CHAPTER 6

LIFE CYCLE ANALYSIS
ENVIRONMENTAL STUDY

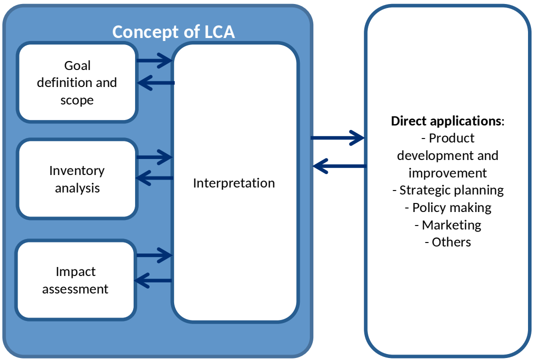
6.1 GOAL

The main goal of a Life cycle analysis —LCA— (in this particular case) is to study the environmental impacts of current Colombian Biofuels: sugarcane–based ethanol (EtOH), and palm oil-based biodiesel. This involves studying their complete life cycle, and their comparison with reference fossil fuels used in Colombia (regular gasoline and diesel fuel). Furthermore, LCA seeks to identify optimization potential for biofuel production in a more friendly way to the environment. Similar approaches have been considered in the literature and they have provided fruitful results for policy design (Khatiwada, Seabra, Silveira, & Walter, 2012). Finally, this LCA study proffers to gather some data to implement the Sustainability Quick Check for Biofuels tool (SQCB).

6.1.1 Methodology of LCA

With the purpose of evaluating the environmental performance of different biofuels, LCA was implemented based on the established regulations ISO 14040 and 14044 (ISO, 2006). LCA Methodology is a holistic approach to assess environmental impact related to the life cycle of the goods or service as a whole (C.A. Ramírez Triana, 2011). System boundaries for this study are defined by the biofuels production chains, extending from the very first agricultural stage, through to the final use of these biomass-based fuels within a regular vehicle. In addition, this study is implemented following the guidelines set by the Global Bioenergy Partnership (GBEP, 2009).

Figure 6.1. Four key stages in a LCA, according ISO 14040



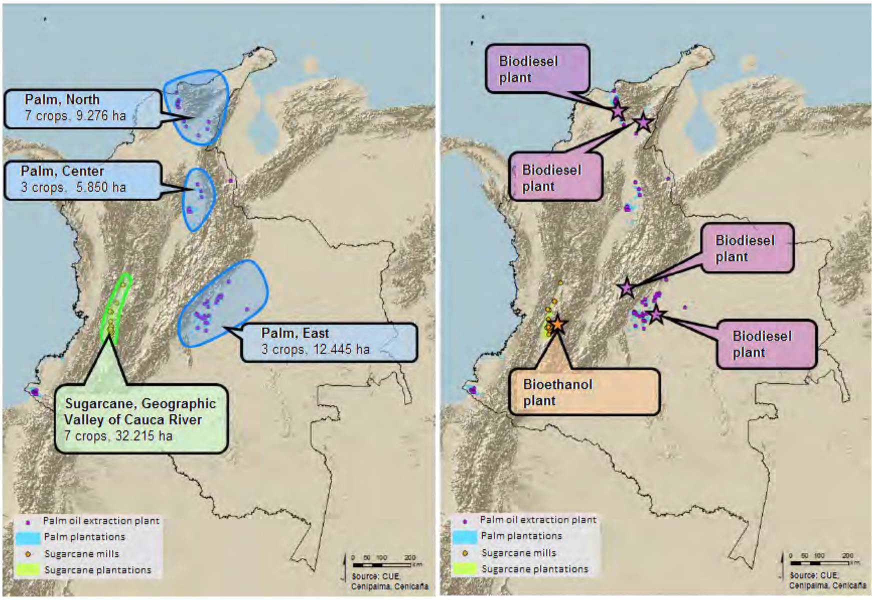
This LCA study requires a definition of the goal and a clear determination of scope. Once this has been established it is understood that the presented results are valid only for this particular goal and defined scope.

6.1.2 Scope

This study assessed the average environmental impact of biofuels in Colombia. Therefore, those results presented here do not reflect individual performance of the ongoing plantations, facilities or processing plants, in this way respecting any confidential information.

With the purpose of reflecting Colombian local context, primary data in the most representative locations was gathered (as presented in Figure 6.2 below). In the case of sugarcane the sample information presented here makes reference of 7 plantations areas (which is 24% of all the crops used for ethanol production), whereas in palm oil where selected 3, 4, and 3 plantations in the East, North and Central zones correspondingly (which is 26% of all the crops used for biodiesel production).

Figure 6.2. Studied areas for sugarcane and palm trees 2010



This information was gathered by Cenicaña and Cenipalma research teams and it applies for 2010, therefore the effect of "La niña" (a that time) was taken into consideration. IDEAM showed that "La Niña" had greatest impacts on the Cauca and Magdalena rivers, but it did not break down effect in every agricultural sector (IDEAM & MAVDT, 2011). This phenomenon had a repetition in 2011, with decreasing effects in a lesser extent in production indicators and increasing impact on regarding harvesting tasks (Cenicaña, 2012). Statistics gathered by Asocaña indicates that, from

2004 processed sugarcane has exhibited a decreasing trend, reaching a floor in 2008, and then fluctuated between 19.2 (in 2008) and 23.5 (in 2009) thousand tons, later on the level has tried to stabilize around 21.5 thousand tons (2013). Sugar production has followed the same trend as sugarcane, unlike ethanol production, which has been growing without interruptions since 2010 (291 million l/y) up to 2013 (387 million l/y) (ASOCAÑA, 2014). The sugarcane industry has been slowly recovering from this climatic effect.

Studied areas for sugarcane (green) and palm (blue) on the left side. Studied processing plants for manufacturing of ethanol (orange) and biodiesel (purple), on the right side.

Functional unit

Neat biofuels (pure bioethanol E100, and pure biodiesel B100), and different biofuel blends (90% regular gasoline and 10% ethanol E10, and 90% regular diesel fuel and 10% biodiesel, B10) are compared with fossil fuels (gasoline and diesel, for specifications see table 88) in different categories:

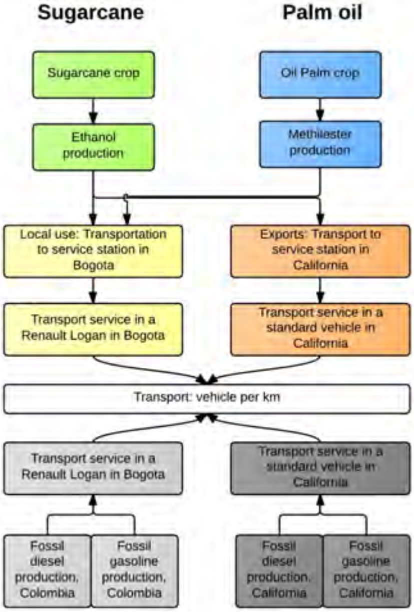
Energy unit at the delivery point (MJ)
Consumption per driven kilometer in an average vehicle in Colombia (Renault Logan) and in the Unites States of America (in a standard passenger vehicle).

The main target of the study is to compare different fuels instead of comparing different vehicles. Such comparison is only possible if vehicles properties are identical in terms of aerodynamics, weight and energy consumption. The best option is to choose a vehicle for which it is possible to obtain manufacture and performance information with both diesel and gasoline engines under different blend levels of biofuel. In Colombia, the Renault Logan is widely used and it can be driven with different motor units.

Limits of the system

The figure below presents a general vision of the processes for comparison. In this study, limits or boundaries of this system are defined by the whole biofuel production chain, from agricultural feedstock production to final use of biofuels in a car, including intermediate steps. In addition, it includes the edification process, maintenance and recycling / final disposal of infrastructure, including buildings and roads.

Figure 6.3. General overview of compared systems: Bioenergy and fossil energy



Scope in time

In this study the reference year regarding land use change (LUC) is 2000 while the baseyear changes in technology of processes was 2009. The year 2000 was chosen due to the availability of land use maps in Colombia (used in the Geographic Information System). Furthermore, the year 2000 can act as a good reference year given that it avoids deforestation processes or substantial changes (replacement) within the vegetable cover in natural conservation areas, due to the setting of new projects. In 2000, no biofuel processing plant had been authorized, and so, along with the availability of data the selection of such year is justified.

With the purpose of proving optimization potential, considered within this study are such technologies that might be implemented in the near future. This study considered the LCA implemented by ECOPETROL in regards to fossil fuels production and use, which was designed for the refining scheme of the year 2008 in the refining plant in Barrancabermeja.

Therefore in this doctoral thesis is presented how the current trends of production of biofuels in Colombia, can create impacts (cradle-to-grave) along the manufacture and distribution chains, having into the account forefront technologies (within the national context). In contrast to some other studies, like

Geographic Scope

In this study the scope is national as was mentioned in the main goal of this section, the set of data is representative for Colombian conditions. Notwithstanding, it is important to bear in mind that these results reflect a national average and cannot be associated with individual crops arrays or processing plants.

Allocation method

In the biofuel value chain the production of several by-products is substantial (like palm kernel cake, compost, and electricity, among others). Therefore, as the environmental loads (e.g. Biochemical Oxygen Demand - BOD, Kilowatts per hour – Kwh, CO2, Particulate matter – PM, waste, etc.) are not registered specifically for each product and by-product (i.e. wastes from cutting tasks, bagasse, vinasses, sugar, etc.) it is necessary to distribute these loads between these product and by–products in each stage of the value chain, which is known as "allocation". Thus, due to the fact that products and by–products of the biofuel value chain possess different functions (for instance, some by-products are used for energy purposes and some others for nutrients recycling), the economic allocation method was considered the more suitable one. However, an energy allocation was carried out to analyze the sensibility of the allocation method.

6.1.3 Information for the inventory

In the analysis of the Life Cycle Inventory (LCI) are quantified materials and energy flows for the systems processes. Through the evaluation of all inputs and outputs the interchange within the systems can be evaluated and compared with the environment and therefore their impacts.

Within this study, the consumption of all raw materials, inputs, energy, emissions and residual wastes are considered. In addition, transportation distances, infrastructure and land requirements are also included.

Types and data sources

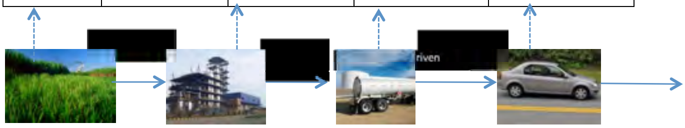
In general, the inventory of the employed data can be broken down in primary and secondary data. Primary data is related specifically with the production system, and they are real and verified, collected directly in the field, through interviews with experts and/or use of relevant publications. The figure below provides a general vision on the sources of specific data.

Secondary data is not directly related with the production system, so they are brought from generic data bases from the LCA. Some examples of this data are fertilizers production or electricity generation. In this particular case the secondary data are obtained from the data base LCA of Ecoinvent v 2.2 (Hischier et al., 2010). Ecoinvent is the most complete and transparent international data base regarding LCI information, and all pieces of information from this data base are established as having high quality standards.

Furthermore, this study adapted and incorporated the SQCB tool, which employs its own values by default (Faist Emmenegger, Reinhard, & Zah, 2009). With the use of this tool it is also possible to calculate potential impacts following the guidelines of the European Renewable Energy Directive, RED (EC, 2008)

Figure 6.4. Inventory data sources for specific processes Specific data

	Specific data			
	1. Cultivation	2. Processing	3. Transportation to pumping station	4. Use/transportation
Information sources	Field questionnaires Interviews with experts: Cenipalma/Cenicaña Emission models Literature	Field questionnaires Interviews with experts: Cenipalma/Cenicaña Literature	Transportation distances: GIS Transportation vehicles: Interviews with experts Literature	Interviews with experts (Renault) Literature



Generic data / standard values

LCA: Ecoinvent database (for example: fertilizers production, infrastructure, etc.)

Methodology to establish all the inventory data consisted in collecting information in the field from different sources and collecting different perspectives. Data obtained from different sources were consolidated by an expert and later validated. In addition this data were verified by experts from some of the involved stakeholders (in particular CENICAÑA and CENIPALMA)[1].

In the upcoming section is going to explain briefly, and in a general way, the nature of

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[1] Thus, it is noted that such primary data comes from external institutions and are not the result of this particular research. There is a positive effect from this circumstance which is the adaptation of a well–known methodology with regional data, therefore results and conclusions may be more accurate. On the other hand there may be a risk of lack of rigour in the building of the database whose construction is not given in complete detail.

these different sources:

- Field data: some field data was obtained through interviews with selected farmers and engineers from processing plants, using a selection of representative farms and manufacturing plants. This data was prepared by the consortium CUE.
- Selection of farms: Made in each region a selection of farms based on their representation. Considered were farms that provide feedstock for biofuels production exclusively. Methodology and selection criteria for both sugarcane and palm oils crops will be described further down.
- Sample size: Sampling included approximately 20% of cultivated area (for both sugarcane and palm oil trees crops) and 80% of biofuel processing plants at national level, and it considered the following activities:
  - Literature review: secondary data were obtained from several sources
  - Interview with experts: experts were consulted when data in literature was not available or the nature of data required doing so.
  - Consolidation by Experts: Inventory data review was managed by the experts from the consortium, with the purpose of guaranteeing integrity and consistency in the information.

Emission models (on field)

Recent studies on LCA (UNEP. Biofuels Working Group & Management, 2009) unveil that biofuel impact is frequently determined by diverse emissions in the cultivation stage, mainly related with the use of fertilizers among other agro-chemical boosters.

Air emissions, such as N2O or NOx were calculated based on the formulas proposed by the IPCC (De Klein et al., 2006; IPCC, 2006).

$$NO_2 = \tfrac{44}{28} \times (0.01 N_{tot} + N_{cr}) + 0.01 \times \tfrac{14}{17} \times NH_3 + 0.0075 \times \tfrac{14}{62} \times NO_3$$

$$NO_2 = \text{Nitrogen emission } (Kg\, NO_2/ha)$$

$$N_{tot} = \text{Total Nitrogen in mineral and organic fertilizers}$$

$$N_{cr} = \text{Content of Nitrogen in residuals}$$

$$NH_3 = \text{Losses of Nitrogen in form of ammonia}$$

$$NO_{3-} = \text{Losses of nitrogen in form of Nitrate}$$

$$NO_x = 0.21 \times NO_2$$

For sugarcane and palm oil, agricultural wastes were only considered as emissions of N_2O and NO_x, thus some other types of emissions are left out following recommendations of Ecoinvent.

Emissions of NH_3 of those mineral fertilizers applied to crop lands are calculated with emissions factors that are previously determined for each group of fertilizers. Instead of suggested emission factors presented in the model (Agrammon, 2009) (i.e. 15% for urea and 2% for all the other mineral fertilizers) it applied a set of emission factors that include a larger number of fertilizers groups (Asman, 1992). Organic fertilizers are calculated by using values proposed by the Agrammon group, while the correction factors are left out.

Table 6.1. Emissions of NH3 - Mineral fertilizers (% of N emitted in form of NH3)

Type of fertilizer	Emission factor per NH3 - N (%)
ammonium nitrate, calcium ammonium nitrate	2
Sulphate of Ammonia	8
Urea	15
Multi-nutrient fertilizers (NPK-, NP-, NK-fertilizers)	4
Urea Ammonium Nitrate	8.5
Liquid ammonia	3

Source (Agrammon, 2009)

Water and land pollution by cause of nitrates and phosphorous is calculated following the method of (Faist Emmenegger et al., 2009), taking into account parameters by region, such as climate and land type. Land pollution by metals was modeled as the difference between heavy metals (concentration levels in pesticides and fertilizers) and absorption levels within the crops. As referenced by (Jungbluth et al., 2007).

