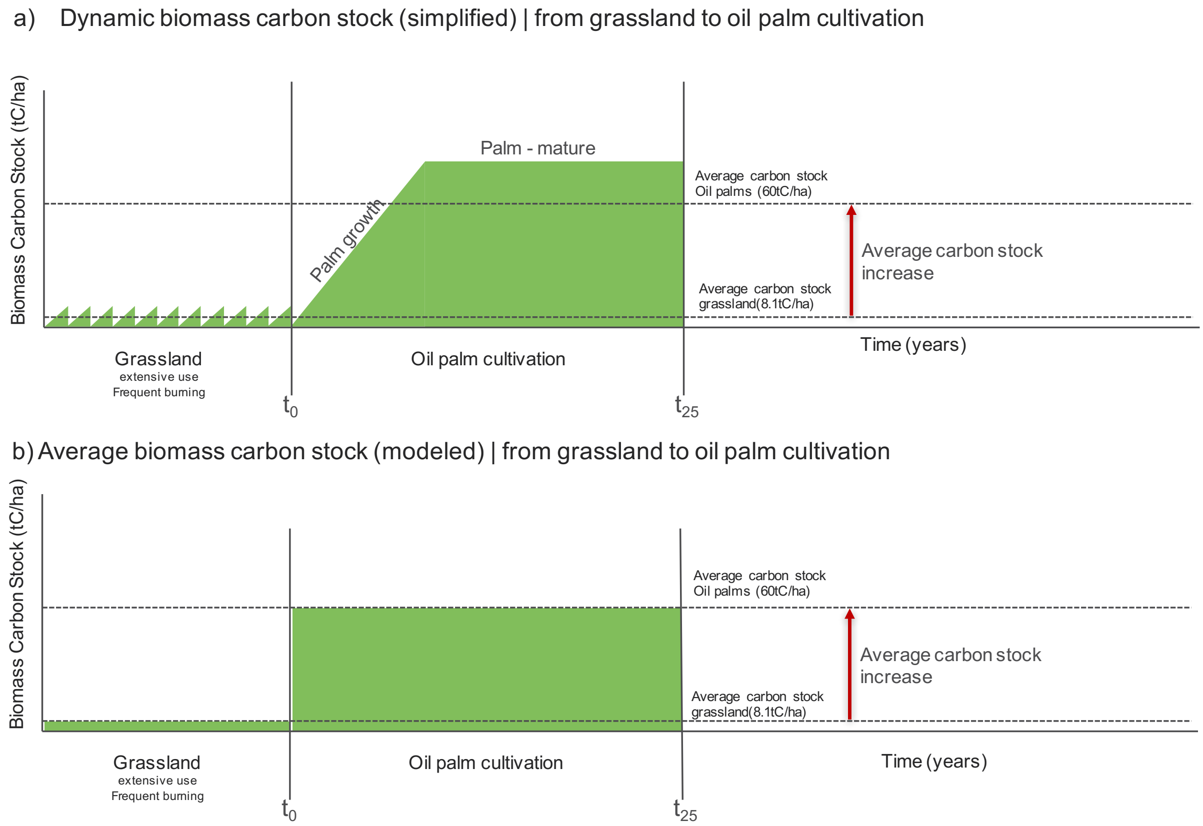

Figure 4: Biomass carbon stock of reference land use (grassland) and oil palm plantations in tC/ha. a) the changes of the carbon stocks over time (a) and the average carbon stock (b) of grassland and oil palm plantations.

It has to be noted that "grassland" is not a clearly defined term and that the carbon stock of different grassland types can vary significantly. To analyse the sensitivity of the carbon stock data on the overall results and conclusion, we use the conservative value of 15.75 tC/ha. As additional sensitivity analysis we calculate the effect of converting scrubland and gallery forests.

3.2.3 Soil carbon stock change

The soil carbon stock changes are modeled based on the Tier 1 approach proposed by IPCC (2006), as specified by the Commission decision on LUC (EC, 2010). The actual soil carbon stocks (SOC in tC/ha) is calculated based on the soil carbon stock under natural land cover (SOC_{REF}) and the influence of land use (F_{LU}), management (F_{MG}) and input (F_I) factors. F_{LU} considers they type and duration of land use, F_{MG} considers the tillage for cropland and the management for grassland, while the F_I considers the amount fertiliser and crop residue management (see IPCC 2006 for more details). The SOC_{REF} is determined by the soil type (high active clay soils), which have a carbon stock of 65 t C /ha (EC, 2010).

$$SOC = SOC_{REF} * F_{LU} * F_{MG} * F_I$$

The influence factors of land use, management and input for palm oil (F_{LU}=1, F_{MG}=1.15, F_I=1), annual crops (F_{LU}=0.48, F_{MG}=1.15, F_I=1) and natural systems and extensively used grassland (FLU=1, F_{MG}=1, F_I=1) are based on IPCC Tier 1.

3.2.4 Annualized carbon emissions of biofuels

The previous land use (grassland – tropical moist) stores 8.1 tC/ha in biomass and 65tC/ha is stored in soil, which sums to 73.1 tC/ha, which is in the range of the values provided in Figure 5 (WWF, 2014).

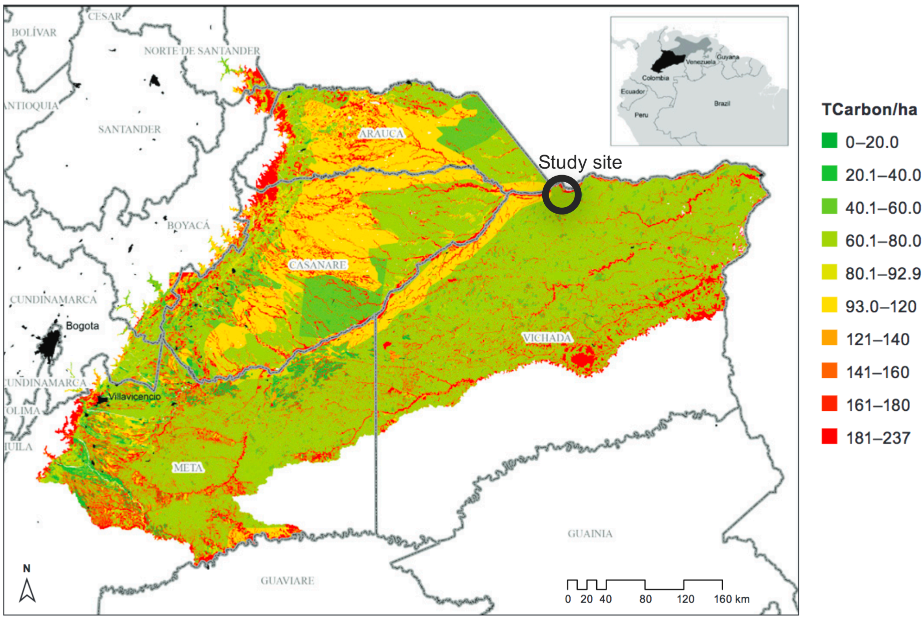

Figure 5: Carbon stock of the Orinoco basin (tC/ha). Source (WWF, 2014)

The carbon stock of oil palm plantation is significantly higher with 60 tC/ha stored in biomass and 74.8 tC/ha stored in soil (total of 134.8 tC/ha).

The GHG emissions related to land use change are calculated as the sum of C_{veg} change and SOC change (61.65 tC/ha) and is annualized over 20 years[9] (according to IPCC 2006) and using the CO_2 to C conversion ratio of 44/12. Consequently the LUC emissions are – 11.3 t CO2eq / ha. The negative value indicates a net carbon capture.

[9] The carbon emissions of land use change are equally distributed over 20 years. E.g. if the average carbon stock increases by 60 tC / ha the annual carbon stock increase is 3 tC/ha/yr.

Table 2: Main parameters of LUC calculation for the default scenario according to EU RED and for the sensitivity analysis.

Parameter	Unit	Defaults (grassland)	Grassland (higher carbon stock)	Scrubland	Gallery forest
Land expansion since 2008					
Grassland – tropical moist	%	100%	100%	0%	0%
Scrubland	%	0%	0%	100%	0%
Natural Forest	%	0%	0%	0%	100%
Total expansion	**%**	**100%**	**100%**	**100%**	**100%**
Biomass carbon stock					
$Cveg_0$ (previous land use)	ton C/ha	8.1	15.8	53.0	180.0
Cveg act (oil palm)	ton C/ha	60.0	60.0	60.0	60.0
Cveg change	**ton C/ha**	**-51.9**	**-44.3**	**-7.0**	**120.0**
Soil type					
High activity Clay soil	%	100%	100%	100%	100%
Soil Organic Carbon content					
SOCref = SOC_0 (previous land use)	ton C/ha	65.0	65.0	65.0	65.0
SOCact (oil palm)	ton C/ha	74.8	74.8	74.8	74.8
SOC change	**ton C/ha**	**-9.8**	**-9.8**	**-9.8**	**-9.8**
GHG emissions from LUC	**t CO2/ha / yr**	**-11.3**	**-9.9**	**-3.1**	**20.2**

3.3 Palm oil plantations (e_{ec})

3.3.1 Farming system

Cultivating oil palm not only requires the right climate and soil. Obtaining maximum yields at each production stage also depends on the quality of seeds used, a rigorous selection process of seedlings in the nursery, good soil preparation before planting, the correct setting up of coverage plants and the right use of fertilizers (Fedepalma 2009).