Land Use Change (LUC)

Carbon emissions due to Land Use Change (LUC), are calculated based on the methodology proposed in level 1 of the IPCC document (IPCC, 2006).

The change in carbon stock is calculated as the difference between:

- the content of carbon in the superficial biomass above ground (AGB) level,
- biomass below ground level (BGB),
- decomposed organic matter (DOM)

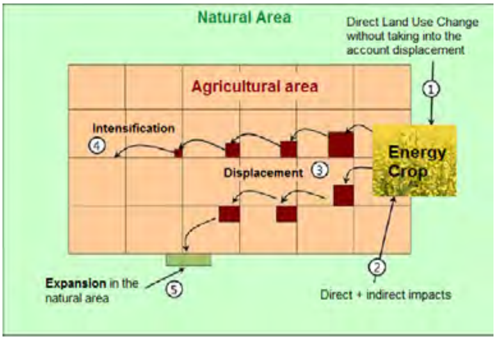
- and soil organic carbon (SOC), before and after sugarcane and palm oil plantations.

Changes in stocks are evaluated in a period of 20 years (which is the standard in the IPCC/EU). The reference year is 2000, and therefore it did not consider the LUC caused by plantations established before 2000.

Analysis of the indirect land use change (iLUC)

The debate around "food vs fuel" was the trigger that led to the concept of Indirect Land Use Change (iLUC), and despite the fact that neither LCA nor carbon footprint (CF) studies require its inclusion it is relevant to present a complete picture in terms of the environmental balance of bioenergy products (Finkbeiner, 2014). Such effect is produced when an additional crop emerges, and such is established in a land that was previously used for some other crops, and not in land that was not cultivated (when a direct displacement of some agricultural activity ends up somewhere else and when diversion of crops to other uses adds pressure on land demand) (Wicke, Verweij, van Meijl, van Vuuren, & Faaij, 2012). Thus, unlike direct LUC the iLUC effects (ecological, environmental, social or economic) cannot be linked to the production unit (van Dam, Junginger, & Faaij, 2010). In this case, the direct effect on the carbon balance can turn positive (quite often), when it passes from extensive land activity, such as grazing, to a tree crop (such as happens in the case of palm oil).

Figure 6.5. Illustration of the indirect land use change (iLUC)



Source: CUE (2012)

Nonetheless, the former activity is moved somewhere else, to other zones, creating a series of subsequent displacements. Displacement can take place locally, when adjacent farmers begin to cultivate the displaced product, with the purpose of satisfying the demand within the local market. Displacement can also take place on a larger scale, if the displaced product satisfies not only a domestic demand but also one at global scale.

Finally, the additional demand for the agricultural area is satisfied by the intensification of production, or the expansion can take place in non-cultivated areas. The extent of these effects, along with land tenure and other social impacts, depends highly on governance strategies. For instance, they can be reduced by establishing new plantations in degraded lands and by directing some research efforts to increase yield productivity and land management schemes (Wicke, Sikkema, Dornburg, & Faaij, 2011).

For this project it was assumed that displaced products are produced somewhere else in another region in Colombia. For instance, if palm crops are being extended to grazing land, the corresponding amount of livestock that used to feed in this zone are moved to a marginal zone occupying the same area, if it is assumed expansion is 100%. If, on the contrary it assumed 100% of intensification, the displaced livestock will be kept in the rest of the terrain, without moving to any other natural areas, but, of course, density per area will be increased. The actual scenario will be somewhere between these two possibilities. For this study it was assumed the extreme case of 100% expansion as the worst case scenario. Nonetheless, it must be discussed in detail, to what extent the expansion effect can be overlapped by intensification practices. This study presents these two extreme cases, the effect of iLUC, and indirect expansion in natural areas, with the purpose of reflecting the magnitude of impact.

Biofuel crop cultivation takes place in zones of wet tropical forest and tropical jungles. In the northeast there are possible expansions of livestock farming initiatives to tropical bushes. As a consequence, indirect effects of assuming 100% expansion in these three eco-zones were calculated.

On the other hand, the production of additional grass due to an increase in biofuel feedstock crop increase and their indirect effects were not taken into consideration.

There are indicated primary production areas (striped area) and main potential areas for expansion (dotted areas). Vegetation zones are defined by FAO for the guidelines of IPCC (IPCC, 2006) and the expansion potential areas are based on interviews with experts.

Contrary to these, there could be indirect effects of land use by changing the use of a resource. As an illustration, the use of sugarcane for producing ethanol is affecting sugar exports. Mechanisms and consequences of a potential decrease in exports are highly uncertain, and the potential implication could be the expansion of sugarcane somewhere else, leading to iLUC effects. In the same way this could happen for the palm oil case. It is really important to highlight that the iLUC effect was measured in order to set a reference case, however, there are some scholars, such as Mathews and Tan, that ask for caution in the conclusions in this regard because badly defined assumptions can mislead policy decisions regarding biofuel promotion (Mathews & Tan, 2009b).

6.1.4 Assessment of the environmental impact

The stage of Life Cycle Impact Assessment (LCIA) is the third evaluation stage of the LCA. The purpose of the LCIA is to provide additional information to measure results for the LCI for the production system, with the aim of gaining a better understanding of its environmental meaning (ISO, 2006).

In order to establish the impact of Colombian biofuels into the environment, this study selected and quantified those possible impacts that are in the category of Global Warming Potential (GWP) and Cumulative Energy Demand (CED). (This step is called indicator selection). Once these indicators are selected, results of LCI are allocated to the mentioned categories of impact in regards to environmental contribution capacity of the substances (Classification step).

In the next stage, the impact of each emission is modeled quantitatively according to the characterization mechanism. Impact was expressed as a mark of impact in a common unit for all the components of a particular category of impact through the application of characterization factors (for example: kg CO2 equivalent for GHG's that contribute to climate change). A characterization factor is a specific factor of a particular substance calculated with a characterization model to express the impact of flows of an element regarding the common unit of the category indicator.

The last report of Assessing Biofuels of the UNEP was taken into consideration, in which it is stressed the need of implementing bigger efforts to include not only the effects on the GHG's, but also some other impacts such as eutrophication and acidification, to be as complete as possible. Assessments of different environmental impacts include several middle point indicators (acidification, eutrophication, and eco-toxicity) and some totally agglomerated impacts (end point indicators). A selection of additional impact indicators provide complementary perspectives in regards to potential benefits and challenges to be faced by biofuel industry.

6.1.5 Interpretation

Interpretation of the environmental impacts of the LCA is the final stage of this process, in which the results of a LCI or LCIA, or both, are summarized and commented for final conclusions, recommendations and decision-making guidance under the framework drawn by the goal and scope of this study. These steps also include a sensitivity analysis on:

a. production
b. technology level
c. allocation methods and
d. indirect Land Use Change (iLUC).

6.1.6 Limitations of the study

The assessment of environmental impacts in the life cycle in general requires a large set of data and assumptions for the model. Through the recompilation of real field values for steps of the life cycle —such as cultivation and processing— and through the state-of-the-art emission models, an effort to maximize data accuracy was made.

The LCA is static and it reflects impacts of cultivation and processing of sugarcane and palm oil in 2009. With the optimized scenario were included improvement possibilities in the study. Nevertheless, results are not valid for any other sort of processing technology for biofuel production, nor for future feedstocks crops.

Furthermore, the goal of this study is to represent an average national impact of biofuel production, and therefore results do not represent individual cases (i.e. feedstock production from organic crops is not included and presumably would have different impacts).

Even though this study is quite wide, some environmental factors were left out. For instance, the impact on fresh water caused by biofuel feedstock cultivation is not considered within the LCA study, but it is approached in the following chapter (see Expansion potential).

Environmental aspects such as eutrophication, ecotoxicity and some other issues have been covered in a study implemented by a research deparment of the UPB (Universidad Pontificia Bolivariana) and are presented in appendix 9.4.

Albeit the LCA methodology is suitable to assess environmental sustainability, it is not the best to evaluate a social context in which these bioenergy initiatives are implemented. It is also not suitable to determine unchained socio-economic effects caused. With the purpose of obtaining a complete vision on sustainability, results on LCA must be interpreted in conjunction with some other tools of assessment.

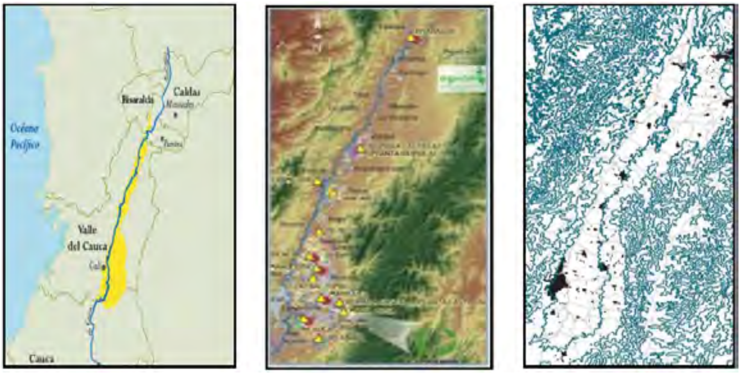
6.2 INVENTORY ANALYSIS

Within the following section are presented the analysis of LCI, which combines input/output data in relation with the system under study (i.e. sugarcane-based ethanol and palm oil-base biodiesel).

6.2.1 Sugarcane crop

Sugarcane (Saccharum officinarum) is a perennial grass of tropical height and it comes from the south of Asia and Southeast Asia. Sugarcane has a carbon fixation path C4, with the same as the rest of grasses, and it is able to turn up to 1% of incident solar energy into biomass (James, 2007). There are some branched stems normally between 2m and 4m high (or even higher) and approximately 5cm diameter. Sugarcane is cultivated regularly in tropical and subtropical lands with commercial purposes, with high preference for solar irradiation and evenly distributed rainwater (or irrigation water) during the growth process. Nevertheless, the stage previous to harvest (when cane is ripening) weather must be relatively dry. Hours of sunlight must be abundant during the whole agricultural process (James, 2007).

Figure 6.6. Geographic location of the sugarcane plantation area



In 1564 sugarcane was brought to Cali, Colombia by Sebastian de Belacazar and later on was spread from there to all the basin of the Cauca River (CENICAÑA, 2011). The geographic valley of the Cauca River is very suitable for sugarcane production due to high solar exposure all year round and favorable rain conditions. Sugarcane expansion took place in a period that was known as "la violencia" between 1946 and 1958, leading to the consolidation of its control over the Colombian sugar market (Mondragón, 2007). Today, cultivation of sugarcane occupies near to 216,768 hectares, of which 24% are owned by the ingenios (sugarcane processing plants) and 76% to individual sugarcane farmers (Asocaña, 2010).

Selection of the study location

The main goal of this part of the study is to establish representative results for LCA, which reflect average sugarcane production in Colombia and in addition they reveal variations of results depending on different cultivation methods. With the purpose of establishing representative inventories, selection of locations of study in the geographic valley of Cauca River was based on the following criteria:

1. Sampled crops deliver sugarcane to at least one of the five processing plants that produced ethanol in 2009.
2. The crop area is representative in term of agro-ecologic features (soil type and humidity)
3. The crop area is representative regarding average size.

Criterion 1: Plantations suppliers of ethanol plants only
Within the total plantation area for sugarcane (216,768 hectare s) the study only considered those crops that supply sugarcane for sugar ingenios with an attached ethanol processing plant (134,006 hectare s), while some other sugarcane crops do not create an environmental impact in terms of the sugarcane-based ethanol production. In the following table are presented the areas of these 5 ethanol producing companies in the Cauca Valley.

Table 6.2. Ethanol producing companies in Colombia

Process	E001*	E002*	E003*	E004	E005	Total
Ethanol production (thou l/d)	300	250	250	150	100	1050
Total cultivated area (ha)	38883	30723	27735	22510	14155	134006

Source: (Asocaña, 2010)

Sugarcane from these 134,006 hectare s is delivered to the processing plants, reflecting 62% of the total area dedicated to sugarcane cultivation. Approximately 37,000 hectare s (28%) out of 134,006are dedicated to ethanol production. In the selected sample for this study were visited 3 of the main firms (noted with asterisk in the previous table). Selected firms represent the 45% of the total cultivated area and 72% of the area that supply ingenios with attached ethanol processing plant.

Table 6.3. Selection of agro-ecological zones

Type of soil	Humidity	E001	E002	E003	Total
10	H3	1002	778	613	2393
10	H5	2162	-	20	2182
11	H0	804	3048	5586	9438
11	H3	6023	-	-	6023
18	H0	52	725	689	1466
5	H5	859	-	-	859
6	H1	1843	9821	5308	16972
-	Total	12745	14372	12216	39333

Source: Based on Cenicaña website

Criterion 2: Selection of representative agro-ecologic zones (soil type and humidity)
The study selected the most representative agro-ecologic zones based on soil type and humidity conditions. In general there are 238 different types of soil and 6 kinds of humidity. Nonetheless, / agro-ecologic zones represent a 29% of the 134,006 hectares.

Criterion 3: Selection of the largest cultivation areas
In order to select those crops that constitute part of this study, size was used as criterion of classification. Those farms with the largest extension of land in each agro-ecological zone were selected. At the end, 9 farms were selected, and 7 of them successfully interview. The information collection tool covers a total area of 32,215 hectares, representing 24% of the total area.

Table 6.4. Identification of specific location (for ethanol production)

Type of soil	Humidity	E001	Number	E002	Number	E003	Number	Total
10	H3			778	C001			778
10	H5	2162	C007					2162
11	H0			3048	C001	48	C003	7506
						10	C005	
						4400	C004	
11	H3	6000	C006					6000
18	H0			353	C001			353
5	H5	838	C007					838
6	H1			274	C002	73	C003	14578
				9821	C001	10	C005	
						4400	C004	
	Total	9000		14274		8941		32215

Source: CUE based on Cenicaña

The table below gives a summary of exclusion criteria (formerly described) and their corresponding representation is expressed as a percentage.

Table 6.5. General information on the studied location (for ethanol production)

Criteria	Area (ha)	% of total area	% of EtOH area
Total area (excluding infrastructure)	216768	100%	-
Criterion 1: 5 ethanol firms (total area)	134006	62%	100%
Ethanol firms: area for EtOH	37000	17%	28%
Criterion 2: Soils and representative humidity	39333	18%	29%
Criterion 3: Representative cultivation area	32215	15%	24%

Source: CUE based on Cenicaña

Data assessment

All the data drawn from these 7 questionnaires were modeled independently and therefore analyzed the specific impact of each location. In addition, this data was aggregated with the purpose of building set of averages, representative for all the geographic valley of Cauca River region. Aggregation of information of individual locations to form an average, was undertaken by employing a weight factor based on the plantation area within the sample. This method allows expressing the whole range of parameters at inventory level (i.e. N-fertilizer: 50-100 kg/ha/year, or transportation distance between 5 to 15 km) and of environmental impact (this is CO2 emissions: 1-2 kg/kg of sugarcane).

Table 6.6. Area and weighting factor within the selected studied locations

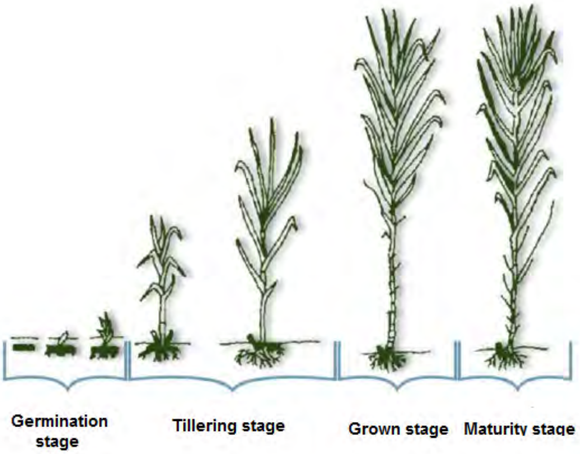
Parameter	Questionnaire						
	C001	C002	C003	C004	C005	C006	C007
Agro-ecologic zone	10H3 11H0 6H1 18H0	10H3 11H0 6H1 18H2	10H3 11H0 6H1 18H3	10H3 11H0 6H1 18H4	10H3 11H0 6H1 18H5	10H3 11H0 6H1 18H7	10H3 11H0 6H1 18H8
Yield (ton/ha/y)	114,9	121,9	142	118,6	142	110,7	90,7
Area (ha)	14000	274	120,9	8800	20,3	6023	3000
Weighting factor (%)	43,4%	0,8%	0,4%	27,3%	0,1%	18,7%	9,3%

Source Cenicaña

Agriculture production system

The most common system for sugarcane cultivation is the row array, either in flat lands or slight hills. Before planting, land is prepared by removing roots and rocks, and if necessary, the required slope is created, and soil conditions improved. Once terrain is prepared cane sprouts introduced into the ground (vegetative reproduction), and the crop cycle starts (Ellis & Merry, 2007). Crop cycles can be broken down into 4 different phases:

Figure 6.7. Sugarcane crop cycle



Source: (Netafim, 2011a)

The germination phase starts around 7 to 10 days after sprouts have been sown, and lasts between 30 to 35 days until germination is completed. Then follows the tillering phase, and it lasts up to 120 days, and is a physiologic process of repeated underground branching. That is immediately followed by the growth phase, and it lasts approximately 270 days. During this stage sugarcane stems are stabilized. Ripening phase is the last stage, and it lasts near to three months, and the vegetative growth is reduced while the sugar synthesis takes place along with a rapid accumulation of sucrose. As the ripening progresses, those sugars in simple forms (monosaccharide compounds like fructose and glucose) are turned into proper sugar (sucrose, which is a disaccharide). Ripening of sugarcane happens from the bottom to the top, therefore the lower part contains much more sugar compounds than the upper section. Sunny, warm days and clear night skies(i.e. more temperature variation during the day) along with dry weather are highly favorable for this ripening process (Netafim, 2011a).

After the ripening phase, which took between 12 to 13 months after sowing, sugar cane can be cut and collected. Right after this step the shoots produce a new set of stems without need of replanting. New sprouts grow and develop, while old roots die and rot. So, each crop is maintained by water and nutrients from its own system of roots. The issue that emerges in this practice is that with each cycle, soil loses its structure and it gets compacted by intense mechanization. Inclination mentioned earlier in the land preparation step no longer exists, or it is vastly reduced by the second or third cycle; therefore:

- storage and movement of air and water can be diminished,
- the content of salt and sodium in soil increases,
- roots are easily damaged by the collection equipment and,
- in general sense, plants are more vulnerable to plagues and diseases, so their exposure to them is more costly.

Table 6.7. Sugarcane crop cycle (Cauca Valley River)

Area and weighting factor within the selected studied locations								
Parameter	Questionnaire							Average
	C001	C002	C003	C004	C005	C006	C007	
Agro-ecologic zone	10H3 11H0 6H1 18H0	6H1	11H0 6H1	11H1 6H2	11H2 6H3	11H3	10H5 5H5	
Cuts (times)	8	9	5	5	5	5	5	6
Average (months)	13,5	12,7	13	13	13	12	12	12,7
Area (ha)	14000	274	121	8800	20	6023	3000	
Weighting factor (%)	43,4%	0,8%	0,4%	27,3%	0,1%	18,7%	9,3%	100,0%

Source: CUE from data field

In conclusion, a proper root system formation is more difficult to obtain for further shoots in future cycles, reducing the potential population of plants along with the yield to the extent that it is less expensive to start all over again (Ellis & Merry, 2007). As is shown in the table below, average crop cycle in the geographic valley of Cauca River takes between 11 to 13 months and depending on location, sugarcane can complete from 5 up to 9 cycles.

Table 6.8. Sugarcane Collection method within de geographic Valley of Cauca River

Parameter	Questionnaire							Average
	C001	C002	C003	C004	C005	C006	C007	
Agro-ecologic zone	10H3 11H0 6H1 18H0	6H1	11H0 6H1	11H1 6H2	11H2 6H3	11H3	10H5 5H5	
Burning	70%	70%	70%	70%	70%	70%	70%	70%
No-burning	30%	30%	30%	30%	30%	30%	30%	30%
Manual	55%	100%	100%	50%	0%	79%	79%	66%
Machinery	0%	0%	0%	50%	100%	21%	21%	34%

Source: Cenicaña

Biomass of remaining foliar material that comes from crops varies depending on the type of sugarcane that has been used, therefore the self-destruction and the ratio of mass leave/stem might have significant effect in collection costs and following performance tasks. Crop burning, right before harvesting, eliminates most of dead vegetation without creating a substantial impact in the inner part of the plant, and it also gets rid of potential plagues of hazardous species that can represent a threat to sugarcane cutters (James, 2007). This burning practice is widely utilized in Colombia as can be seen here.

Collection can be implemented through manual labor, or it can be done mechanically. When this task is done manually it implies that sugarcane is cut with a machete after the burning process, or otherwise when still unripe. Manual harvesting process requires trained labor, given that inadequate collection leads to yield loss, deficiencies in juice quality and problems during milling process due to presence of alien materials. In most areas, nevertheless, the cut of unripe sugarcane contains higher levels of alien materials (earth, leaves, and other material without sucrose content) that the harvest that has gone thought the burning process (James, 2007).

If the ratooning process is implemented (which is the agricultural practice of using sugarcane shoots from a previous cycle, as described earlier), then it is preferred to use manual cutting, rather than mechanic methods, given that mechanical equipment tends to destroy roots and the likelihood of soil compaction increases. Furthermore, collection with mechanical axes is directly proportional to higher levels of strange material, in comparison with the manual method. Notwithstanding, when the price of labor is high or labor otherwise scarce, mechanic methods can become financially feasible and attractive (James, 2007).

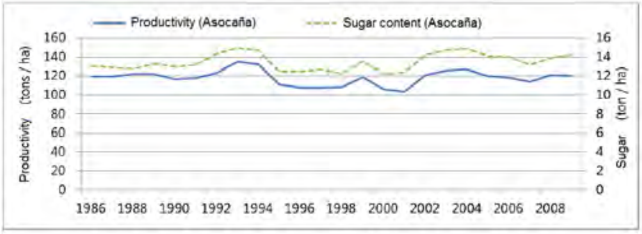
Once harvest is done, cut stems are loaded and transported to the ingenio (or milling plant), and the land is left to rest after the last cycle corresponding with the collection of the last ratoon.

Productivity

Due to favorable climatic conditions and good agricultural practices, Colombia produces a high yield of 14.6 tons of sugar per ha/year; and annual average yield is near to 120 tons of sugarcane/ha/year in the north of the Geographic Valley of the Cauca River, 127 ton/h/y in the center and 105 ton/ha/y in the south of this region (Asocaña, 2010). Productivity values provided by ASOCAÑA are of 120 tons of sugarcane per ha for 2009 and 117.6 tons of sugarcane per ha as average between 2000 and 2009 (Asocaña, 2010).

Annual variation of production can be explained by changing weather conditions, whereas agricultural practices have not experienced any great modification. Due to fluctuation of annual productivity, average yield values from 2000 to 2009 were taken for this study. As shown below, productivity of selected plantations varied between 91 and 142 ton/ha/year with an average of 114 ton/ha (weighted average regarding the zone).

Table 6.9. Sugarcane yield and sugar yield



Source: (Asocaña, 2010)

Table 6.10. Sugarcane yield for the assessed plantation sites

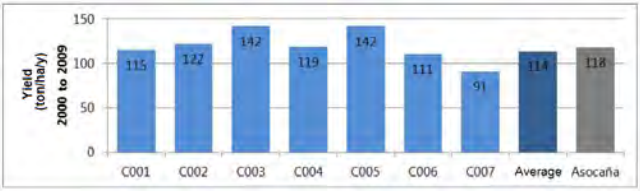
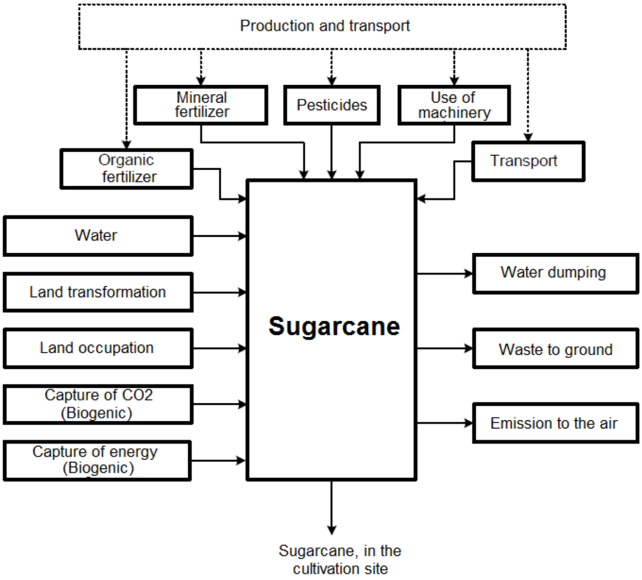


Table 6.11. Sugarcane inventory overview



System characterization

Here, there are illustrated inputs that are used for the sugarcane crop and emission. Individual flows are described in upcoming sections.

Feedstock and supplementary raw materials

Seedlings

In commercial plantations of sugarcane the method of vegetative propagation is implemented, if the stems are cut in three scions they sprout out before being covered. All these sprouts germinate in an array of continuous rows of uniform growth. For manual planting, densely sown ranges go from 5 to 10 seeds of sugarcane per hectare. For this study, it was assumed extreme condition of 10 tons sugarcane seed per hectare. The use of cuts is included in the calculation of productivity of sugarcane, throughout yield reduction.

Fertilizers application

With the purpose of offsetting nutrient loss after the harvest, sugarcane crops are fertilized and in the case of plagues and diseases some measures of bio-control are implemented. Typical fertilizes are urea, Diammonium phosphate —DAP—, Ferticaña, vinasses, compost and are presented by hectare in the next table.

Table 6.12. Fertilizer application in studied locations (kg/ha/y)

Entry	Questionnaire							Average
Mineral fertilizer	C001	C002	C003	C004	C005	C006	C007	
Urea	400	0	369	369	323	160	160	321
KCL	0	95	92	0	92	0	0	1
DAP	0	0	0	0	0	25	25	7
Boron and Zinc	0	0	0	0	0	0	0	0
Boron and Zinc (liq)	0	0	0	0	0	0	0	0
Zinc Sulphur	0	24	0	0	0	0	0	0
Zinc Sulphate	0	5	0	0	0	0	0	0
SAM	156	0	0	0	0	0	0	68
Calphos	0	0	0	0	0	0	45	4
Agricultural lime (calcium carbonate)	0	0	0	0	0	0	594	55
Organic fertilizer								
Vinasse 35%	0	0	0	0	0	5825	5825	1625
Compost	0	0	0	0	0	8000	8000	2232
Chicken manure	0	1421	0	0	0	0	0	13
Ferticaña*	1	0	1	0	0	0	0	0
Crop residuals	44444	47368	50769	50769	50769	55000	55000	49218
Total N	227,6	12,8	169,9	169,8	148,6	105,2	105,2	176
Total P2O5	6,4	0	0	0	0	0	0	3
Total K2O	0,1	0	0	0	0	0	0	0
Weighting	43,5%	0,9%	0,4%	27,3%	0,1%	18,6%	9,3%	100%

Source: Cenicaña; * Assessment unit: lt/ha/year

The amount of nutrients applied to the field is shown in the table below, and it is compared with the values and recommendations from the literature.

Table 6.13. Recommended dose of fertilizers (N-P-K) for sugarcane crops. Assessment unit kg/ha/y

Description		N	P2O5	K2O
Geographic Valley of Cauca River (Colombia)	Minimum (a)	13	0	0
	Average (a)	176	12	52
	Maximum (a)	227	37	183
Organic crop (Colombia) (b)		50-100	60-120	60-150
Cenicaña (Colombia) (c)		40-175	0-50	0-100
Ecoinvent (Brazil) (d)		55	51	101

Source: (a) Data from field, (b) www.sugarcanecrops.com/agronomic_practices/fertigation (c) www.cenicana.org/pdf/documentos_no_seriados/libro_el_cultivo_cana/libro_p153-177.pdf (d) Ecoinvent

Biological control and pesticides application

Within last years, biological control of plagues and diseases has gained great importance. In particular, in the study locations stingless wasps, or Trichrogramma, are used, along with some Nitrogen fixing organisms and some species of Tachinidae (true flies). Nonetheless, in order to avoid plagues and diseases in vast monoculture fields, use of pesticides and chemicals is common practice.

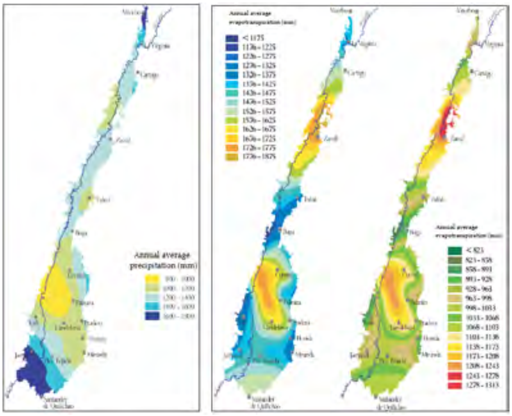
Table 6.14. Pesticides application per year and hectare

Entry of pesticide / herbicide	C001	C002	C003	C004	C005	C006	C007	Average
Glyphosate (kg/ha)	-	-	-	-	-	1,4	1,6	0,41
Roundup 747 (Glyphosphate) (kg/ha)	-	0,3	0,4	0,4	0,4	-	-	0,12
Sulphur (kg/ha)	-	18,8	-	-	-	-	-	0,16
Roundup (kg/ha)	-	-	-	1,3	-	-	-	0,36
Gasapax (l/ha)	1,1	1,2	0,8	0,8	0,8	-	-	0,70
Larmex (kg/ha)	1,8	-	1,2	1,2	1,2	-	-	1,11
Terbutryn (l/ha)	0,6	0,8	0,8	0,8	0,8	-	-	0,47
Amina (l/ha)	0,8	0,7	0,7	0,7	0,7	0,8	0,8	0,78
Index A (kg/ha)	-	-	-	0,4	0	0,4	-	0,19
Cosmoagua (kg/ha)	-	0,2	0	-	0	-	-	0,00
Percloron (kg/ha)	-	0,2	-	-	-	0,2	0,2	0,06
Diourion (kg/ha)	-	-	-	-	-	2	2	0,56
Ametrina (kg/ha)	-	-	-	-	-	1	1	0,28
Atrazina (kg/ha)	-	-	-	-	-	2	2	0,56
Mexclater (kg/ha)	-	-	-	-	-	2,5	2,5	0,70
Fusilade (l/ha)	-	-	0,6	0,7	0,7	-	-	0,19

Source: CUE

Irrigation and draining

Figure 6.8. Precipitation (left), Evaporation (right), in the geographic valley of Cauca River



Source: (Cenicaña, 2011)

Annual precipitation in the geographic valley of the Cauca River varies between 800 and 2600 mm/year and it exhibits an average of 1000 mm/year. Historically there have been 2 main rainy seasons, from March to May and from October to November. Crop requirements start from 900 to 1300 mm/year approximately, during almost 13 months (that is 1 cycle). In the figure 6.8, is shown precipitation and transpiration in the Geographic Valley of Cauca River.