The lifecycle of an oil palm usually starts in a nursery, where seedlings develop in polybags for about 10 to 20 months. Before planting the site should be leveled and all vegetation to a radius of 1m around the pit (deeper than 1m) should be cleared. Commercial oil palm plantations are typically established as monocultural fields using a symmetric spacing of 9m x 9m.

The oil palm typically starts yielding in the second or third year after plantation. The yield increases continuously and starts stabilizing after seven to ten years. Overall the productivity and growth of oil palms is determined by optimal water and nutrient availability, temperatures and the presence of pests and diseases.

Oil palm production can last more than 50 years (Fedepalma 2006). But after 25 years, the oil palm is difficult to harvest because of its height (the lifespan of 25 years is used within this study). After the plant has reached the maximal height, either Glyphosate is injected into the palm so that it dies or the tree is cut and cleared out. The replanting is done on the cleared field or between the dead palms.

3.3.2 Productivity

The oil palm gives the highest yields per hectare of all oil crops at present (Corley and Tinker 2007). The yield of oil palms depends upon on various factors (e.g. management, soil fertility, diseases, climate, etc.) and shows a typical distribution over the age of the oil palm (see Figure 6).

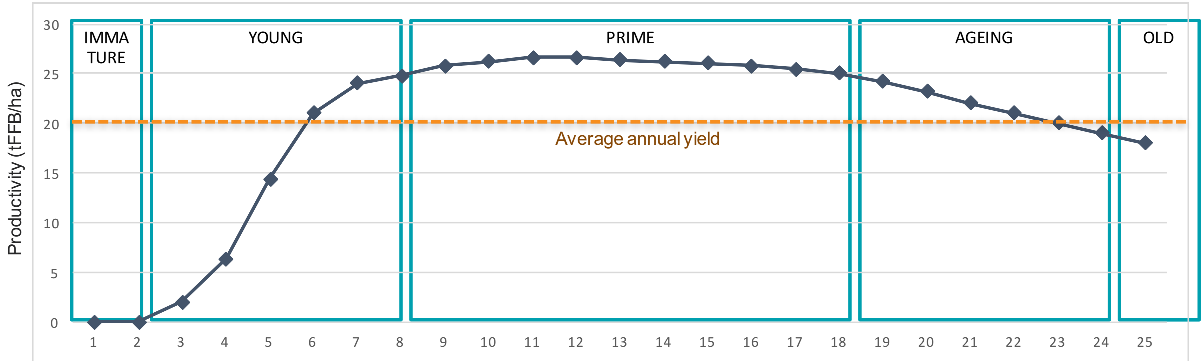

Figure 6: Expected yield distribution by age of oil palm at El Cimarrón (in t FFB/ha)

Currently there do not exist yield figures for oil palm cultivation in Nueva Antioquia, Vichada, due to the absence of mature oil palm plantations. For this study we use an average annual yield of 20 tons FFB per hectare, which is in line with the average literature value of 20.2 ton FFB/ha as indicated in Table 5.

3.3.3 System characterization

Figure 7 shows the inputs used for palm oil cultivation and the emissions. The single flows are described in the following chapters.

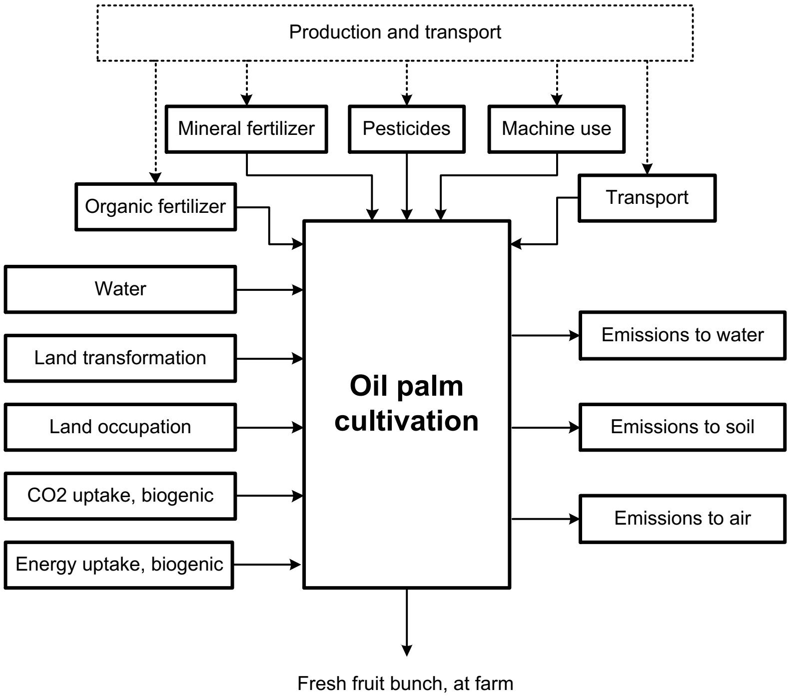

Figure 7: Schematic overview about oil palm inventory.

3.3.4 Mineral and organic fertilizer

The amount and type of supplementary fertilizer depend on the kind of plants that are grown and the soil conditions. In Table 3 the nutrient supply of palm oil plantations are provided.

The amount of NPK fertilizer currently applied (marked in green in Table 3) does not represent the average fertilizer amount, since the plantation are not yet mature. For this study we calculated the fertilizer application based on the agronomic recommendations:

Year 0 to 7: 5.5 kg of fertilizer per palm and year (148 palms / ha)

Year 8-25: 8 kg of fertilizer per palm and year (148 palms / ha)

The fertilizer composition is 13/5/27 and thus the average annual fertilizer application rate is 147 kg N, 57 kg P_2O_5 and 306 kg K_2O per hectare.

Not all the nutrients will be supplied by mineral fertilizer. A share is also supplied by the compost produced from the organic oil mill residues and by products. Per ha about 2 tons of compost will be applied (2.2/1.2/2.9 NPK ratio and a moisture content of 50%). Compost typically shows a higher nutrient availability for plant growth as mineral fertilizer. For this study however, we have assumed a ration of 1:1, reducing the mineral fertilizer demand to 121kg N, 44kg P_2O_5 and 275 kg K_2O per hectare.

Nitrate fixing plants are used to increase the soil fertility.

Table 3: Fertilizer amounts (kg of nutrient per hectare).

Oil palm cultivation (per ha)			Estimate	Literature								This study
			Estimate Prestige	CUE (2012)	Castanheira (2016)	Ylva (2016)	Sampattagul (2011)	Lee (2013)	Queiroz (2012)	Schmidt (2007)	Literature average	**This study**
	Parameter	**Unit**	**CO**	**CO**	**CO**	**IDN**	**TH**	**IN**	**BR**	**IDN**		**CO**
Flow	**Productivity**											
OUT	FFB	ton	20.0	20.0	19.5	26.0	17.9	20.9	18.5	18.9	20.2	**20.0**
	Fertilizer											
IN	N - Fertilizer	kg	79.3	88.7	140.0	143.0	132.5	144.5	64.4	104.0	116.7	**121.4**
IN	P2O5 - Fertilizer	kg	56.9	49.3	60.0	97.5	32.6	45.8	42.9	70.0	56.9	**44.4**
IN	K2O - Ferilizer	kg	153.0	194.2	250.0	190.6	324.1	326.8	107.3	204.0	228.1	**275.9**
IN	EFB	kg	0.0	4600				15000			9800	**-**
IN	Compost	kg	2080	117							117	**2080**

3.3.5 Pesticides

Various agrochemicals are applied in order to control fungus, herbs, insects and pests. The literature average was used to calculate the carbon footprint related to pesticide application.

3.3.6 Energy consumption

The following describes the transport of the input materials (fertilizer) and the machinery used for harvest.

Fertilizing and pesticides: A main fertilizer of oil palm plantation is the compost, which is transported from the oil mill back to the plantation by truck. The mineral fertilizers and pesticides are also transported by truck to the field border and distributed using labors.

Weeding: Usually plants are allowed to spring up naturally and/or are planted (e.g. nitrogen fixating plants) between the oil palms, but are controlled by periodic slashing, mowing grazing or by the use of herbicides especially close to the stem and rooting system (Corley and Tinker 2007).

Harvesting: The fresh fruit bunches are harvested manually using a long harvesting knife. After the FFB is cut from the tree, the fruits are grouped so that they can be loaded more efficiently.

For this study we assume a transportation distance for the FFB of 10 km from the field to the extraction plant (maximum expected distance to use a conservative assumption). For other transports and machinery the 2015 data for the diesel consumption (43kg/ha) and gasoline consumption (12kg/ha) are used.

3.3.7 Emissions to air

The airborne emissions caused by fertilizing are listed in Table 57. The emissions are calculated according to the world food life cycle database guidelines.