Table 6.15. Water requirements for sugarcane using different irrigation systems (cubic meters/ha)

Water saving and applied volumes with the use of irrigation technologies *	One irrigation	Four irrigations with hydric balance	Four irrigations without hydric balance
Water volume applied in the crop irrigation without implementing any of the mentioned technologies	1800	7200	12600
Minimum water savings if Irrigation Administrative Control (IAC) is applied	200	800	1400
Water volume after implementing the IAC	1600	6400	11200
Minimum water savings if alternative furrow irrigation is applied	300	1200	2100
Water volume after implementing the IAC and alternative furrow	1300	5200	9100
Minimum water savings if pipelines with lock gates are established	200	800	1400
Water volume after implementing the IAC, alternative furrow and pipelines with lock gates **	1100	4400	7700
Minimum water savings if pulse irrigation is adopted	200	800	1400
Water volume after implementing the IAC, alternative furrow, pipelines with lock gates and pulses	900	3600	6300

* Estimated values based on research implemented by Cenicaña in conjunction with sugar mills and sugar farmers.

** Values reached by Manuelita Ingenio in 2011

Figure 6.9. Irrigation channel in sugarcane plantations

Source: Cenicaña ©

With the purpose of recovering losses from transpiration during dry periods, most sugarcane plantations in the Geographic Valley of the Cauca River must be irrigated (Cassalett, Torres, & Isaacs, 1995). Aside from natural climatic conditions, required amounts of irrigation water will depend on the irrigation technique. In general, open channels are employed to water sugarcane plantations.

Irrigation frequency is approximately 5 times per year, and applies between 5000 to $9000\,m^3$ per hectare. However, if a pipeline system is installed the water amount can be reduced to $3600\,m^3$ (Cenicaña, 2010).

The predominant irrigation system in the locations of study is the open channel, moving water by way of gravity, while some plantations use more efficient pipeline systems. Depending on the location and irrigation technique, the amount of irrigated water varies between 1800 and $6250\,m^3$ per ha/year. Therefore the amount of irrigated water varies between 20 and 75 liters per ton of sugarcane.

This study assumed the use of a water pump with an engine of 100 HP that has a capacity of deliver $341\,m^3$ per hour, and creates an energy demand, for that matter, of 0.22 kWh per m^3.

Use of machinery and energy

Preparation and land use

Most machinery is utilized with the purpose of establishing the whole plantation and, of course it has an important role in harvesting activities. It is crucial to carefully prepare plantation land, given that crop spends between 5 to 6 years in the same site before it is replaced by a new one. The main goals behind land preparation are to prepare a layer of soil that receives a set of seeds, allowing perfect relationships between air–water–land; to add residual wastes from previous crops and organic fertilizers, in order to ease corresponding microbial activity and subsequent creation of good physical conditions for penetration and early proliferation of roots into the ground.

A typical land preparation within the geographic valley of Cauca River is implemented via mechanized alternatives and it involves the following steps:

Figure 6.10. Machinery and equipment used for land preparation

Source: Cenicaña ©

In the same manner, the table 6.16 presents energy requirements for land preparation in the case of sugarcane crops:

Table 6.16. Energy requirement for land preparation in the sugarcane case

Machinery	Goal	Diesel consumption		Ecoinvent process
		l/ha	kg/ha	
Harrow I	Mix of crop residuals, destruction of faeces	18	15	Farming, rotating cultivator/ CH U
Roots cut	Compacted soil breaking in order to ease roots depth	48	39,9	Harrow, raking, by rotating harrow / CH U
Plough	Mix of soil	24	20	Farming / plough
Harrow II	Good surface for cultivation land	18	15	Farming, raking, by rotating rake / CH U
Harrow III	Preparation of the cultivation land	18	15	Farming, raking, by rotating rake / CH U
Leveling	Filling of irregular surfaces and application of grids to drain water excess	7	5,8	Farming, raking / CH U
Furrower	Land furrowing	16	13,3	Farming, raking / CH U
Fertilizer	Improve nutrient features of land. Application of lime	5	4,2	Fertilization by transmission/CH U
Tractor	Sowing activity	7	5,8	Plantation/ha/CH

Source: Data field. CUE study

Harvesting

Harvesting starts with the burning process (if applied), followed by cutting. Afterwards, sugarcane is loaded onto some wagons to be transported to the mill. In general, transport and sugarcane processing must take place within 36 hours after the burn takes place (and the same case when the cane is cut unripe), in order to avoid sucrose losses.

Figure 6.11. Green manual harvest (on the left). Loading of cut sugarcane after pre-harvest burning (on the right)

Manual harvest (either burnt or unripen), as mentioned before, implies cutting with a machete, loading onto wagons, and transporting to the ingenio. For the loading task in the Cauca Valley region they employ mechanic lifters with hydraulic arms.

Table 6.17. Energy consumption of the mechanic and manual harvesting process

Process	Diesel consumption (l/ha/y)	kg/ha/y	Econinvent data set	Description
Manual harvesting	12,9	13,73	Fodder load per automatic trailer / CH U	The inventory takes into account diesel consumption and the quantity of agricultural machinery that must be attributed to sugarcane wagons. In addition , it takes into account the amount of emissions to the air by combustion and the residuals left on the ground by tires abrasion
Mechanic harvesting	75,4	62,73	Crop, per complete cultivator, beetroot / CH U	The inventory takes into account diesel consumption and the quantity of agricultural machinery that must be attributed to sugarcane wagons. In addition , it takes into account the amount of emissions to the air by combustion and the residuals left on the ground by tires abrasion

Source: Data field. Ecoinvent Data set

In a broad way of speaking, diesel consumption is between 24 to 86 liters per ha/year, depending on the type of harvesting method (manual or mechanic). In Brazil, diesel consumption varies between 68 and 285 liters per ha/year (average of 164 liter/ha/year) (Isaias C. Macedo, Seabra, & Silva, 2008). Nevertheless, the value that is presented for the Brazilian case includes transportation from the plantation to the mill, which used 90 liters per hectare, therefore values are comparable.

Land use Change

The next table presents land use per kg of sugarcane. All the plantations as part of this study were established decades ago on these lands, therefore, there is no direct impact on the LUC. However, land occupation avoids conversion of these plantations to their original natural state; hence some impact is created in such regard.

Table 6.18. Transformation of the Land use and occupation of the sugarcane plantations within the studied locations

Parameter	Questionnaire							
	C001	C002	C003	C004	C005	C006	C007	Average
Land use in 2000 (type of land)	Sugar-cane	Sugar-cane	Sugar-cane	Sugar-cane	Sugar-cane	Sugar-cane	Sugar-cane	Sugar-cane
Occupation (m2)	8,80E-02	8,30E-02	7,10E-02	8,60E-02	7,10E-02	9,20E-02	1,10E-01	9,20E-02
Transformation, from cultivable (m2)	4,40E-03	4,10E-03	4,10E-03	3,60E-03	4,30E-03	3,60E-03	5,60E-03	4,50E-03
Transformation, to cultivable (m2)	4,40E-03	4,10E-03	4,10E-03	3,60E-03	4,30E-03	3,60E-03	5,60E-03	4,50E-03

Source: Cenicaña

Furthermore, it is assumed that carbon content contained in the ground remains constant during the sugarcane cycle.

Carbon absorption and energy from biomass

Absorption of carbon dioxide is calculated from carbon content within sugarcane (0.451 kg of CO2 per kg of sugarcane), while the energy of biomass is calculated based on the reported energy content of sugarcane (4.95 MJ per each kg of sugarcane) (Jungbluth et al., 2007).

Emissions to the atmosphere

Fertilizers application, in conjunction with the burning process before harvesting tasks, creates emissions of pollutants to air. For the pre-harvest burning process consider the values presented in the literature, presented here:

Table 6.19. Emissions to the atmosphere from the burning process before harvesting tasks (kg/kg of sugarcane)

Substance	Amount
Nox (a)	1,07E-04
CH_4 (b,c,d)	3,03E-04
CO (a,c,d)	3,27E-02
Particles > 10 µm (a)	2,62E-03
Particles > 2.5 µm (a,c,d)	2,84E-04
CH (a)	5,30E-03

Source: (a) Leal 2005, (b) Macedo 1997, (c) Jungblunth 2007, (d) Dinkel et.al 2007

Ammonia emissions were calculated by employing emission factors from the Agrammon model (SHL, 2010). For urea, emissions of NH3 are 15% of total nitrogen applied and the model forecast that some other mineral fertilizers release only 2% of the total amount of nitrogen. For compost and poultry manure, it is estimated that 80% and 30% of Total ammoniac nitrogen are emitted in the form of NH3, respectively. Emissions of NO2 and of NOx were modeled by employing emission factors from IPCC (Solomon et al., 2007).

Table 6.20. Emission to the atmosphere from fertilizers application (kg/kg of sugarcane)

Parameter	C001	C002	C003	C004	C005	C006	C007	Average
NH_3 - N	2,60E-04	8,60E-07	1,80E-04	2,20E-04	1,60E-04	2,10E-04	2,50E-04	2,40E-04
N_2O	7,80E-05	4,20E-05	5,90E-05	7,00E-05	5,60E-05	7,70E-05	9,40E-05	7,70E-05
NO_x	1,60E-05	8,80E-06	1,20E-05	1,50E-05	1,20E-05	1,60E-05	2,00E-05	1,60E-05

Source: CUE based on emission models

For wastes on land see appendix 9.5.

6.2.2 Sugarcane processing plant (ingenio) and ethanol production

The installed capacity of sugarcane-based ethanol production has reached 1,050,000 liters per day. Inventory data used in this study were collected from those firms signed with asterisk (*) and are presented in the next table:

Table 6.21. Ethanol plants in Colombia 2009

Company	Region	Capacity (liter/day)
Incauca (*)	Miranda, Cauca	300000
Providencia (*)	El cerrito, Valle	250000
Manuelita (*)	Palmira, Valle	250000
Mayagüez (*)	Candelaria, Valle	150000
Risaralda	La virginia, Risaralda	100000
Total		1050000

Source: (Fedebiocombutibles,2012)

In addition there is an ethanol plant that uses cassava as feedstock, located in Puerto Lopez, Meta (see appendix 1). The company that owns this plant is GPC Etanol, and has an installed capacity of 25,000 liters per day. There are projected investments for 2 bioethanol plants with sugarcane as feedstock with a combined installed capacity of 850,000 liters per day. It was reported in 2009 that the company Bioenergy is planning to build an ethanol plant in Puerto Lopez with a minimum capacity of 480 m3/day of anhydrous ethanol (Fernández Acosta, 2009). As the plant is not currently operating, it is not included in this study.

With the purpose of establishing a set of representative data of ethanol production in Colombia, data was collected from 4 out of 5 fully operating plants (which correspond by volume to 90% of the sample). The average was calculated as a weighted average for most inputs and outputs of matter and energy. Weighting factors are calculated based on the real annual production for 2009 for both sugar and ethanol plants (see table below).

Table 6.22. Weighted average of production of different ethanol production companies

Annual production	Unit	E001	E002	E003	E004	Total
Produced ethanol	ton/y	60992	56656	42483	78432	238,562
Produced ethanol	l/d	232775	216228	152870	299336	938,926
Weighting factor	%	26%	24%	18%	33%	100%

Source: CUE based on interviews to experts

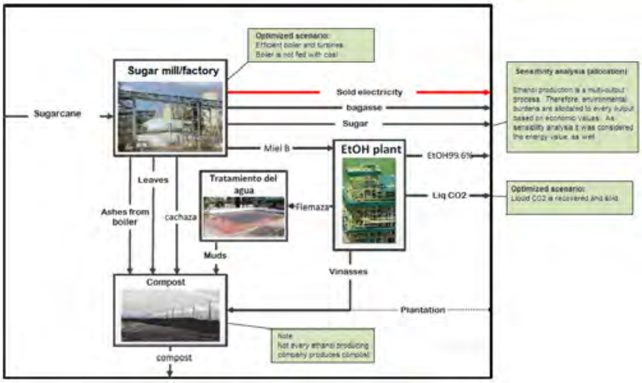
Description of the system

Within this study the ethanol production process can be broken down into 4 stages:

- Milling stage (sugar processing plant–ingenio). Within this stage is included the presence of turbines and industrial boilers.
- Ethanol plant (includes fermentation, distillation, dehydration, and vinasses concentration)
- Waste residual treatment plant
- Compost

The figure below shows a depiction of the mentioned process and flow of materials.

Figure 6.12. Ethanol production process in Colombia



Despite the fact that ethanol production and sugar processes are quite alike for this sample of firms, they do differ, particularly in the use of by-products. Main differences are presented in the table 6.23. In this study, besides modeling of the average ethanol production in Colombia, it also identified the optimization potential, by using a scenario from the "optimized system" as is shown in the previous figure. For both scenarios assumptions for different treatment choices are identified.

Table 6.23. Mass flows and technologies for sugar and ethanol plants in Colombia

Product/ process	Company 1	Company 2	Company 3	Company 4	Average scenario	Optimized scenario
Sugar mill						
Sugar	100% sugar (special refined)	19.6% sugar, 80.4% refined sugar	100% refined sugar	100 % (special refined)	Average	Refined sugar
Filtered mud	Compost	Application in plantation and compost	Application in plantation	Application in plantation	Compost	Compost
Leaves and residuals of the sugarcane plant	Compost	Compost	Application in plantation	Compost	Compost	Compost
Ashes	Compost	Compost	Application in plantation	Application in plantation	Compost	Compost
Ethanol production						
Boiler feeding	Bagasse	Bagasse and charcoal	Bagasse and charcoal	Bagasse and charcoal	Average	Bagasse
Exchange of bagasse with the paper industry	Yes	No	Yes	Yes	Average	Average
Feedstock for ethanol	Molasses B	Molasses B	Molasses B	Molasses B % Clear juice	Average	Average
CO2	It is released to the atmosphere and it is also sold	It is released to the atmosphere	It is released to the atmosphere	It is released to the atmosphere	Average: Atmosphere and sold	It is sold
Vinasse treatment	Evaporation : Flubex and compost	Evaporation : Flubex and compost	Evaporation : Flubex and compost	Evaporation : Flubex and compost	Evaporation : Flow and compost	Compost
Flemaza (Residuals from the rectification column)	Residual water treatment plant (RWTP). Pool	RWTP. Pool	RWTP. Pool	RWTP. Pool	RWTP. Pool	RWTP. Pool
Water treatment	Pool (femazas) Irrigation-fertilization	Pool (femazas) Irrigation-fertilization	Pool (femazas) Irrigation-fertilization	Pool (femazas) Irrigation-fertilization	Pool (femazas) Irrigation-fertilization	Pool (femazas) Irrigation-fertilization

Source: Interviews with experts

The inventory of the average sugarcane processing plant in Colombia has been calculated in two stages. Firstly, were established inputs and outputs of sugarcane and ethanol plants, per 100 tons of raw sugarcane. Given that sugarcane processing is a procedure with multiple outputs, the environmental share has to be distributed among the individual outputs. The second stage calculated the impact for a kg of ethanol.

Sugarcane mill and sugar processing plant (Ingenio)

Here is a summary of the sugarcane transformation process through the chart, and this information is complemented and widened in appendix 9.9

Figure 6.13. Sugarcane transformation process

Source: (Manuelita website, 2010)

Material and energy inputs

Substances and energy required to process 100 tons of sugarcane are displayed as follows. All these values are assessed in wet weigh and the standard deviation is presented as well:

Table 6.24. Material and energy consumption of the sugar processing factory per every 100 tons of sugarcane

Process	Entry	Unit	Average and optimized scenarios	SD	Reference Ecoinvent
Sugar mill	Sugarcane	Ton	100	-	-
Heating	Calcium	Ton	0,08	0,01	Limestone, grinded, in plant / CH U
Clarification	Flocculant	Ton	1,18E-03	9,14E-04	Organic chemicals, in plant / GLO S
Sulphitation	Sulphate	Ton	0,01	0	Sulphur dioxyde, liquid, in plant / RER U
Boiler and wash	Water	ton	57,55	50,75	Tap water, used / RER U
Wash	NaOH	ton	0,02	0,01	Sodium hydroxide, 50% in H2O, production mix, in plant / RER U
Milling	Biocides	ton	1,64E-04	1,11E-04	Benzene chloride, in plant / RER U
Evaporation	Surfactants	ton	7,22E-05	1,21E-04	Ammonium chloride, in plant / GLO U
-	Auto-generated electricity	kWh	3,003	699	-
-	Electricity network	kWh	257	120	Electricity, average voltage, CO production, to the grid
-	Steam	ton	53,49	9,89	-

Source: CUE based on data field

Due to the fact that the optimization process only took into account the cogeneration alternative, the material and energy inputs are not affected whatsoever. This is the reason why the two scenarios (average and optimized) exhibit the same values.

Energy generation and consumption

In general, ingenios are self-sufficient in terms of energy, which means that energy embedded in the bagasse is enough to satisfy energy requirements expressed in steam and electricity. In some cases some electricity surplus is sold back to the main energy grid.

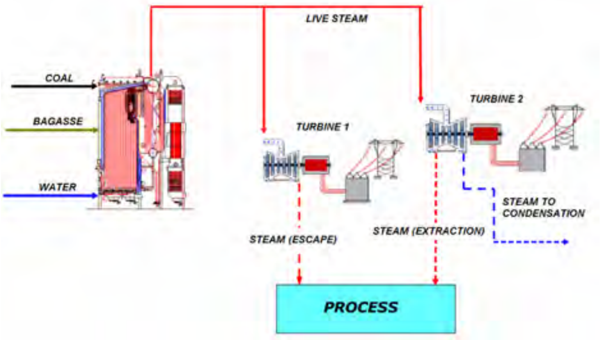
Due to economic reasons, the sugar industry in the geographic valley of Cauca River exchanges some of their bagasse for charcoal that comes from the paper industry. Most of the boilers of sugar processing plants employ a fuel mix of bagasse and charcoal. Composition and calorific values of these materials are presented in data from the UMPE, and are presented in table 25 (ACCEFYN, 2003).

Table 6.25. Properties of bagasse and charcoal

Parameter	Unit	Bagasse	Charcoal
Inferior calorific power	(MJ/kg)	9	26,91
Humidity	%	42 to52	7,9
C	%	46	66,99
Humidity	%	16	3
S	%	0	1
O	%	38	8
Ashes	%	2	12

Source: (ACCEFYN, 2003)

Figure 6.14. Illustration of the co-generation system applied within sugar mill facilities



Source: (Castillo, 2009)

Steam that comes from high pressure boilers is sent to turbines in order to produce electricity, whereas low pressure steam is used directly in the sugarcane treatment process. The figure 6.14 shows a general illustration about the cogeneration system for the sugarcane processing industries.

The table below contains a summary of inputs, outputs and efficiency of cogeneration for different firms per each 100 tons of processed sugarcane.

Table 6.26. Summary of cogeneration processes of the different companies per 100 tons of processed sugarcane

	Detail	Parameter	Unit	Average	SD	Optimized
Boiler	Input	Bagasse	ton/100 ton of sugarcane	25	4	25
		Charcoal	ton/100 ton of sugarcane	1	0	0
		Water	ton/100 ton of sugarcane	55	8	43
	Technology	Mill	TCH	453	116	400
		Boiler	psig	987	343	970
			°C	478	64	510
		Capacity	lb steam/h	344	193	400
		Efficiency	Charcoal	83%	5%	0%
			Bagasse	66%	1%	66%
	Output	Bagasse	MJ/ton of sugarcane	148605	25224	148605
		Charcoal	MJ/ton of sugarcane	22443	7020	0
		Total	MJ/ton of sugarcane	171048	26245	148605
		Steam (mill)	ton steam/100 ton of sugarcane	53049	9899,89	53,49
		Steam (EtOH)	ton steam/100 ton of sugarcane	0,07	0,01	0,07
		Total steam	ton steam/100 ton of sugarcane	53,57	9,88	53,57
		Ashes (charcoal)	ton /100 ton of sugarcane	0,18	0,06	0
		Ashes (bagasse)	ton /100 ton of sugarcane	0,25	0,04	0,25
Turbine - Electricity	Input	Total steam	ton steam/100 ton of sugarcane	54	10	54
	Technology	Steam rate	kg of steam/kWh	15	4	15
		Efficiency	kWh el/kWh (thermal)	8%	2%	9%
			kWh el/kWh inputs	5%	1%	6%
	Output	Electricity (mill)	kWh/100 ton of sugarcane	3003	699	3003
		Electricity (sold)	kWh/100 ton of sugarcane	257	376	115
		Electricity (EtOH)	kWh/100 ton of sugarcane	415	157	415
		Total	kWh/100 ton of sugarcane	3675	1072	3533

Source: CUE based on data field

Energy loss from boilers is approximately 33% and they produce 2.2 tons of bagasse. Thus, per each 100 tons of sugarcane 53.6 tons of steam is produced, which matches with those values provided by CENICAÑA (i.e. from 45 to 68 tons per each 100 tons of sugarcane) (Castillo, 2009). Low pressure steam is mainly used for the evaporation process (37%-50%) (Castillo, 2009). Ash content is calculated as 2% of dry weight for bagasse and 19% in the case of charcoal.

An average of 5% of energy contained in steam converts into electricity (11.8% in the optimized system). In general 5% of energy contained in the mix of bagasse and charcoal in turned into electricity (it reaches 6% in the optimized system), residual heat is used in the treatment process. Each 100 tons of sugarcane produced uses 3.675 kWh of electricity, which is on the upper limit of the band reported by CENICAÑA (from 2200 to 3600 kWh). Sugarcane production in Brazil exhibits an energy consumption of 2900 kWh every 100 tons of sugarcane (Jungbluth et al., 2007). For charcoal combustion, the reference from Ecoinvent "heat, in a charcoal industrial oven 1–10MW" was used as an approximation to corrected efficiency of 83%.

Infrastructure

Infrastructure is based on the Ecoinvent process "Sugar refinery /p/GLO/I". Plant production capacity is 1650 kton of sugarcane, and it has a lifespan of 50 years. Boiler infrastructure data was adapted from the set of data "wood chips, in cogeneration 6400 kWth, wood", regarding ongoing water content, charcoal and fuel energy (bagasse and charcoal)

Table 6.27. Infrastructure of the sugar mill, furnace and turbine per every 100 tons of sugarcane

Infrastructure	Lifespan (years)	Capacity	Unit	Value (every 100 ton of sugarcane)	Reference Ecoinvent
Sugar mill	50	1650	kt/y	1,63E-08	Sugar refinery / GLO
Boiler	20	6400	kWth	7,63E-05	Co-generation unit 6400 kWth, firewood burning, construction
Boiler and turbine	20	6400	kWth	1,73E-04	Co-generation unit 6400 kWth, firewood burning, common components for electricity-heat
Turbine	20	6400	kWth	1,73E-04	Co-generation unit 6400 kWth, firewood burning, components for electricity only

Source: CUE based on data field

Transport

Transportation distances are expressed as the quantity of tons moved over a given distance (assessed in km) by a determined vehicle (finally assessed in ton/km).

Sugarcane transportation from the plantation place to the plant exhibits an average of 23.27 km. For the remaining entries, it was assumed standard distances that are shown on table below. In general, close to 2,405 t/km are moved by truck with the purpose of transporting all material to the sugar refinery (see appendix 9.7).

Products and by-products from the ingenio

Outputs from sugar processing plants are presented as follows (again for every 100 tons of sugarcane). Main agricultural wastes are used for compost or for direct application to the ground.

Sugar production, in the Colombian case, presents an average of 9.3 tons, whereas Ecoinvent reports 12 tons of sugar every 100 tons of sugarcane in Brazil. However, if the sugar that is produced for alcohol fuel purposes is taken into consideration, the production yield would reach 12 tons in the geographic valley of Cauca River, as well

(Asocaña, 2010). Reported production of bagasse in Brazil is 25 tons for every 100 tons sugarcane(Gunkel et al., 2007). The range of values provided by CENICAÑA is between 24 to 35 tons (Castillo, 2009) and therefore the average value used in this study of 28.6 tons, can be considered as valid.

Table 6.28. Products and residuals from the sugar plant per every 100 tons of sugarcane (tons)

Output	Average and optimized scenario	SD	Destination
B-honey	6,30E+00	4,40E-01	EtOH plant
Clear juice	1,00E+00	2,80E+00	EtOH plant
White sugar	4,50E+00	4,40E+00	Market
Refined sugar	4,80E+00	1,50E+00	Market
Filtered mud	4,20E+00	4,10E-01	Compost
Bagasse to the boiler	2,50E+01	4,10E+00	Boiler
Bagasse for paper industry	5,40E+00	3,70E+00	For paper industry
Cane residual on plant floor	1,30E-01	-	For compost
Sugarcane leaves	5,80E-01	-	For compost
Steam	6,00E+01	4,20E+01	To the atmosphere

Emissions to the atmosphere

Emissions from the sugarcane burning process into the boilers were considered based on the set of data from Ecoinvent, assuming bagasse is burnt "wood chips, burned in cogeneration 6400 kWht, emissions control". Inventory was adapted according to the following rules:

- All the inputs to the technological sphere of the process are considered proportional to the input of dry matter.
- Hydrocarbon emissions is proportional to carbon inputs.
- Emissions of residual heat are proportional to energy inputs.
- All the remaining emissions are proportional to dry matter inputs.

In addition, specific values for sugarcane burning of NOx and PAHs were taken from the report AP42 (EPA, 1996). All values are reported in appendix 9.8.

Residual disposal

All residuals created within the sugarcane processing plant are exhibited in the following table.

Table 6.29. Residuals from sugarcane per every 100 tons of sugarcane (tons)

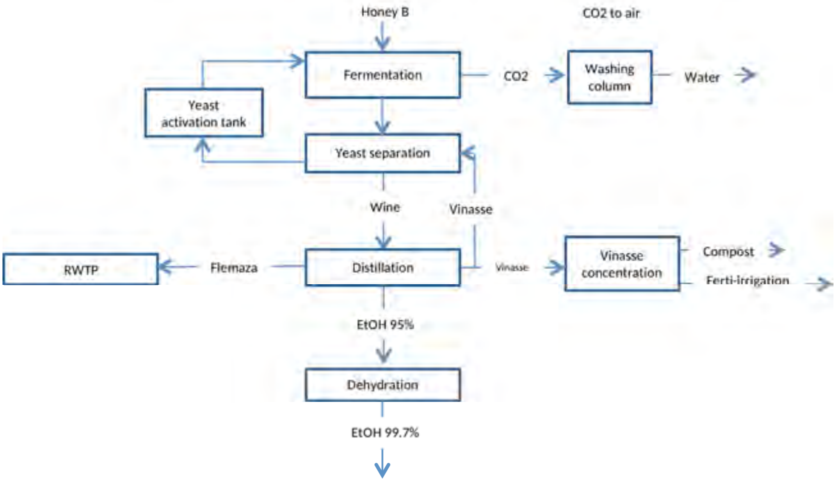
Residuals	Average and optimized scenario	SD	Ecoinvent reference
Junk	6,30E-03	4,30E-03	Steel and iron recycling / RER U, Junk in plant / RER U
Ordinary residuals	3,80E-03	-	Urban solid residual disposal, 22.9% water, to municipality incineration / CH U
Used oil	5,20E-04	-	Disposal, used mineral oil, 10% water, hazardous residual incineration / CH U
Hazardous residuals	3,20E-04	-	Disposal, hazardous residuals, 25% water, hazardous residual incineration / CH U
Paper	2,30E-04	-	Paper containers' disposal, 13.7% water, landfill site / CH U
Packing	1,80E-03	2,10E-03	Paper containers' disposal, 13.7% water, landfill site / CH U

Source: Cue based on data field

Ethanol production

Below is presented an illustrated and organized summary of the path that is followed in an ethanol processing plant in Colombia. Main processes include microbial fermentation, distillation and dehydration, which are described in appendix 9.9.

Figure 6.15. Summary of the sugarcane–based ethanol manufacture process



Raw materials and energy inputs

In the table below are displayed the main inputs for the ethanol obtaining process for every kg of alcohol fuel produced.

Table 6.30. Inputs and energy employed in the ethanol elaboration process (kg per kg of ethanol at 99,6%, unless indicated otherwise)

Process	Input	Average Scenarion	SD	Optimized scenario	Ecoinvent reference
Fermentation	B-Honey	3,30E+00	2,10E-01	3,30E+00	B. honey, sugar refinery/CO U
Fermentation	Clear juice	-	5,30E-01	5,30E-01	Clear juice, sugar refinery /CO U
Fermentation propagation	H2SO4	1,80E-02	5,50E-03	1,80E-02	Sulphur acid, liquid, plant/RER U
Cleaning	NHO3	1,10E-03	9,40E-04	1,10E-03	Nitric acid 50% in H2O, plant/RER U
Fermentation (with pollution)	General antibiotics	2,70E-05	2,30E-05	2,70E-05	Organic chemicals, plant/GLO U
Fermentation	Anti-foam	8,20E-04	1,20E-03	8,20E-04	Organic chemicals, plant/GLO U
Fermentation	Phosphoric acid	1,80E-04	2,50E-04	1,80E-04	Phosphoric acid, industrial, 85% in H2O, plant/RER U
Distillation	Refrigeration water	1,30E+00	2,80E+00	1,30E+00	Tap water, user/RER U
Cleaning	NaOH	8,50E-03	4,90E-03	8,50E-03	Sodium hydroxide 50% in H2O, production mix, plant/RER U
Nutrients	Urea	1,80E-03	1,90E-03	1,80E-03	Urea with ammonia nitrate, as N, regional storage /RER U
Fermentation propagation	Ammonium phosphate	2,00E-04	1,90E-04	2,00E-04	Ammonium phosphate, as N, regional storage /RER U, Ammonium phosphate, as P2O5, regional storage / RER S
Fermentation (with pollution)	Lacostab antibiotic	4,90E-05	9,50E-05	4,90E-05	Organic chemicals, plant/GLO U
Fermentation propagation	Nutri-Plex Plus	7,30E-06	1,40E-05	7,30E-06	Organic chemicals, plant/GLO U
Cogeneration	Nalco Pulv	1,80E-06	2,70E-06	1,80E-06	Sodium sulphate from viscosa production, plant/GLO S
Fermentation	Potassium Metabisulfite	2,40E-06	3,70E-06	2,40E-06	Organic chemicals, plant/GLO U
Fermentation	Bioclean 5980	8,10E-03	1,20E-02	8,10E-03	Organic chemicals, plant/GLO U
Cleaning	Hypochlorite	4,80E-04	7,30E-04	4,80E-04	Regional storage, 15% in H2O, plant /RER U
Cogeneration	Nalco 3DT	1,20E-05	1,80E-05	1,20E-05	Sodium sulphate from viscosa production, plant/GLO S
Fermentation	Masthone	2,80E-06	4,20E-06	2,80E-06	Organic chemicals, plant/GLO U
Fermentation	Nalco Action	2,40E-05	3,60E-05	2,40E-05	Sodium sulphate from viscosa production ,plant/GLO S
Fermentation	Steam	3,90E+00	2,40E-01	3,90E+00	-
Fermentation	Auto-generation electricity (kWh/kg EtOH)	2,10E-01	8,20E-02	2,10E-01	Electricity, sugar refinery/CO U
Fermentation	Grid electricity (kWh/kg EtOH)	2,20E-02	6,30E-02	2,20E-02	Electricity, average voltage, CO production, red/CO U

Source: Cue based on data field

Infrastructure

The reference ethanol processing plant presented in Ecoinvent as "ethanol fermentation plant / p / CH / 1" was used for infrastructure (Hischier et al., 2010). Ecoinvent plant relies on a lifespan of 20 years and it produces 90,000 tons of ethanol per year. Per each kg of ethanol produced it requires the equivalent to 5.5 E-10 plants.