For **ammonia emissions** the emission factors from the EMEP-EEA air emission inventory guidebook Tier 2 approach are considered (EEA 2013) to determine the share of applied N lost as NH_3. For urea the NH_3 emissions are 20% of the total nitrogen applied, for other fertilizers the emissions are typically lower (1-9%). The applied crop residues include 9 tons of prunded fronts per hectare and year (12kg N ton-1 dry matter) and 60t of felled biomass at replanting (6 kg N t^{-1} biomass) every crop rotation (25yr).

Nitrogen oxides stem mainly from the nitrification process. The IPCC emission factor of 0.012 kg NO_x per kg N applied is used. The NO_x emission is calculated after the subtraction of N emitted as NH_3.

Dinitrogen oxide is produced from nitrification and denitrification and is a powerful GHG. RED leaves it open which kind of database for emission factors shall be used and how the N2O emissions are calculated. Within this study we apply the Tier 1 approach of IPCC (2006). The **nitrate emissions** used to calculate the indirect N2O missions are based on the NO_3-SQCB model and the parameters used are specified in

Table 4.

Table 4: Field emission data used to model the NH_3, N_2O, NO_x, NO_3 and CO_2 emission related to oil palm plantations.

Parameter	Unit	Value
Nitrogen application (Input)		
N - mineral fertilizer	kg N / ha	121
N - crop residue (EFB, prunes, trunk)	kg N / ha	40
N - organic fertilizer (compost)	kg N / ha	26
N2O emissions		
N2O	kg N2O/ha	4.7
Nox emissions		
NOx	**kg Nox / ha**	**2.2**
NH3 emissions		
NH3, tot	**kg NH3 / ha**	**5.7**
NO3 emissions		
Precipitation	mm/yr	3'216
Irrigation	mm/yr	-
Precipitation + irrigation (P)	**mm/yr**	**3'216**
Clay content	%	49
Rooting depth	mm/yr	1
Corg	%	2
Bulk density	t soil/m3	1'300
Corg, EMPA	t C/ 3000m3	59
Soil Volume	m3	5'000
r c/n	-	11
rNorg	-	1
Norg	kg N / ha	7'598
Nitrogen uptake	kg N / ha	120

NO3	**kg NO3/ha**	**972**

3.3.8 Overview about life cycle inventory

An overview about the estimated data, the data from literature and the data used for small and large scale plantations is specified in Table 5

Table 5: Life cycle inventory data for oil palm plantation (per hectare). ¶The values estimated by Prestige (green), from literature (blue) from different countries (CO: Colombia, IN: India, TH: Thailand, IDN: Indonesia, BR: Brasil) and the values used in the study (orange) are listed.

Oil palm cultivation (per ha)			Estimate	Literature								This study
			Estimate Prestige	CUE (2012)	Castanheira (2016)	Ylva (2016)	Sampattagul (2011)	Lee (2013)	Queiroz (2012)	Schmidt (2007)	Literature average	**This study**
	Parameter	**Unit**	**CO**	**CO**	**CO**	**IDN**	**TH**	**IN**	**BR**	**IDN**		**CO**
Flow	**Productivity**											
OUT	FFB	ton	20.0	20.0	19.5	26.0	17.9	20.9	18.5	18.9	20.2	**20.0**
	Fertilizer											
IN	N - Fertilizer	kg	79.3	88.7	140.0	143.0	132.5	144.5	64.4	104.0	116.7	**121.4**
IN	P2O5 - Fertilizer	kg	56.9	49.3	60.0	97.5	32.6	45.8	42.9	70.0	56.9	**44.4**
IN	K2O - Ferilizer	kg	153.0	194.2	250.0	190.6	324.1	326.8	107.3	204.0	228.1	**275.9**
IN	EFB	kg	0.0	4600				15000			9800	-
IN	Compost	kg	2080	117							117	**2080**
	Pesticides											
IN	Herbicide	g	1158.0	2046				750	11000	2400	4049	**4049**
IN	Pesticide	g	0.0							310	310	**310**
IN	Fungicide	g	0.0							13	13	**13**
	Irrigation											
IN	Water	m3	0.0	114.6		9524					4819	**0**
	Energy used											
IN	Diesel	kg	42.3			171.3		3.2	9.2		61.2	**42.3**
IN	Electricity	kWh	0.0							0.0	0.0	**0**
IN	Gasoline	kg	11.8									**11.8**
	Field Emissions											
OUT	CO2 - urea fertilizer	kg			223.2			119.3		1.5	114.7	0.0
OUT	Nitrous Oxide	kg		3.9	22.9			0.0		10.1	9.2	4.7
OUT	Nitrogen Oxide	kg		0.8	6.6						3.7	2.2
OUT	NH3	kg		7.2						18.3	12.8	5.7
	Land use change											
OUT	CO2 - LUC	kg										-11303

3.4 Palm oil extraction (ep)

3.4.1 System description

The palm oil extraction process includes following processing steps:

Loading: The heavy FFB are unloaded from the trucks into wagons of oil palm FFB.

Sterilization: Sterilization is carried out with steam at relatively low pressures for about 90 minutes.

Treshing: A mechanical process separates the oily fruit from the fruit bunch. The empty fruit bunch is transported on conveyor belts to the compost facility.

Digestion and pressing: Digestion is the process of releasing the palm oil in the fruit through the rupture or breaking down of the oil-bearing cells. The digester commonly used consists of a steam-heated cylindrical vessel fitted with a central rotating shaft. Through the action of the rotating beater arms the fruit is pounded.

Clarification and drying: The oil is clarified through the gravity separation method which is based on different densities. The clarified oil is stored in tanks. The oil is dried to reduce moisture, either by heating in a tank system or by atmospheric or vacuum drying.

Effluent treatment: The oily water which is the by-product of the clarification process is passed through centrifuges in order to recover oil. The remaining effluent is treated in a waste water treatment system, i.e. composting at El Cimarrón.

Defibration and Kernel mill: The mixture composed of fiber and nuts is separated. The shell of the nuts is broken and the kernel removed. The kernel passes the silo drying and the oil is pressed. The kernel oil is sold and the kernel cake is used as fodder. The fiber and the shell are collected and used as a fuel in the boiler

3.4.2 Products and coproducts

In Table 6 the material and energy input per 100 ton FFB is provided.

Table 6: Material and energy input per 100 ton of FFB.The values estimated by Prestige (green), from literature (blue) from different countries (CO: Colombia, IN: India, TH: Thailand, IDN: Indonesia) and the values used in the study (orange) are listed. Other oil mill outputs such as effluents and vapour are not listed.

Extraction Plant (per 100 ton FFB)			Estimate	Literature values												This study
			Estimate Prestige	Fedepalma_2015	Castina (2014)	Guineensis	CUE (2012)	Pedoman Pengelolaan	Salomon et al_2013	Sampattagul (2011)	Lee (2013)	Ylva_2016	R.Kaewmai	Schmidt 2007	Literature Average	**This Study**
Flow	**Mass balance**	**Unit**	CO	CO	CO	CO	CO	IN	CO	TH	IN	IDN	IN	IDN		CO
IN	FFB	ton	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	**100.0**
OUT	EFB	ton	20.0		20.0	21.9	21.3	21.5	20.5	20.0	25.8	21.0	19.9	22.5	21.5	**20.0**
OUT	CPO	ton	21.0	20.9	21.5	21.2	21.4	22.5	24.0	17.0	22.5	25.0	16.5	20.0	21.1	**21.0**
OUT	Fiber	ton	15.0		14.0	13.3	13.2	13.1	10.7	14.0		14.0	9.6	13.0	12.8	**15.0**
OUT	Nut	ton				10.6	7.9	10.4							9.6	**11.5**
OUT	Palm Kernel	ton	4.5	4.0	8.5	4.5		5.0		6.0			3.3	5.3	5.2	**4.5**
OUT	Palm Kernel Oil	ton	2.0		2.5		2.0	2.5			1.3		0.8	2.4	1.9	**2.0**
OUT	Palm Kernel Meal	ton	2.5		6.0		2.9	2.5			2.5		1.5	2.8	3.0	**2.5**
OUT	Shell	ton	7.0		6.0	6.0	7.9	5.4	3.8	7.0		6.5	6.1	7.0	6.2	**7.0**

The average extraction rate of 21t CPO per 100 ton FFB is in line with the average CPO extraction rate for Eastern Colombia of 20.9%. The average mass balance of palm kernel of about 4.5% is slightly higher as specified in (Fedepalma, 2015) but lower as the literature average.

3.4.3 Material and energy demand

The total electricity demand for palm oil extraction is assumed to be 2500 kWh per 100 ton of FFB. This includes the electricity demand for administration and composting.

Currently the electricity is generated based on diesel. At a large scale operation, the use of biomass energy to cover the electricity demand (thus replacing the diesel aggregate) becomes economically viable. Thereby heat from biomass, EFB in our case, is burned in a furnace and the heat is transferred to the craft engine using a heat exchanger. The craft engine operates on an organic ranking cycle (ORC), which is similar to a steam engine process, but uses other fluids than water. These fluids have lower boiling points and other positive abilities that make them more suitable for low-temperature operations.