Transport

Exact transport distances for most substances and the utilized equipment for ethanol process are not known. Nevertheless, in accordance with the approximate distance of production sites, there are estimated distances and corresponding vehicle fleet data for transportation purposes. Total transportation was calculated in ton/km per kg of ethanol fuel, based on the amount of product that required transportation, multiplied by the distance.

Table 6.31. Transportation distances for ethanol production

Product	Transportation distance		Quantity (kg / kg of EtOH)
	Truck > 28t (km)	Cargo ship (km)	
B-Honey	-		3,30E+00
Clear juice	-		5,20E-01
H2SO4	8,50E+01		1,70E-02
NHO3	1,10E+03		1,10E-03
Antibiotics	1,20E+03	9,30E+03	2,70E-05
Anti-foam	1,20E+03	9,30E+03	8,00E-04
Phosphoric acid	1,20E+03	9,30E+03	1,80E-04
NaOH	2,50E+02		8,30E-03
Urea	2,50E+01		8,30E-04
Ammonium phosphate	2,50E+01		3,40E-05
Lacostab antibiotics	4,00E+01		4,80E-05
Denatured gasoline	4,00E+01		7,20E-06
Nalco (powder)	4,00E+01		1,70E-06
Potassium Metabisulfite	4,00E+01		2,40E-06
Bioclean 5980	4,00E+01		7,90E-03
Hypochlorite	4,00E+01		4,70E-04
Nalco 3DT	4,00E+01		1,10E-05
Sodium Metabisulfite	1,20E+03	1,50E+04	2,70E-06
Nalco action	4,00E+01		2,30E-05
Total (ton/km)	6,26E-03	9,06E-03	-

Source: Cue based on data field

Products and by-products

Results from fermentation, distillation and dehydration processes are listed below.

Table 6.32. Products, by-products, and residuals from the ethanol process (kg / kg EtOH)

Output	Average	SD	Optimized	Destination
Ethanol 99.6%	1,00E+00	0,00E+00	1,00E+00	Market
CO2 to the atmosphere	9,50E-01	3,70E-02	9,50E-01	Atmosphere
Liquid CO2	1,60E-02	2,40E-02	1,60E-02	Market
Vinasse 32.5	7,80E-01	-	7,80E-01	Compost
Vinasse 35	1,60E+00	8,50E-01	1,60E+00	Compost
Vinasse 55	2,40E-01	-	2,40E-01	Fertilization
Fusel	2,00E-03	3,80E-04	2,00E-03	Mix with EtOH
Flemaza to RWTP	3,90E+00	1,30E+00	3,90E+00	RWTP

Source: Cue based on data field

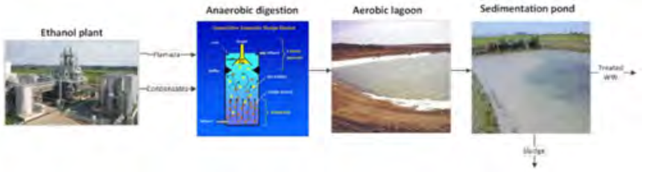
Fusel alcohol is an alcohol of superior class, formed by 1-propanol, isopropanol, n-butane, isobutene, alcohol amyl and furfural. In most cases fusel alcohol is sold for paints or to be mixed with ethanol.

Water treatment

Vinasses and a residual that emerges from distillation process called “flemaza” have a high content of organic matter and therefore a high biological oxygen demand —BOD—. If these substances are added to surface water, the dissolved oxygen in water is greatly reduced. This situation can reach such an extent where aerobic organisms (from aerobic bacteria to fish) cannot survive. Also, vinasse contains high concentrations of potassium, which can accumulate in the ground to toxic levels. With the purpose of avoiding environmental stress, it is required to treat these effluents. There are different sorts of treatment for these water residuals (Briceño, 2006). In Colombia, vinasses are concentrated from 10% up to 55% of solids in the Flubex, with the aim of reducing the amount of residual waters in a ratio of 3 – 5. Concentrated vinasses are used in the production of organic fertilizers.

Nevertheless, evaporation of condensed gases, and the water used in the process have to be treated in the residual water treatment plant. In general, water is treated biologically, by using an anaerobic reactor and an aerobic lagoon.

Figure 6.16. Residual Waters treatment



Source: www.praj.net, www.usba.org, and www.isu.edu

Anaerobic digestion is based on the use of a diverse group of microorganisms that reduce organic compounds to carbon dioxide and methane gas (biogas). Anaerobic treatment has the advantage of great performance in substance degradation, particularly when they are concentrated and resistant. A remarkable aspect of this method is the production of a low amount of mud, with lower energy requirements than those presented in aerobic choice. In Colombia the anaerobic reactor type UASB is used. The maximum capacity rate for this equipment in regular operation is 15 kg Chemical oxygen demand COD $/m^3$ per day. This reactor can retain the treated mix on average 2.1 days. Removal of average COD from the whole set of residual waters (from vinasses) was 60%, in the reactor in a single stage.

The resulting biogas is burnt, whereas effluents of the UASB are treated aerobically through bacteria, with the purpose of discoloring main colorants, melanoidins and reducing COD and BOD.

In the last step, a sedimentation pool to separate muds from treated water is used. Treated water flows like surface water, and the mud is dried up and used for land preparation in further cycles. The whole mass balance for water treatment is presented in appendix 9.10.

Compost

Vinasses, as they come out of the process, are concentrated and therefore they cannot be applied directly; nonetheless, they can be mixed along with some of the other types of residuals from the sugar refinery. Residuals used for compost production are the mud filter (mud sieving process), sugarcane wastes that emerge from the sugarcane treatment, and from the boilers ash.

Compost is a biological process of degradation of organic matter under anaerobic and aerobic conditions. The whole compost process takes between 45 to 60 days until the organic matter is pathogen-free, thus it can be taken back to the field, adding nutrients and minerals.

Pre–treatment of solid waste (5-10 days): with the purpose of reducing moisture from solid waste (filter cake, ashes and leaves), they are piled up and frequently mixed using special equipment (Backhus turner). Homogeneity is fundamental for guaranteeing and activating biologic decomposition of organic matter. Decomposition matter is activated with a concentration of oxygen of 5%. Temperatures can reach levels between 55 to 60°C

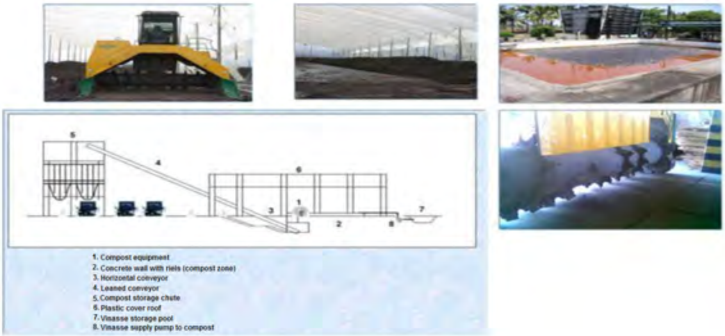
Vinasse addition (10-30 days): In the second step, the pile is mixed with vinasse in a ratio defined as a function of the humidity content of the mentioned pile. In general, it is applied in a proportion of 1:1.5. Such vinasse that comes from the evaporation processes (Flubex) is stored in a pool, from where the needed amount for compost purposes is taken.

The optimal relationship for Carbon-to-Nitrogen is 25:1 to 30:1. Carbon is used for microorganisms as an energy source for growth, and nitrogen is used for reproduction and proteins synthesis. In the next step, vinasse addition starts, depending on the pile humidity. Vinasse is combined with the pile on a daily basis, controlling temperature and humidity in order to reach the required proportion to produce high quality organic fertilizer.

Stabilization (30–45 days): After the vinasses addition, the pile needs to go through a natural drying process, maturing, stabilization and eventually is taken to the packaging area to be sold in standard units of 40 kg per sack. Based on the physical and chemical composition, it is commercialized as Kompostar – registration number ICA 4574, Vycompost–registration number ICA 6091 or Nutri Humicos – registration number ICA 5496.

The compost section of the visited processing plant for modeling the process is presented below:

Figure 6.17. Compost general process



Mass balance for compost stage is presented in appendix 9.11.

Transport and Machinery

Vinasses are moved via pipelines from pools to compost plants (approx. 100 m). Compost is mixed mechanically with the purpose of maintaining a homogeneous composition. Blackhaus equipment is employed to mix 60 tons of compost per day. 27 MJ of diesel is consumed, per ton of sugarcane.

Infrastructure

The most employed technique for mixing filtered muds with vinasses is open land method. Therefore the set of data presented by Ecoinvent “compost plant, open / CH / IU” is used as an approximate reference of infrastructure.

Material outputs

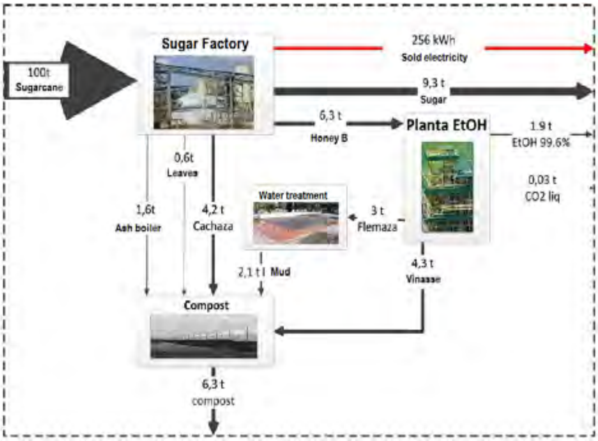
Compost is applied in the sugarcane plantation fields or in other local agricultural areas using the recommended application ratio of 9-15 tons per hectare.

General inventory overview and inventory allocation

In the following section, the main material flows and energy values, which are used for determination of allocation factors, are provided:

Mass flow within the ethanol value chain

Figure 6.18. Mass flow of processing 100 tons of sugarcane for ethanol production



Based on the data field from this study, Colombia produces, on average, close to 9.3 tons of sugar and 2 tons of ethanol per every 100 tons of sugarcane. Bagasse, as a by-product, is used for steam generation purposes and electricity as well. Surplus energy is sold to national or local energy grids. Furthermore, organic by-products are used for compost production, or they are treated in waste water treatment plants.

In conclusion, in Colombia there are no plants for the exclusive production of ethanol, given that the ongoing ethanol plants are attached to former sugar processing plants. In Brazil, as it was mentioned earlier, there is production close to 12 tons of sugar per every 100 tons of sugarcane, whereas the amount of ethanol is just 0.9 tons (Jungbluth et al., 2007). In Colombia, it can be said that the yield in terms of sugar production is fairly equal to the Brazilian case (i.e. 12%). In Brazil, the amount of vinasses is generally higher than that found in Colombia (9.3 tons per every 100 tons of sugarcane); nevertheless, in Colombia vinasses are more concentrated due to the content of dry matter (in Brazil the level is close to 15% of dry matter, while in Colombia it can be over 35%). Depending on the concentration, vinasses production in Colombia reaches a level between 0.8 to 3 liters, per every liter of ethanol (Asocaña, 2010).

Allocation factors

With the purpose of assessing the environmental impact of each individual output, it is required to allocate corresponding total environmental impacts along the biofuels production chain. The main allocation method is based on the economic value of the products. However, an energy allocation method is applied for a sensitivity analysis.

Table 6.33. Allocation factors for the ethanol production (Average scenario)

Scenario: Average	Mass balance		Economic allocation		Energy allocation	
	Amount	Unit	COP/unit	%	MJ/t	%
Input						
Sugarcane	100	ton	-	22,3%		21,6%
Output						
Special sugar	4,5	ton	1423	35,1%	16,5	31,5%
Refined sugar	4,79	ton	1491	3,9,2%	16,5	33,5%
Ethanol 99.6%	1,9	ton	2137	22,3%	26,8	21,6%
Biocompost	6,13	ton	96	3,2%	5	13,0%
Sold electricity (COP/kWh)	256,79	kWh	146	0,2%	3,6	0,4%
CO2 liquid	0,03	ton	80	0,0%	0	0,0%

Allocation factors for these optimized scenarios do not change, due to the fact that the main optimization activity is to avoid the use of coal. Carbon capture has neither energy nor economic significant effects in the total value; therefore it is not taken into account as an allocation factor.

Table 6.34. Allocation factors for the ethanol production (Optimized scenario)

Scenario: Optimized	Mass balance		Economic allocation		Energy allocation	
	Amount	Unit	COP/unit	%	MJ/t	%
Input						
Sugarcane	100	ton	-	22,5%		22,5%
Output						
Special sugar	4,5	ton	1423	35,5%	16,5	32,8%
Refined sugar	4,79	ton	1491	39,6%	16,5	34,9%
Ethanol 99.6%	1,9	ton	2137	22,5%	26,8	22,5%
Biocompost	4,36	ton	96	2,3%	5	9,6%
Sold electricity (COP/kWh)	114,51	kWh	146	1,0%	3,6	2,0%
CO2 liquid	0,09	ton	80	0,0%	0	0,0%

Economic Value

Prices are calculated as factory prices instead of being calculated as market prices. In addition, some prices are quite volatile; as a consequence the average price over several years was considered (timespan will be specified shortly). Furthermore, it is not possible for all products (or by-products) to be sold in a previously established market, thus trade opportunities emerge. However, this trading effect does not change results to a significant extent, due to the fact that main valuable products (such as sugarcane and ethanol) rely on well-defined markets; even though they can present price volatility. Some other by-products, such as compost and bagasse, are absorbed by the sugar-ethanol production chain.

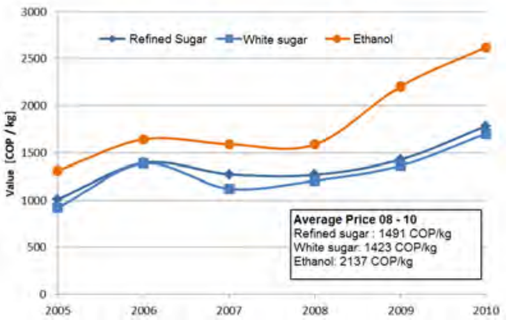
Table 6.35. Economic values of the products of the sugar refinery and ethanol plant (COP/k unless indicated otherwise)

Product	Value	Description	Reference
White sugar	1423	Average prices from 2008 to 2010. Prices were weighted regarding volumes and prices of national and export markets	(Asocaña 2011)
Refined sugar	1491	Average prices from 2008 to 2010. Prices were weighted regarding volumes and prices of national and export markets	(Asocaña 2011)
Ethanol 99.6%	2137	Average prices from 2008 to 2010.	(Asocaña 2011)
Biocompost	96	In 2010	Value provided by companies staff (personal communication)
Sold electricity (COP/kWh)	146	In 2009	Value provided by companies staff (personal communication)
CO2 liquid	80	In 2009	Value provided by companies staff (personal communication)
Bagasse for the paper industry	47	In 2009	Value provided by companies staff (personal communication)

Price for domestic sugar in Colombia is widely influenced by international prices and adjusted to domestic conditions. The New York Stock Exchange determine the floor for crude sugar and the refined sugar price floor is given by the quote provided by the London sugar market. Additionally, transportation costs are added (Pinzon, 2009). Nevertheless, the world sugar market is highly distorted and for most producers production costs frequently surpass export prices offered at a global level. Therefore, the use of sugarcane creates a high impact in exports markets (implying that the higher the ethanol production the lesser the sugar exportation level), while, on the other hand domestic markets do not face a direct impact.

In this study allocation factors are based on average prices from 2008 to 2010. Sugar prices are determined by weighted prices (national and export prices weighted by the volume of both markets). Sugar and ethanol national prices were provided by ASOCAÑA, and export prices were based on the average export price (data provided by ASOCAÑA as well).

Figure 6.19. Prices of refined and white sugar



These prices have been weighted based on the amount traded, price of the local market and export price.

Electricity is sold in long run contracts with a fixed price and indexed to the CPI (Consumer Price Index). CO2 is sold under contract. Prices employed in this study are based on interviews with experts in the field. Nevertheless, given that quantities and prices are low, the allocation factor is not sensitive to the employed values (therefore, allocation factors are determined by sugar and ethanol prices).

Table 6.36. Energy value of the products and by-products of the sugar refinery and ethanol plant (MJ/k unless indicated otherwise)

Special sugar	Value	Description	Reference
Special sugar	16,5	-	Cenicaña (personal communication)
Refined sugar	16,5	-	Cenicaña (personal communication)
Ethanol 99.6%	26,8	Standard energy content for ethanol 99.6% is taken from Ecoinvent	Jungbluth, Dinkel et.al. 2007)
Biocompost	5	Compost with a humidity content of 27.5%	Estimated based on the humidity content
Sold electricity (MJ/kWh)	3,6	Conversion factor	-
CO2 liquid	0	-	-

Palm oil crop cultivation

Origins of the African oil palm, known as Elaeis Guineensis, come from the Guiney Gulf in Western Africa (Corley & Tinker, 2008; Fedepalma, 2006b). The Elaeis Guineensis is considered as a perennial tree with a single cylindrical stem with short inter-nodes, and can grow up to 30 m. It has short thorns on leaves petiole and on the fruit bunch. Fruits hang in a large and compacted bunch, which has a weight between 10 and 40kg. Fruit pulp, which provides palm oil, surround the nut, which in turn, contains palm seeds (Corley & Tinker, 2008).

Figure 6.20. Palm plantations in Colombia

Nowadays, palm oil exists wild in nature, semi-wild, and cultivated in three main areas in the equatorial tropics: Africa, South East Asia, and central and south America. In Colombia, palm oil trees were introduced in 1932, but only in the middle of the 20th century did the palm oil crop cultivations start to be commercialized throughout the country, backed up by government policies biased to develop agricultural lands and supply Colombian territory with palm oil from domestic production (Fedepalma, 2006b). Planted surface in the year 2008 is estimated to be 336,956 hectares, which represent an increase of 9.8% in regards to the year before (306.878 ha). Only 66% of the total planted area is productive, the remaining fraction is still under development. As is shown below, most of the cultivation area has been placed on the eastern side of Colombia (121,135 hectares), where 36% of the total area has crops at the moment. In the Northern region there is a substantial portion as well (32%, with 106,635 ha), and the other 2 production spots are located in the central region (26%, with 87,525 ha), and a small fraction in the south-western region (6%, with 21,661 ha) (Fedepalma, 2009).

Figure 6.21. Main cultivation zones for palm oil in Colombia 2008

Source: (Fedepalma, 2009)

Selection of study locations

For this particular project and in order to establish the LCA study the main palm oil cultivation areas were chosen. Table 6.41 presents a distribution of the planted area sown in hectares of planted palms per zones.

The south-western region was excluded from the study due to the fact that during the last two years 16.700 hectares of palm oil crops were lost (Fedepalma, 2006b), as a consequence of the widespread disease of bulb rot, therefore the focus of the study was set in the eastern, central and northern regions. Selection of these places was based on the following criteria:

Exclusion criteria 1: Location must be representative for biodiesel plants

There must be a direct link between crop and biodiesel producer. Therefore, just those crops in charge of providing Fresh Fruit Bunches (FFB) to a palm oil extraction plant were selected, which in turn provide oil to the biodiesel processing plant.

Exclusion criteria 2: Representative crops

Regarding size, the most representative crops associated to the biggest extraction plants that fed biodiesel processing plants were selected. This information was provided by sector experts.

Exclusion criteria 3: Crop age

Some crops were established recently; therefore they were left out of the sample. The reason is that some values, for instance, crop yields do not reflect the total yield for the whole LCA.

In general three crops in the Eastern regions were studies, with a total area of 12,455 hectares, four crops in the north (9,276 ha) and three crops in the central region (5,850 ha). To sum up, with the values collected represent 26% of all the crops linked to biodiesel production in Colombia.

Table 6.37. Palm oil plantation and sampling areas (East, North and Central regions)

Area / Region	North	Central	East
Total	106635	85525	121135
Sampled	9276	5850	12445,4
Representation	8,70%	6,84%	10,27%

Source: CUE and Fedepalma

Agricultural system

Palm oil crop cultivation demands particular climate and soil conditions, but also it requires:

- a very specific quality of seeds,
- a strict selection of seedlings in the nursery,
- good land preparation before planting,
- the right selection of cover plants,
- and the right use of fertilizers,

in order to obtain maximum yield in each stage of production (Fedepalma, 2009).

In broad terms, the life cycle of a palm tree starts in the nursery, where seedlings are developed in plastic bags during 10 to 20 months. Before sowing, the ground must be leveled and all surrounding vegetation located in a 1 meter diameter from the place (with a depth larger than 1 m) must be removed. Commercial plantations of palm oil are established normally as monocropping practice with a symmetric distribution of 9m x 9m.

Figure 6.22. Palm tree. Different ages

Palm oil starts production in the second or third year after sowing. Yield rises continuously and it reaches a stable level after 7 to 10 years. Generally speaking, productivity and growth of palm oil is determined by the optimal availability of water and nutrients, temperature, and the presence of plagues and diseases.

Palm oil production might last up to 50 years (Fedepalma, 2006b), however after 20 to 25 years, it is hard to harvest the plant due to its substantial height. In this study a useful lifespan of 25 years was considered. After the tree has reached maximum height it is injected with glyphosate in order to make it die, otherwise the palm tree is just cut and removed. The re-planting takes place in clear fields or between dead palm trees.

Productivity

Palm oil offers the highest yields per hectare of all oil crops at present times (R. H. V. Corley & PBH Tinker, 2007). In general, around 20 tons of FFB's are produced per ha/year. As it is shown in table 50, yield level hinges on the geographic area of production and from the crop age. During recent years a great amount of new plantations have been established (plantations that are not productive yet), therefore the average yield experienced a descending trend.

Table 6.38. Annual yields of production per zone (ton/ha/y)

Product	Zones	2004	2005	2006	2007	2008
FFB of palm oil	East	19,56	18,44	19,29	16,33	14,76
	North	21,44	20,73	19,48	17,05	15,15
	Central	20,42	20,85	21,71	22,4	23,49
	West	19,47	19,07	19,36	15,45	12,98
	Average	20,28	19,79	19,41	17,94	16,96

Source: Fedepalma 2006; Fedepalma 2009

Below is shown palm oil production per cultivated area.

Figure 6.23. Palm productivity in the study locations

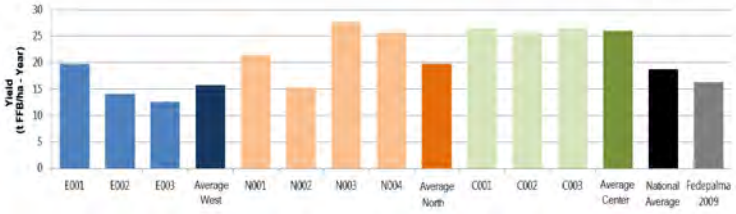
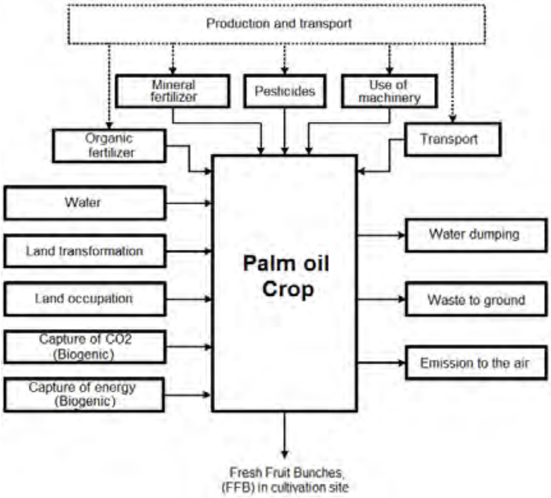


Figure 6.24. Chart on palm oil inventory process



System characteristics

The next chart presents employed inputs and generated emissions for palm oil crops. In the next sections are described individual flows.

Raw materials and auxiliary materials

Mineral fertilizers

Here are presented entries of fertilizers to the system per cultivated area. Furthermore, it shows the level of the total Nitrogen, as well as P2O5, MgO, K2O and B2O3. The amount and the type of fertilizer applied depends on local conditions and on the farmers' budget.

Table 6.39. Inputs of mineral fertilizers for the different palm oil plantation zones (kg/ha/y)

Mineral fertilizer	E001	E002	E003	N001	N002	N003	N004	C001	C002	C003
Abotec	-	-	-	319,4	319,4	-	-	-	-	-
Ammonium nitrate phosphate, as P2O5	73,3	51,7	-	-	-	-	-	-	-	-
Borax	11,5	8,1	-	14,6	14,6	2,4	39,4	-	18,5	42,9
Boron trioxide	-	-	11,5	-	-	-	-	13,7	-	-
DAP, as N	-	-	-	2,2	2,2	-	0,1	20,9	-	-
DAp, as P2O5	-	-	39,8	5,6	5,6	-	-	53,4	-	-
Dolomite	228,7	161,4	134,1	-	-	-	-	-	-	-
Fortaleza (Abomicol)	-	-	-	-	-	170,8	-	-	-	-
Granufos 40	-	-	-	-	-	-	-	-	22,1	-
Hydran	-	-	-	-	-	393	-	-	-	-
KCl	-	-	-	141	141	-	-	422,3	-	429
Kieserita	-	-	-	62,1	62,1	-	199,8	-	-	-
Mags	-	-	-	-	-	-	-	-	-	286
MAP	-	-	-	-	-	19,5	97,2	-	-	-
Magnesium sulfate	-	-	-	-	-	46,6	-	-	-	-
Nitromag	-	-	-	22,6	22,6	-	-	-	-	-
Nitrosam	-	-	-	174,6	174,6	-	-	-	-	-
Nutritional phosphorous	-	-	-	-	-	-	-	-	-	286
Nutrimon	-	-	-	-	-	-	-	-	494,4	572
Some other N compounds	-	-	-	-	-	-	0,4	-	16,8	-
Potassium chloride	322,8	227,8	262,3	-	-	106,2	-	-	106,9	-
potassium nitrate	-	-	-	-	-	-	1,4	-	-	-
potassium sulphate	-	-	-	105	105	-	696,1	-	-	-
SAM	-	-	-	-	-	52,5	473,9	592,3	-	286
Sulfomag	-	-	-	34,1	34,1	-	-	-	-	-
Sulphur	-	-	-	-	-	-	1,2	-	-	-
Tripel 18	-	-	-	-	-	-	0,7	-	-	-
Urea	181,3	128	35	32	32	-	0,2	-	-	-
Zinc sulphate	-	-	-	-	-	-	-	-	-	441,9
Summary										
Total N	83,4	58,9	16,1	118,4	118,4	104,5	107,6	142,3	81	133
Total P2O5	73,3	51,7	39,8	25,3	25,3	32,3	48,6	53,4	38,5	111,5
Total K2O	193,7	136,7	157,4	219,9	219,9	123,3	354,7	253,4	177,8	460,5
Total MgO	50,3	35,5	29,5	35,5	35,5	93,1	48	-	29,7	71,5
Total B2O3	5,5	3,9	11,5	7,3	7,3	1,1	18,9	13,7	10,1	22

Source: CUE based on data field

Organic fertilizers

It is a customary practice to use the bunch's cob-like waste (the remaining fraction of the bunch once all the fruit has been removed) in order to close the nutrients cycle and improve soil structure. The composition of this bunch's cob-like waste is presented here.

Table 6.40. Nutrients composition in palm oil fruit residues in both wet and dry weights

	N	P2O5	K2O	MgO
Dry weight	0,54%	0,14%	2,77%	0,32%
Wet weight	0,28%	0,07%	1,41%	0,16%

Source: (Heriansyah, 2008)

The use (application) of the bunch's cob-like waste is not uniform, given that those companies that rely on extraction plants have a more frequent use that those that act independently. Furthermore, in some cases composts comes back to palm plantation fields instead of being sold to third parties. The following table has a summary of all organic fertilizer entries. The amount of bunch's cob-like waste in most cases depend of the distance between plantation and extraction plants, therefore the closer it is the location of the plantation the more intensive is the application.

Table 6.41. Fertilizer inputs in kg/ha/year for different cultivation areas

Organic fertilizers	E001	E002	E003	N001	N002	N003	N004	C001	C002	C003
Tusa	127.660	-	-	8.600	1.430	-	-	11.120	9.016	-
Compost	-	-	-	-	-	3.848	-	-	-	-

Source: CUE based on data field

Pesticides

In order to control fungus, herbs, insects and plagues some agrochemicals are applied. Appendix 12 has a summary of these chemicals applied in different cultivation zones.

Transport and machinery

The following section describes transport of entry materials (fertilizers) and employed machinery for irrigation purposes and harvesting activities.

Irrigation: During dry periods, palm oil plantations are irrigated by use of underground sources and surface waters. In such tasks water pumps are used and they are powered by using diesel fuel or electricity.

Fertilizers and pesticides: The main fertilizer in palm crops is the bunch's cob-like waste, which is transported from the extraction plant to the plantation using trucks. Afterwards workers distribute these agricultural inputs from chemical and organic nature. Herbs and weeds elimination: In general, the growth of other varieties of plants near the palm oil is permitted, however they are controlled through periodic cuts or via herbicide application (R. H. V. Corley & PBH Tinker, 2007)

Figure 6.25. From collecting task up to loading in trucks (palm oil)

Harvesting: fresh fruit bunches are collected using a long knife. After FFB's are cut from the palm tree, fruits are piled up in such a way that they can be loaded efficiently.

Depending on transportation distances, FFB's are moved around mechanically, or by use of some beast of burden (in case the distance does not exceed 5 km) to the extraction plant.

Figure 6.26. Transportation methods (palm oil)

This report only considered the use of vehicles for transportation purposes and animals were excluded. Average distance of transportation using either truck or tractor is between 19km and 2.6km respectively. The inventory of this task was based on these values, due to the fact that total fuel consumption is known for the entire crop (including all the related activities) (see table below). This path was chosen instead of breaking the assessment between different sub-tasks or individual activities.