The conversion of biomass energy to electricity has a typical electric efficiency of 10%[10]. Consequently the use of 1kg EFB with a lower heating value of 18MJ generates 1.8MJ of electricity (or 0.5 kWh).

We use the ORC technology as default and compare the carbon footprint of diesel electricity generation in a sensitivity analysis.

3.4.4 Combustion emissions

The energy consumed to extract the palm oil is generally generated by the boiler and turbine system. The by-products of the extraction, such as fibers and shells, are usually used as fuels. The composition of the input energy carriers is listed in Table 65.

Table 65: Properties of the fiber and the shell (Source: Ecoinvent).

Parameter	Unit	Shell	Fiber
Lower heating value	MJ/kg	12,57	8,98
Moisture	%	6,16	28,76
Carbon content	%	51,8	58,9
H - content	%	25,1	20,15
S - content	%	0,3	0,24
N - content	%	5,15	4,21
O - content	%	12,35	8,62
Ash content	%	4,96	5,55

The processing of 100t FFB results in about 10 ton of fiber and 7 ton of shell, which are used in the boiler to produce steam.

The emissions are calculated based on the "Cogen unit 6400kWth, wood burning" process from Ecoinvent. The emissions per MJ fiber and shell, as well as per 100 ton of FFB are listed in Table 7.

Table 7: Airborne emissions from the combustion of 1MJ fiber, 1MJ shell and per 100 ton FFB (Jungbluth, Dinkel et al. 2007).

Emission	Unit	1MJ of fibers	1 MJ of shell	100 ton of FFB
Carbon dioxide, biogenic	kg	2.4E-01	1.5E-01	39'597
Carbon monoxide, biogenic	kg	9.1E-06	1.2E-05	1.1
Methane, biogenic	kg	5.6E-07	7.4E-07	0.1
Dinitrogen monoxide	kg	3.0E-06	3.9E-06	0.4
Nitrogen oxides	kg	1.1E-04	1.5E-04	13.8

[10] http://www.vikingheatengines.com/products

3.4.5 Transportation of FFB to oil mill

The average transport distance from the farm to the extraction plant is 10km (conservative assumption), using the ecoinvent dataset “transport, freight, lorry 7.5-16 metric ton, EURO3”.

3.4.6 Composting

The POME (palm oil mill effluent) is generated during the oil extraction process in the oil mill. The waste water contains high amounts of organic matter and is usually treated in open lagoons. However, at Prestige the POME is used for composting, where it’s mixed with chopped EFB, fibers and shells.

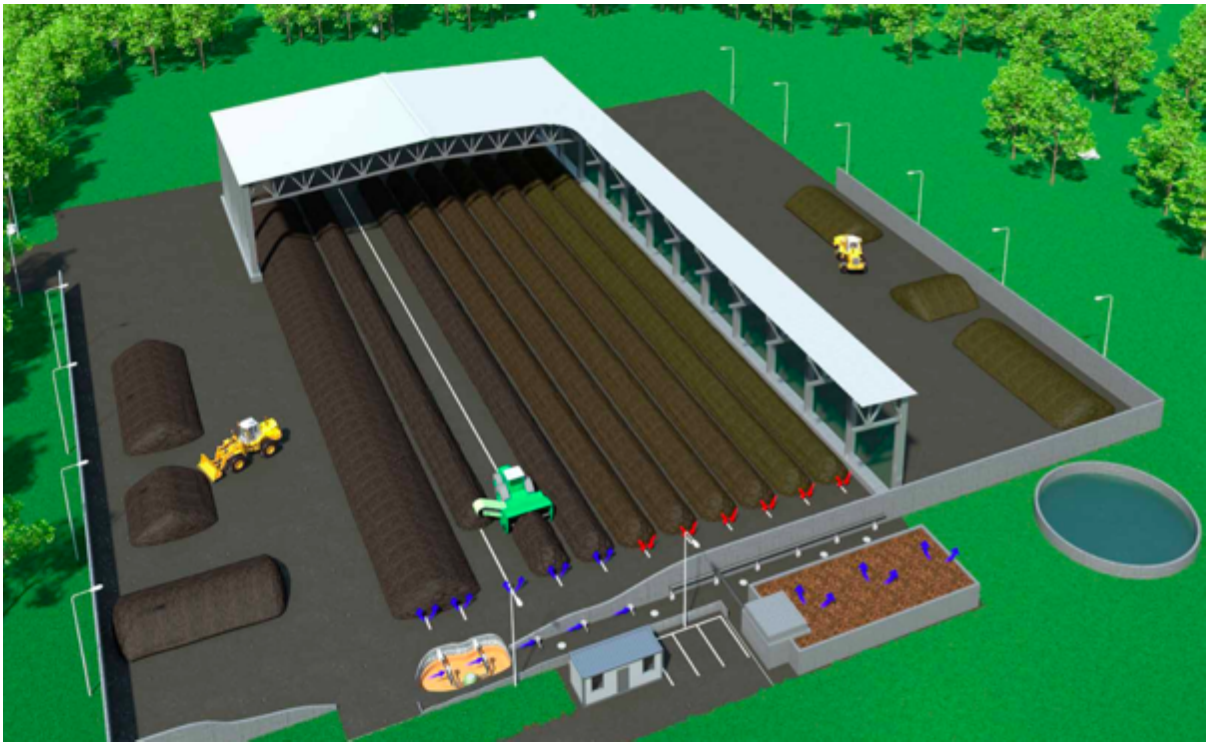

Figure 8: Schematic overview about the composting (source: Compo system).

The composting technology is using aeration in order to avoid CH_4 generation and irrigation in order to control the temperature. The aeration and irrigation are controlled based on the monitored temperature and on CO2 and CH4 concentrations. The composting process implies the aerobic decay of organic material. This reaction results in release of carbon dioxide and water vapor and practically no methane as it would happen in anaerobic decay.

Every week the compost piles are turned using the TracTurn 3.7 truck. After 12 weeks the degradation of the organic feedstock is sufficiently decomposed and reaches a suitable moisture level to be used as organic fertilizer helping to improve soil structure and nutrient content.

Since the rainfall at the site location is over 2000mm per year, the plants are paved and covered in order to control the composting process.

Table 8: Composting material and energy flow (per 100t FFB) for the default scenario (a part of the EFBs are used for electricity generation) and the scenario where electricity is generated based on diesel.

Flow	Mass balance	Unit	Default scenario ORC	Scenario Diesel electricity genergation	Comment
IN	POME	ton	80	80	From oil mill
IN	EFB	ton	15	20	from oil mill, in the default scenario a share of the EFB is used to generate electricity
IN	Fiber	ton	5	5	from oil mill
IN	Electricity	kWh	N/A	N/A	Included in oil mill electricity consumption
IN	Diesel[11]	kg	65.2	81	Norhasmillah et al (2013)
OUT	Compost	ton	10.4	13	Used as fertilizer on field
OUT	Methane	ton	0	0	Assumed to be 0, optimal aeration

Per ton of compost 6.3 kg of diesel is consumed (based on Norhasmillah et al (2013)). Chiew and Shimada (2013) suggested that 2600 kg of fresh EFB resulted in 1000 kg compost.

3.4.7 Organic Ranking Cycle engine

3.4.8 Inventory overview and allocation

Energy allocation was used to assign the environmental burden of the palm oil mill to the different products.

Table 9: Allocation factors for oil mill products in percent.

Product	Amount	Unit	Energy content		Allocation factor
CPO	21.0	ton	37	MJ/kg	86%
Palm Kernel Oil	2.0	ton	17	MJ/kg	4%
Palm Kernel Meal	2.5	ton	37	MJ/kg	10%

3.5 Biodiesel production (e_p)

We use the GHG emissions as specified in the EU RED guideline for refinement and transesterification. 1.048 ton of CPO are required and to produce one ton of PME and 105.6 kg of glycerin. The lower heating value of PME is 37.2 MJ/kg.

The allocation between PME and glycerin is listed in Table 10.

[11] The fossil diesel used could be replaced by the biodiesel produced.

Table 10: Allocation factor for PME and glycerine.

Output	Amount (t/t PME)	Energy content (MJ/kg)	Allocation factor
PME	1	37.2	95.7%
Glycerine	0.11	16	4.3%

3.6 Distribution to the filling station (e_{td})

The aim is to export the biodiesel via Venezuela, using barge when the Rio Meta carries sufficient water (8months) and to use the road until Puerto Carreño by Orinoco river during the dry season (4 months). Due to political restrictions, this route is not operational at the moment and thus we use the exportation route via Cartagena which is already established as an alternative (sensitivity analysis).

3.6.1 Export through Venezuela

The transportation mode and export route from Nueva Antioquia via Venezuela to Europe depends on the season:

Rainy season (8month): It is possible to transport biodiesel from Nueva Antioquia to the Atlantic Ocean, through Venezuela, by fluvial means using the Meta[12] and Orinoco River. During winter, river transportation predominates, but there is lack of land transportation to the docks. Actually, the Meta river has a considerable flow that allows its navigation during 8 months of the year, from April to December. However, there are plans to dredge the river and turn it seaworthy during all seasons. The Orinoco river is navigable for boats transit all over the year. Once in Puerto Ordaz, biofuels can be directed to Europe by maritime means.

Table 11: Distribution from Venezuela to the filling station during rainy season

From	To	Distance	Vehicle (EI v3)	Comment / Source
Biodiesel plant	Nueva Antioquia port	30	Truck 32 t	Google maps, distance from projected biodiesel plant to port
Nueva Antioquia port	Puerto Carreño	250 km	Barge	Google Maps
Puerto Carreño	Puerto Ordaz (Venezuela)	840 km	Barge	http://www.iirsa.org/admin_iirsa_web/Uploads/Documents/aic_19_navegabilidad_del_rio_meta.pdf
Puerto Ordaz (Venezuela)	Oslo	8595 km	Tank ship	http://www.sea-distances.org/
Oslo	Depot	150 km	Truck	EU RED
Depot	Filling Station	150 km	Truck	EU RED

[12] http://www.asorinoquia.org/publicaciones/socializacion-estudio-de-navegabilidad-rio-meta

Dry season (4months): During dry season the Meta river is not navigated, so terrestrial transport should be performed. No paved road exists, but a dirt road exists which can be used by trucks during dry months (from January to March). Nevertheless, studies have begun for construction a major route that will link the center of the country with the Orinoquía zone. It will connect Puente Arimena and Puerto Gaitán (Meta), with Puerto Carreño (Vichada). The proposal deadline is until the end of 2017, but it most likely takes longer to finalize constructions.

Transportation by fluvial means should be performed using the Meta and Orinoco River. Actually, the Meta river has a considerable flow which allows to navigate it during 8 months of the year, from April to December. However, there are plans to dredge the river and make it travelable all over the year. The Orinoco river does not present inconveniences for the boats transit throughout the year.

Once the biofuels reach Puerto Ordaz, it can be sent to Europe by Transoceanic ships.

Table 12: Distribution from Venezuela to the filling station during dry season

From	To	Distance	Vehicle (EI v3)	Comment / Source
Nueva Antioquia	Puerto Carreño	270 km	Truck 32t	https://co.rutadistancia.com/distancia-entre-puerto-carreno-a-nueva-antioquia
Puerto Carreño	Puerto Ordaz-Venezuela	840 km	Barge	http://www.iirsa.org/admin_iirsa_web/Uploads/Documents/aic_19_navegabilidad_del_rio_meta.pdf
Venezuela	Oslo	8595 km	Tank ship	http://www.sea-distances.org/
Oslo	Depot	150 km	Truck	EU RED
Depot	Filling Station	150 km	Truck	EU RED

3.6.2 Export via Cartagena

The transportation mode and export route from Nueva Antioquia via Cartagena to Europe depends on the season:

Rainy season (8months): The other route would be through the Meta River from Nueva Antioquia to Puerto Gaitan. Actually, the Meta river has a considerable flow that allows to navigate it during 8 months of the year, from April to December, along 800 km from Puerto López to Puerto Carreño. Once in Puerto López, the biofuel can be transported to Cartagena by truck.

Finally, in Cartagena Port it can be transport to Europe by maritime means.

Table 13: Distribution from Cartagena to the filling station during rainy season

From	To	Distance	Vehicle (EI v3)	Comment / Source
Nueva Antioquia	Puerto Gaitán	385 km	barge	Google maps
Puerto Gaitán	Cartagena	1374	Truck 32 t	https://co.rutadistancia.com/distancia-entre-puerto-gaitan-a-cartagena-meta
Cartagena	Oslo	9030 km	Tank ship	http://www.sea-distances.org/
Oslo	Depot	150 km	Truck	EU RED
Depot	Filling Station	150 km	Truck	EU RED

Dry season (4months): Basically there are two ways to transportation routes to Cartagena. The first one consists of transport the biofuel from Nueva Antioquia to Cartagena by truck, the main problem of this transportation means is the vial infrastructure during the raining season. From Nueva Antioquia to Puente Arimena terrestrial transportation is only possible during the dry season. No road has been built to allow transit throughout the year. There is a path marked by the footprint that vehicles leave with their passage. It is passable by trucks and campers only during 4 months of the year which corresponds to the dry period. From Puente Aremida to Cartagena the road infrastructure does not present limitations or greater problems that avert vehicular traffic during the whole year.

Table 14: Distribution from Cartagena to the filling station during dry season

From	To	Distance	Vehicle (EI v3)	Comment / Source
Biodiesel plant	Nueva Antioquia port	30	Truck 32 t	Google maps, distance from projected biodiesel plant to port
Nueva Antioquia	Puerto Lopez	382 km	Truck 32 t	https://co.rutadistancia.com/distancia-entre-puerto-carreno-a-puerto-lopez-meta
Puerto Lopez	Cartagena	1266 km	Truck 32 t	http://co.toponavi.com/821-41169
Cartagena	Oslo	9030 km	Tank ship	http://www.sea-distances.org/
Oslo	Depot	150 km	Truck	EU RED
Depot	Filling Station	150 km	Truck	EU RED

3.6.3 Transport in Europe to filling station

The transport of the biodiesel from the port to the depot and from the depot to the filling station is assumed to be 150km each. The energy use of the depot and the filling station is considered with 20 kg CO2 per ton of PME, based on EU RED.

3.7 Use of biodiesel in car (eu)

The emissions of fuel combustion are set to zero according to the EUR RED guidelines.

3.8 Fossil reference (ef)

According to the EU RED, the fossil fuel comparator EF shall be the latest available actual average emissions from the fossil part of petrol and diesel consumed in the Community as reported under Directive 98/70/EC. If no such data are available, the value used shall be **83,8 gCO2eq/MJ** (value used for this study).

It has to be noted that the proposed update of the fossil reference value will be of 94 gCO2eq/J, which will significantly increase the GHG savings (EC, 2016a) Annex V, C.19.

4 Results and Discussion

4.1 GHG balance of biodiesel

Each MJ of biodiesel combusted is linked to -28.6 g of GHG emission. The negative GHG emissions is caused by the carbon sequestration during plant growth, while the main GHG emission is linked to emissions from the oil mill and the biodiesel production. In the following the impacts caused in every life cycle stage are described in more details.

Table 15: GHG emissions biodiesel production and use in g CO_2 equivalents per MJ of fuel combusted. Negative values are carbon sequestration.

Process	Carbon Footprint (g CO2eq/MJ)	Share (%)
Land use change	-62.4	218%
Oil palm cultivation	10.5	-37%
Transport to oil mill	0.2	-1%
Oil Mill	0.4	-1%
Biodiesel plant	17.1	-60%
Transport of biodiesel	5.5	-19%
Use in car	0.0	0%
Total	-28.6	100%

4.1.1 Land provision and oil palm cultivation

In Figure 9 the average global warming potential of oil palm cultivation is indicated, is mainly related to fertilizer production and N2O emissions due to fertilizer application and decomposition of crop residues.

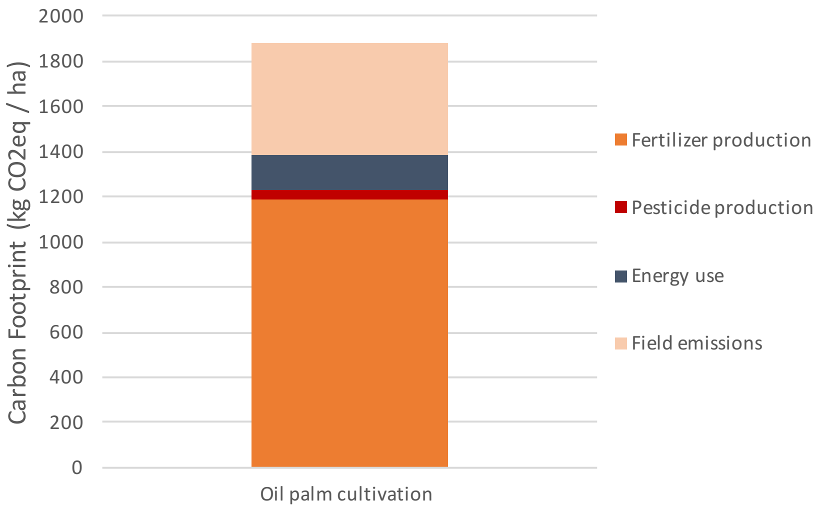

Figure 9: Global warming potential of oil palm cultivation measured in kg CO2eq per ha.

The average GHG intensity of oil palm cultivation excluding LUC of this study is 10.5 g $CO2_{eq}$ per MJ of fuel combusted and. The values are slightly lower as the values provided by a recent study of 13 to 17g of $CO2_{eq}$ per MJ of fuel combusted (Castanheira & Freire, 2016) and the RED default value of 14 g $CO2_{eq}$ per MJ of fuel combusted (EU-Commission, 2008).

Figure 10 shows the carbon footprint of oil palm cultivation including the carbon stock changes caused by oil palm plantations. Overall more carbon is sequestered by oil palm trees compared to the life cycle GHG emissions related to the cultivation. The carbon sequestration is linked to moving from low carbon stock area (low carbon stock grassland & savanna) to oil palm plantation with relatively higher carbon stocks (see chapter 3.2).

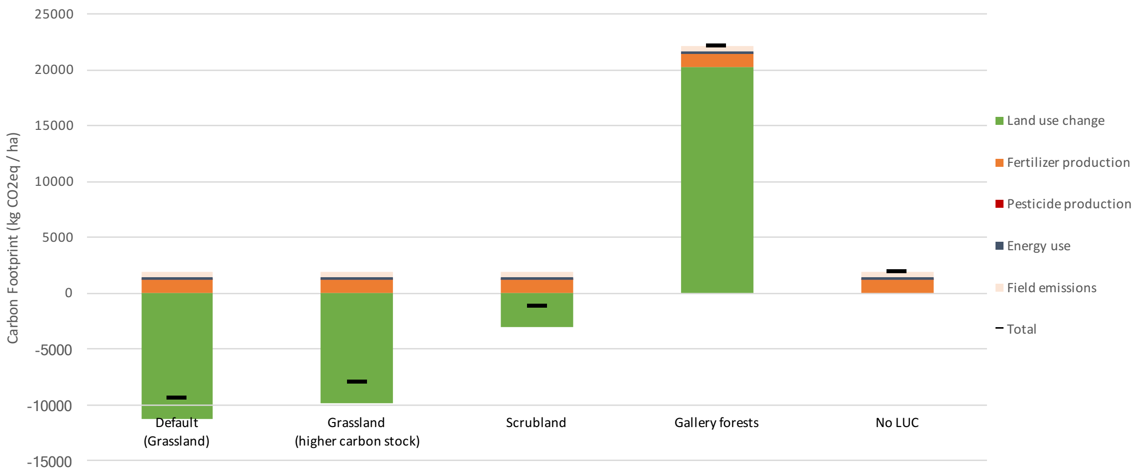

Figure 10: Global warming potential of oil palm cultivation measured in kg CO2eq per ha. Negative values are carbon sequestration.

The default scenario is based on EU RED values for grassland (8tC/ha) and show significant carbon stock sequestration. Even if more conservative values for the carbon stock of grassland are considered (16 tC /ha) or even the conversion of scrubland (53tC/ha) show significant net benefits. Only if gallery forests (180 tC/ha) are clear-cut significant amounts of carbon emissions are emitted (theoretical scenario since gallery forests are protected by law and the oil palms are cultivated using a 100m buffer zone, see Figure 3).

Last, it has to be noted that the LUC benefits and impacts are uniformly distributed over 20 years time horizon (annualised emissions). Once the 20 years are passed, no LUC credits are given to the oil palm cultivation, since the past and current land use are oil palm plantations (no LUC change occurs). If grassland is converted in 2017 (default scenario) the carbon footprint of oil palm cultivation remains constant (-9617 kg CO2eq / ha) until the year 2037 and from year 2038 onwards the carbon footprint is (1699 kg CO2eq / ha, see Figure 9) since the LUC benefits are not anymore accounted for (no LUC scenario in Figure 10).

4.1.2 Palm oil mill and biodiesel plant

As indicated in Table 16, the main GHG emissions related to oil extraction is linked to the energy consumption, which is currently fossil based. In a large scale set-up a part of the EFB biomass will be used in an organic ranking engine to auto-generate electricity. Consequently, the emissions reduce significantly.

Table 16: Global warming potential of the palm oil mill measured in g CO2eq MJ fuel. Values in yellow indicate 0 to 10%, orange 10% to 50%, red >50% contribution.

Process	Oil mill Small scale		Oil mill (incl. autogen. of el.)	
	g CO2eq/MJ	%	g CO2eq/MJ	%
Energy use	2.9	95%	0.3	68%
CHP emissions	0.2	5%	0.2	32%
Composting	0.0	0%	0.0	0%
Total	**3.0**	**100%**	**0.5**	**100%**

In Colombia, the POME treatment in open lagoons under anaerobic conditions typically leads to a much higher GHG intensity as compared to the optimized compost system implemented at the el Cimarron site. The CUE study indicated a GHG intensity of 30 g CO2eq per MJ fuel combusted and 6 g CO2eq per MJ if methane is captured (CUE 2012). (Castanheira & Freire, 2016) indicated that the GHG intensity of palm oil extraction for biogas flared (2.3 g CO2eq MJ−1) was about eight times lower than for biogas released into the atmosphere (19.0 g CO2eq MJ−1). RED specifies processing GHG emissions of 35 g /MJ and 13 gCO2eq / MJ with methane capture (including both the oil mill and transesterification emissions) (EU-Commission, 2008).

The crude oil refining and trans-esterification is responsible for 17.9g CO2eq per MJ, in accordance with the EU RED default values.

4.1.3 Transport to filling station and use in car

The impact of transportation and distribution of the biodiesel show significant GHG emissions, given the remote location of the production site.

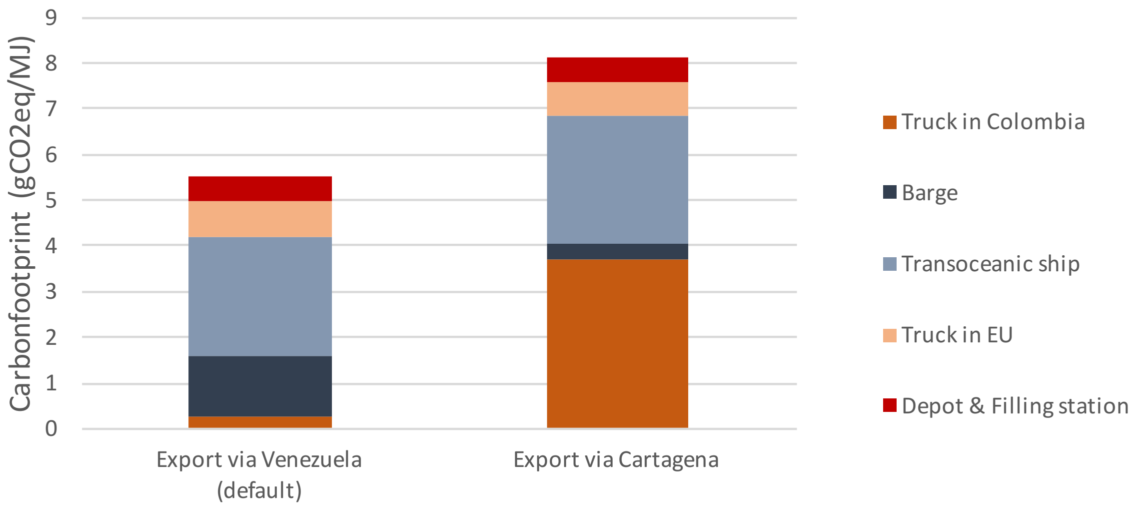

Figure 11: Carbon Footprint of different transportation routes from the biodiesel plant to the filling station in Europe (in g CO2eq / MJ fuel).

The GHG intensity of transport and distribution ranges from 5.5 gCO2 per MJ of fuel combusted for the export via Venezuela to 8.1 gCO2 per MJ of fuel combusted for the export via Cartagena. The relatively remote location leads to higher emissions of transport as the default values published by RED (5 g CO2eq per MJ).

The use of biodiesel assumed to be zero in accordance with the EU RED guidelines for GHG calculation ("carbon neutrality" principle).

4.2 Comparison with fossil fuel

Using biodiesel from el Cimarrón is projected to show 134 % less GHG emission as compared to fossil diesel. This is based on the assumption that the oil palm plantations are established on low carbon-stock grassland, that the by-products are used optimally (e.g. for auto generation of electricity) and that the biodiesel is exported through Venezuela.

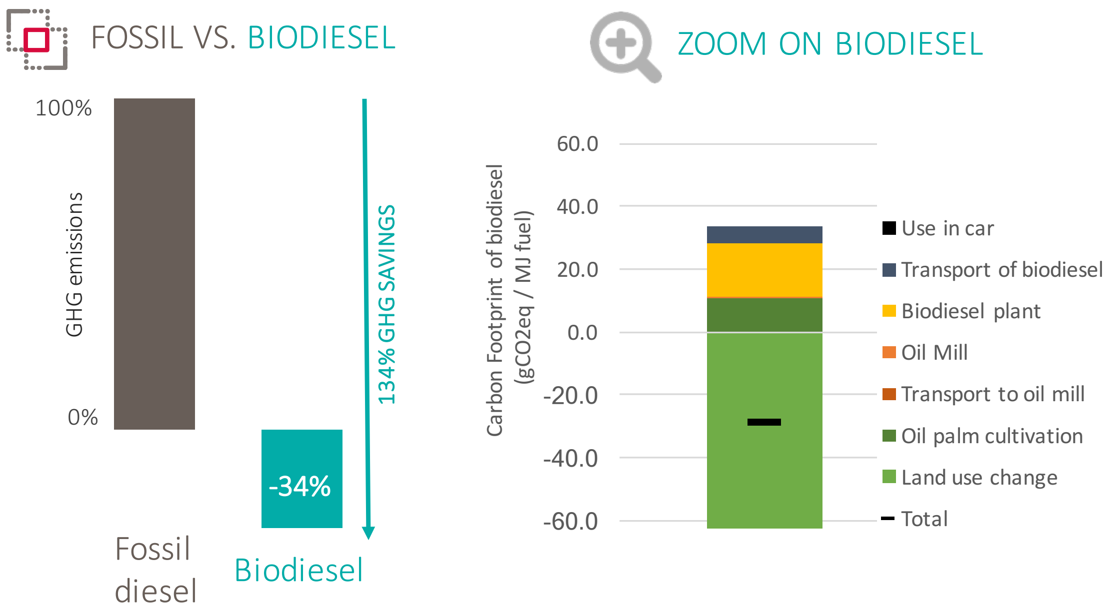

Figure 12: GHG emissions savings of biodiesel compared to fossil fuels (in %), left figure. Biodiesel baseline scenario CO2 equivalent emissions by source, notice land use change is negative as there is more carbon in palms than former savannah (g CO2eq / MJ), right figure.

If the biodiesel is exported through Colombia, the GHG reduction would still reach 131% as emissions from tankers is negligible compared to the volume transported. Using fossil diesel to generate electricity used for processing leads to GHG reduction of 132%.

As explained in chapter 4.1.1, the renewal of oil palm plantations are not considered as changing the land use change (thus no LUC benefits after 20 years can be attributed). Even without accounting for land use benefits, palm biodiesel saves 60% of GHG emissions as compared to fossil diesel if exported via Venezuela (43% if exported via Cartagena).

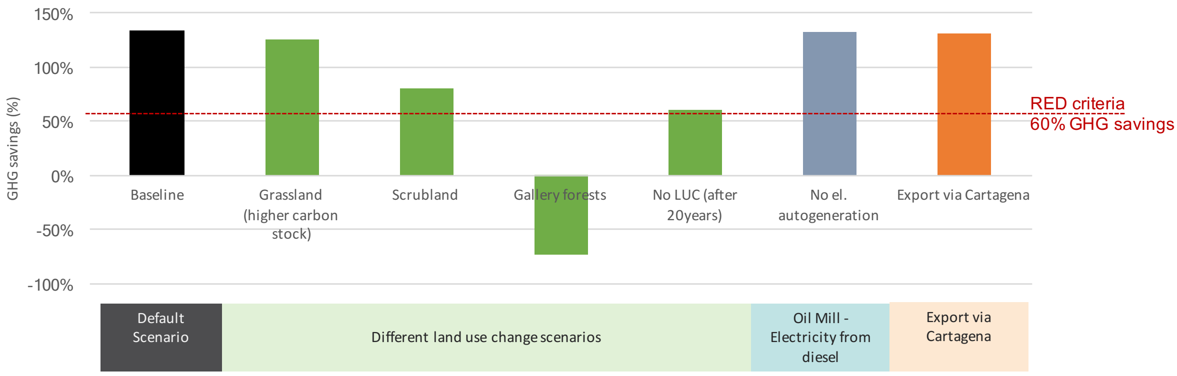

Figure 13: GHG emissions savings of biodiesel scenarios compared to fossil fuels (in %).

In el Cimarrón not all the 60.000 ha will be established at the same time. It can be assumed that every year a 5.000 ha plot will be cultivated over a period of 12 years. Consequently, the carbon sequestration benefit during 20 years will gradually decrease from 134% GHG savings to 60% GHG savings in year 32 (20 years after the last 5.000 ha will be cultivated).

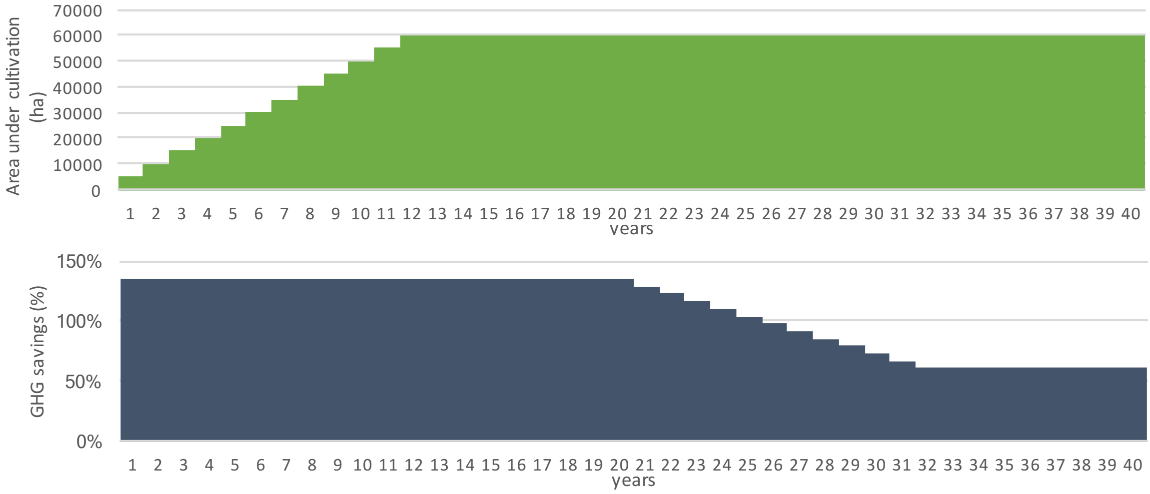

Figure 14: The area under cultivation (in ha) at the top and the associated GHG savings (in %) of biodiesel compared to fossil fuel at the bottom, baseline scenario.

4.3 Comparison with other studies

The RED default values for biodiesel from palm oil of 68g and 37g CO2eq per MJ (including biogas capture and flaring) are significantly higher than for this study (-29g CO2eq per MJ, baseline scenario). The main difference is that the RED default values do not consider LUC (neither emissions nor capture).

Also the updated value from the JEC consortium range from 31 to 62g CO2eq (also LUC is not considered).

The national study from 2012 about GHG emissions of biodiesel (B100) from CPO and ethanol (E100) from sugarcane indicated respectively 83% and 74% of GHG savings compared to fossil fuels (CUE, 2012). The main difference is that in the case of el Cimarron all of the plantations are newly established and thus the total cultivation comes with LUC benefits. In Colombia also oil palm plantations older than 20 years exist, for which no LUC is accounted for (lower carbon sequestration benefits).

Castanheira & Freire calculated that the GHG intensity of palm biodiesel in Colombia ranged from 4 g CO2eq MJ−1 to 25 g CO2eq MJ−1, depending on the fertilization scheme and biogas management option. This translates into a GHG saving of 70% to 95% as compared to fossil fuels (Castanheira & Freire, 2016).

The results are also in line with the WWF study, which indicated GHG savings of more than 60% for most areas of Vichada (WWF, 2014). Only if Gallery forests are cut the emission reduction targets cannot be met (red areas, which are forbidden by law).

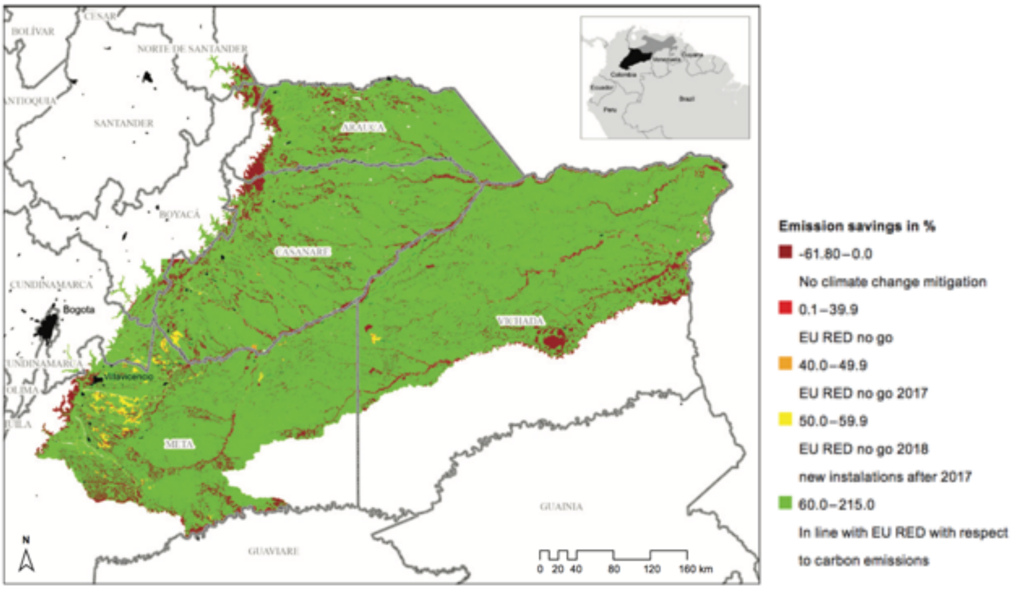

Figure 15: Potential GHG savings from biodiesel production in los llanos (WWF, 2014).

4.4 The EU RED directive for 2030 – change of methodology

The European Commission proposed a change of the current EU RED methodology (EC, 2016a, 2016b). The main differences in terms of GHG calculation are the higher value for fossil reference (94g CO_2eq /MJ instead of 83.8g CO_2eq/MJ), lower emission factors for methane (23 instead of 25 CO_2 eq) and dinitrogen oxide (296 instead of 298 CO_2 eq), the higher default emissions values for transport and distribution (6.9 instead of 5 g CO2 / MJ) and that the threshold of GHG savings increased to 70% for biofuels which are produced in installations starting operation after 1 January 2021.

The proposed changes also include the consideration of indirect land use change (iLUC) emissions. The iLUC has to be considered if the feedstock is not listed in part A of the annex (EC, 2016a) or if the feedstock production has led to direct land-use change, i.e. a change from one of the following IPCC land cover categories: forest land, grassland, wetlands, settlements, or other land, to cropland or perennial cropland. In the case of biodiesel from el Cimarrón no iLUC would be allocated, since the prior land use is "grassland". However, even if the default iLUC factor for oil crops of 55 g $CO2_{eq}$ per MJ (EC, 2016a, Annex VIII, part A) is included the GHG targets of 70% reduction are me.

The results using the newly proposed EU RED methodology for 2030 are indicated in Figure 16.

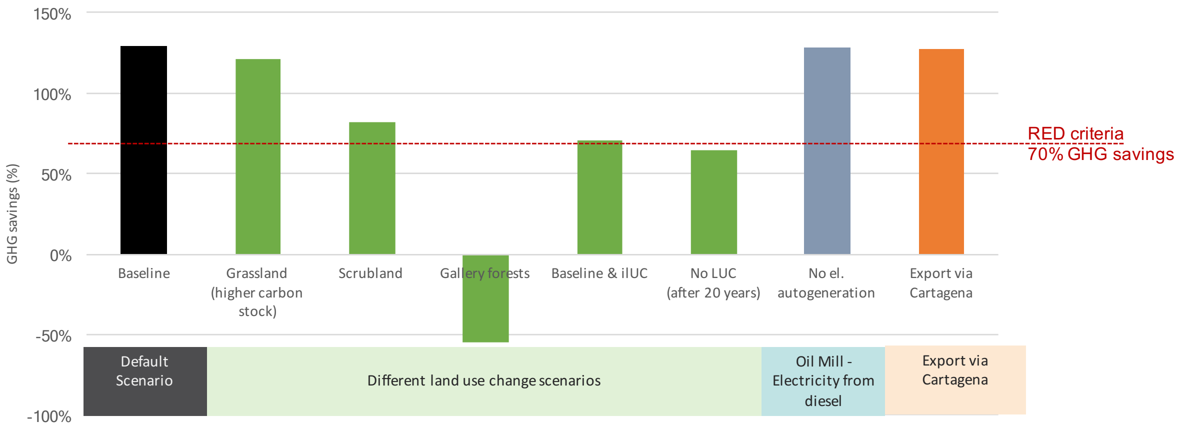

Figure 16: GHG emissions savings of biodiesel scenarios compared to fossil fuels (in %).

Figure 16 shows that also with the proposed update of the EU RED Directive the GHG criteria of 70% savings will be met. Only if gallery forest is cut and after 20 years of establishing the plantations the GHG savings are below 70%

4.5 Limitations

Prospective study: The oil palm plantations and biodiesel production plant are not yet established. Within this study realistic estimates were made and the sensitivity of key parameters was evaluated in order to provide an indication about the expected carbon footprint of el Cimarrón biodiesel. However, once the production system is implemented it is recommended to update the study with real data.

Direct and indirect land use change effects: This study assumes that the oil palm plantations are established on natural and extensively used grassland. Besides the direct LUC (considered in this study) also indirect land use change might occur due to the replacement of pastures. Further, it is also possible that minor parts of the 60.000 ha could trigger a conversion of agricultural land. In the present study potential indirect effects of replacing land pastures and agricultural land are not considered in the baseline scenario. It is assumed that the indirect effects are marginal, given the extensive use of the pastures and the huge potential of intensifying current cattle farming. In order to estimate the contribution of the potential iLUC effect on the overall results we included the iLUC factor proposed for oil crops proposed by the European commission, which represents a worst case scenario for the Colombian conditions.

Other environmental and socio-economic indicators: According to ISO 14040/44 a complete set of environmental indicator needs to be evaluated for comparative assertion. In the case of biofuels, several studies underlined the trade-off between GHG savings and increase impacts such as eutrophication[13] due to fertilizer application, ecotoxicity due to pesticide use, loss of biodiversity due to land transformation amongst others. The national study in Colombia revealed significant impacts of biofuels if also other environmental aspects are considered (CUE, 2012), while other studies show benefits (Gilroy et al., 2015). Further, also

[13] Eutrophication: the enrichment of a water body with nutrients which may result in an algae growth and an oxygen depletion.

other indicators about the social and economic impacts shall be considered for informed decision making. The impacts can be positive (e.g. create jobs) or negative (e.g. land rights of indigenous).

5 Conclusions and recommendations

5.1 Conclusion

- **Biodiesel from el Cimarrón is projected to fulfil the EU RED GHG criteria by showing 134 % less GHG emission as compared to fossil diesel.** This is based on the assumption that the oil palm plantations are established on low carbon-stock grassland, that the by-products are used optimally (e.g. for auto generation of electricity) and that the biodiesel is exported through Venezuela.
- **The GHG saving potential is sensitive to the land conversion.** Only if oil palm plantations are established on low carbon land, which is mainly the case in los Llanos, the GHG criteria can be met. If gallery forest are cut (forbidden by law) the biodiesel production is not compliant with the EU RED GHG criteria.
- **Economy of scale allows optimal use and treatment of by-products.** In terms of GHG balance, the treatment of POME and EFB is of special importance due to potential methane emissions during the treatment and decomposition.
- **Compliance with the proposed update of the EU RED directive for 2030.** Biodiesel production of el Cimarrón will also be compliant with the proposed GHG criteria of 70% savings for installations starting operation after 1 January 2021.

5.2 Recommendation and next steps

It is recommended to **design and implement the future biodiesel system of el Cimarrón taking the climate relevant factors into account**. These include

- Establishing oil palm plantations only on low carbon stock land and avoid indirect land use risks, by not expanding on agricultural land and keeping a buffer zone around gallery forests. Further, indirect land use effects can be mitigated if Prestige continues to produce the displaced crops and cattle, but with an increased efficiency. Intensification leads to a higher productivity and thus less land is required to produce the same amount of products.
- Efficient treatment of POME and EFB for composting, using a technology which avoids methane emissions due to aeration and turning.
- Optimize the transportation of the biofuel to Europe by using short routes (via Venezuela) and barge as a transportation means

It is recommended that **other environmental and socio-economic impacts and benefits are considered for decision making**. Of special importance are social and environmental aspects related to land use.

It is recommended that **the performance of the biodiesel production system in el Cimarrón is monitored and that the carbon footprint study is updated frequently and that the development of the EU RED directive is closely followed.**

6 Reference

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7 Annex

7.1 Annex I – Carbon Footprint of CPO sold in Europe

The CPO can also be sold on the international market instead of oil might be an interesting business opportunity for Prestige Colombia if sold on the international market.

Table 17: Carbon Footprint of CPO (g CO2eq / kg CPO) shipped to Europe

Stage	Amount	Unit	Source
Land transformation	-1 841	g CO2 / kg CPO	This study
Cultivation	316	g CO2 / kg CPO	This study
Oil Extraction	14	g CO2 / kg CPO	This study
Transport to Europe	192	g CO2 / kg CPO	This study
Total	**-1 319**	**g CO2 / kg CPO**	

The carbon footprint is dominated by the carbon sequestration during oil palm cultivation, while the main emission result from cultivation and transportation. The carbon footprint is in the same range as published in other literature for CPO in Colombia (Daigle & Gautreau-Daigle, 2001)(Castanheira, Acevedo, & Freire, 2014). Castanheira et al. (2014) published a range from -0.4 to – 1.7 kg CO_2eq kg^{1} palm oil if the oil palm is cultivated on former savanna land.

7.2 Annex II – Carbon Footprint of Margarine sold in Venezuela

The margarine production from palm stearin and palm kernel oil might be an interesting business opportunity for Prestige Colombia if sold on the Venezuelan market.

Margarine production process involves the deodorisation, bleaching and inter-esterification of oil. The carbon footprint data for margarine production from CPO is taken from literature (Nana Yaw, 2008). For each kg of margarine 1.0525 kg of CPO are used and the carbon footprint is specified in Table 18.

Table 18: Carbon Footprint of Margarine (kg CO2eq / kg margarine), including packaging

Stage	Amount	Unit	Source
Land transformation	-1 938.0	g CO2 / kg margarine	This study
Cultivation	332.8	g CO2 / kg margarine	This study
Oil Extraction	14.6	g CO2 / kg margarine	This study
Oil refinement	4.1	g CO2 / kg margarine	(Nana Yaw, 2008).
Margarine production	30.5	g CO2 / kg margarine	(Nana Yaw, 2008).
Transport to Venezuela	103.2	g CO2 / kg margarine	Estimate
Total	**-1 452.7**	**g CO2 / kg margarine**	

The margarine production causes relatively low GHG emissions compared to the oil palm cultivation and the transportation phase.