Table 6.42. Fuel consumption of the different palm oil plantation areas (ton.km/ kg FFB)

Vehicle	E001	E002	E003	N001	N002	N003	N004	C001	C002	C003
Transport, Tractor and trailer / tkm/CH	9.10E-03	1.30E-02	5.50E-03	4.60E-03	4.60E-03	3.40E-03	3.70E-03	3.50E-03	1.40E-03	8.70E-04
Transport, Truck > 16t. Average fleet/ tkm/ RER	9.40E-03	1.30E-02	5.70E-03	4.80E-03	4.80E-03	3.50E-03	3.80E-03	3.70E-03	1.40E-03	9.00E-04
Transport, passenger vehicle, gasoline, EURO 3/person km/CH	2.90E-04	4.10E-04	5.90E-04	4.10E-03	4.20E-03	1.00E-03	1.10E-03	1.10E-03	6.50E-04	4.70E-04

Source: CUE based on data field

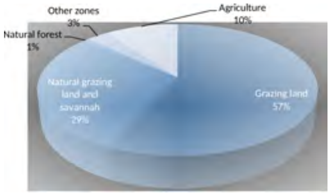
Land use change (LUC)

In accordance with several questionnaires and the Annual statistic report (Fedepalma, 2009), LUC in the year 2000 in the eastern region was 48% of pasture lands, 12%

dedicated to rice cultivation and a 40% there were existing palm plantations. In the northern and central regions, 61% of palm crops were established in former pasture lands, while in 39% were old palm plantations.

Those values that have been collected on-site are coherent with values extracted from the literature presented in figure 30, which summarized the work of Picon (Picon, 2008). The figure indicates that most land in where palm crops were established matched with pasture lands or savannah or agricultural land of small size.

Figure 6.27. Transformation of land due to palm plantations (2000–2008)



Source: (Picon, 2008)

Direct carbon emissions caused by LUC are calculated based on the methodology from Level I of IPCC. Values of carbon reserves were also taken from the literature and calculations are presented below:

Table 6.43. LUC Parameters for different palm oil plantations

IPCC LUC		E001	E002	E003	N001	N002	N003	N004	C001	C002	C003
Pasto	AGB	3	3	3,75	2,88	2,88	2,88	2,88	3,78	1,27	3,78
	BGB	1,13	1,13	1,41	0,81	0,81	0,81	0,81	1,42	0,48	1,42
Palm	AGB	17,42	17,42	17,42	17,08	17,08	17,08	17,08	17,22	17,22	17,22
	BGB	5,34	5,34	5,34	5,24	5,24	5,24	5,24	5,28	5,28	5,28
Rice	AGB	0,23	0,23	-	-	-	-	-	-	0,76	-
	BGB	0,03	0,03	-	-	-	-	-	-	0,09	-
Reservas de carbono en el suelo (natural)		50	50	50	30	30	30	30	20	20	20
Crop parameters	Facto de uso del suelo (FLU)	1	1	1	1	1	1	1	1	1	1
	Factor de manejo (FMG)	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15
	Factor de entrada(FI)	1	1	1	1	1	1	1	1	1	1
Before	AGB	20,65	20,65	21,17	19,96	19,96	19,96	19,96	21	19,25	21
	BGB	6,5	6,5	6,75	6,05	6,05	6,05	6,05	6,7	5,85	6,7
	SOC	50	50	50	30	30	30	30	20	20	20
	TOT	77,14	77,14	77,92	56,01	56,01	56,01	56,01	47,7	45,1	47,7
After (palm)	AGB	44	44	44	44	44	44	44	44	44	44
	BGB	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5
	SOC	57,5	57,5	57,5	34,5	34,5	34,5	34,5	23	23	23
	TOT	115	115	115	92	92	92	92	80,5	80,5	80,5
Difference	t C/ha	37,86	37,86	37,08	35,99	35,99	35,99	35,99	32,8	35,4	32,8
	Years	20	20	20	20	20	20	20	20	20	20
	kg C/ kg RFF	0,1	0,14	0,15	0,08	0,12	0,06	0,07	0,06	0,07	0,06
	kg CO2/kg RFF	0,35	0,5	0,54	0,31	0,43	0,24	0,26	0,23	0,25	0,23

Source: Based on CUE data field and By-default values given by IPCC

Furthermore, the indirect effects of the LUC were taken into account in the sensibility analysis.

Carbon absorption and energy from biomass

Absorption of carbon dioxide is calculated from the carbon content of FFB's (1.14 kg of CO2 per kg of FFB) (Jungbluth et al., 2007).

Emission to the atmosphere

In the following table are noted emissions to the atmosphere caused by fertilization. Emissions of ammonia were calculated through the Agrammon emissions factor (reference SHL 2010). In the case of urea, emissions of NH3 are close to 15% out of the total nitrogen applied and the model forecasts that some other mineral fertilizers emit only a 2% of total nitrogen. In is estimated that 80% of total ammonia nitrogen is emitted as NH3. Emissions of Nh2 and NOx were modeled by employing emission factors from IPCC (Solomon et al., 2007)

Table 6.44. Emissions to the atmosphere due to fertilizer application (kg/kg of FFB)

Emissions to the atmosphere	E001	E002	E003	N001	N002	N003	N004	C001	C002	C003
NH3-N	6,34E-04	6,31E-04	1,91E-04	2,00E-04	2,80E-04	1,09E-04	8,42E-05	1,07E-04	6,30E-05	1,00E-04
N2O	6,97E-04	9,55E-05	3,21E-05	1,41E-04	1,61E-04	6,74E-05	7,29E-05	1,34E-04	8,58E-05	8,74E-05
NOx	1,46E-04	2,00E-05	6,75E-06	2,96E-05	3,39E-05	1,42E-05	1,53E-05	2,80E-05	1,80E-05	1,84E-05

Source: CUE based on emission models

Water spillage

Phosphorous dumping and nitrates to underground and surface waters were calculated used the same method that was suggested by the on-line tool SQCB16 (Faist Emmenegger et al., 2009).

Table 6.45. Water dumping by use of fertilizers

Water dumping	unit	E001	E002	E003	N001	N002	N003	N004	C001	C002	C003
Nitrate	kg NO3/ kg FFB	4.79E-03	7.97E-03	3.62E-03	5.05E-03	1.03E-02	2.54E-03	2.29E-03	3.24E-03	8.86E-04	2.85E-03
Phosphorous to superficial water	kg P / kg FFB	4.55E-05	5.57E-04	1.16E-03	5.10E-04	9.41E-04	6.46E-04	8.31E-04	6.37E-04	7.52E-04	8.16E-04
Phosphate to superficial water	kg P / kg FFB	3.22E-05	2.90E-04	5.79E-04	4.83E-04	8.89E-04	6.52E-04	8.25E-04	9.37E-04	1.07E-03	1.35E-03

6.2.3 Palm oil extraction and production of biodiesel

In Colombia the installed capacity for processing (crushing) of FFB's during the year 2009 was 1,109 tons per hour. From these FFB's is possible to extract approximately 232 tons of crude oil per hour. During the last years the proportion of palm oil that is processed locally for biodiesel production purposes has gained a growth trend. Nowadays, the installed capacity of the biodiesel plants is 486,000 tons per year.

Table 6.46. Biodiesel plants and installed capacity

Company	Region	Capacity (thou l/d)	Beginning of operations
Oleoflores *	Codazzi, Cesar	50	June 2007
Odin energy	Santa Marta, Magdalena	36	March 2008
Biocombustibles del Caribe *	Santa Marta, Magdalena	100	February 2009
Bio D *	Facatitiva, Cundinamarca	100	April 2009
Aceites Manuelita *	San Carlos de Guaroa, Meta	100	June 2009
Ecodiesel	Barrancabermeja	100	June 2009
Total		486	

Source: MADR 2011; Those companies labeled with a star (*) took part in the study

Processing data for this study comes from 4 companies that were operating in 2009: Oleoflores, Biocombustibles Sostenibles del Caribe, Aceites Manuelita, and BioD, which represent 65% of the total production of Colombia (this calculation shows the installed capacity and not necessarily the actual level of processed material). The average is calculated by weighting the participation in the process. Weighting factors are calculated in accordance to the real production in 2009 for palm oil extraction, refinery and transesterification plants:

Table 6.47. Average weight of the different palm oil producing companies

Company	A	B	C	D	E
Palm oil extraction					
Annual production (ton)	146500	114600	274380	273430	60480
Weighting Factor	19%	21%	15%	36%	8%
Palm oil refinery					
Annual production (ton)	82500	45676	102595	73888	NA
Weighting Factor	27%	15%	34%	24%	NA
Biodiesel plant					
Annual production (ton)	50260	45251	45000	72753	NA
Weighting Factor	24%	21%	21%	34%	NA

Source: CUE based on data field and Cenipalma

Description of the system

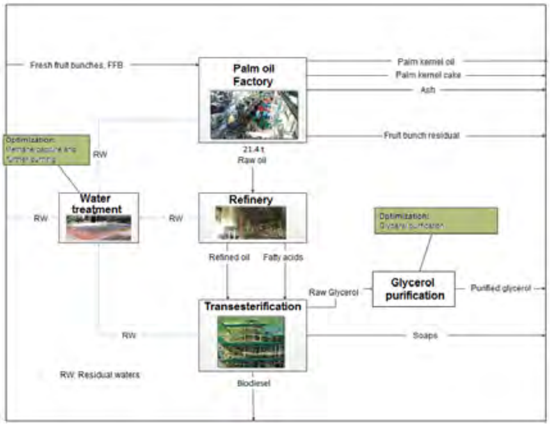
The whole process of producing biodiesel can be broken down into the following steps:

- Palm oil extraction (including participation of boilers and turbines)

- Oil refinery
- Biodiesel plant
- Residual water pool
- Glycerol purification

The following chart presents a general vision on the different processes and the corresponding flows linked to biofuel production by using FFB's of palm oil.

Figure 6.28. Biodiesel production process



This chart depicts the process with some particularities:

1. it exhibits a representative scheme for the palm oil industry in Colombia in 2009 and
2. it represents an optimized system with several improvements that can be implemented in the near future.

All these steps will be described in the following sections.

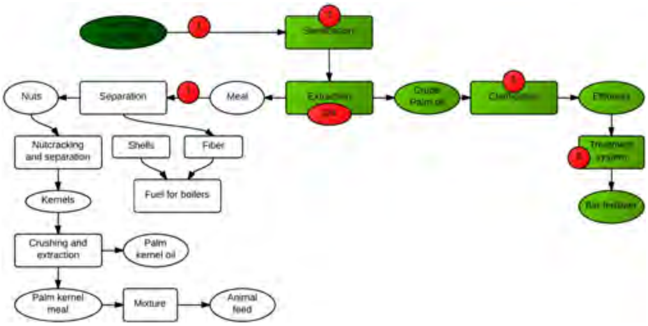
The average biofuel production inventory in Colombia was calculated in two stages. Firstly, all inputs and outputs of oil extraction plants and biodiesel production plants per every 100 tons of FFB's were calculated. Due to the fact that FFB's processing is an activity with multiple outputs, the share on the environment of every one of these impacts must be distributed or analyzed individually (further down, the allocation factor will be explained). In the second stage the impact of producing 1 kg of palm oil-based biodiesel is calculated.

Palm oil extraction

Characterization of the system

The figure below shows a general schematic process. Meanwhile, the table in appendix 13 describes those processes that are included in more detail.

Figure 6.29. System characterization for palm oil extraction



Entry of material and energy

The table below shows the entry of material and energy per every 100 kg of palm for the current (2009) and optimized scenarios. The optimized scenario used those values that come from the extraction plant "Palmera de la Costa" due to the efficient performance that it exhibits in both boiler and turbine.

Table 6.48. Inputs and energy requirements per 100 tons of FFB

Entry	Units	Average	SD	Optimized
FFB	ton	100	-	100
Water	ton	109,84	5,17	109,84
Electricity auto-generated	kWh	740,12	1165,26	2460
Electricity from the grid	kWh	1358,11	820,33	57,24
Diesel electricity	kWh	19,08	21,15	28
Steam	ton	43,35	14,9	48

Source: CUE based on data field

CENIPALMA and Núcleo de estudios de Sistemas Térmicos —NEST— (Thermal Systems Core Studies) calculations present a steam consumption in the extraction process of 550 kg/t of FFB's (Yáñez, Castillo, & Silva, 2011). This value in slightly higher to the result of this study (434 kg/t FFB), which is quite valid due to a higher efficiency. Nevertheless, Wood et.al. found steam consumption of 440 kg/t FFB's (Wood & Corley, 1991). Those values provided by Wood et. al. in terms of electricity (23kWh/t FFB) are coherent with the results obtained by this study (23kWh/t FFB).

Products, by-products and residuals

The table below shows the outputs of the extraction process per every 100 t of FFB's. The conversion efficiency level is assumed equal in both scenarios.

Table 6.49. Outputs from oil extraction of 100 tons of FFB (ton)

Output	Average scenario	SD	Optimized Scenario
Palm crude oil	21,38	0,79	21,38
Cob-like product	21,34	1,81	21,34
Kernel palm oil	2,00	0,70	2,00
Kernel palm flour	2,86	0,61	2,86
Residual water	97,17	6,44	97,17
Fiber	13,16	0,45	13,16
Nuts shell	7,90	1,16	7,90

Source: CUE based on data field

Energy production

The energy required for palm oil extraction is generated in the system of boilers and turbines. By-products of the extraction process, such as fibers and shells, are employed as fuel. Nevertheless, in some cases coal and electricity from the grid are employed as well, and in some others, the employment of diesel engines can be a viable alternative too. The next table summarizes the composition of these entry energy carriers.

Table 6.50. Properties of the FFB, fiber and shells (% indicated otherwise)

Parameter	RFF	Shells	Fiber
Inferior calorific power (MJ/kg)	6,03	12,57	8,98
Humidity	24,24	6,16	28,76
C	54,3	51,8	58,9
Humidity	18,7	25,1	20,15
S	0,22	0,3	0,24
N	3,8	5,15	4,21
O	11,02	12,35	8,62
Ash content	8,93	4,96	5,55

Source: Ecoinvent

Processing 100 tons of FFB's draws close to 13 tons of fiber and 8 tons of shell, which as was just mentioned, are used in the boiler. It is assumed that these materials are used for steam production.

The capacity of an average boiler in a regular extraction process is 20 tons of steam per hour. The steam created has an average pressure between 220 and 290 psi, and a temperature between 160 and 190°C . Therefore, steam has a specific internal energy of 717 kJ/kg. For this study 2 boiler systems were taken into consideration:

1. average boiler,
2. an optimized boiler and pipeline system (from “Palmera de la Costa”).

Emissions are calculated on the process suggested by Ecoinvent, noted as “Cogen unit 6400 kWth, wood combustion”. The same methodology as described before was employed. There are presented emissions of fiber and shells, assessed in MJ but also per every 100 tons of FFB’s in Appendix 9.14.

Infrastructure and machinery

The infrastructure for the palm oil extraction process, and for the boiler, was assumed, based on data from Ecoinvent. Values here are calculated for the processing of 100 kg of FFB and depend on the lifespan of the installed infrastructure and the processing capacity of the facility.

Table 6.51. Process Infrastructure of the Palm oil mill plant

Process	Amount	Ecoinvent reference
Oil Extraction	1.00E-04	Oil extractor / CH
Boiler	8.67E-05	Cogeneration unit 6400 kWth, burning of firewood, construction / CH
	3.47E-04	Cogeneration unit 6400 kWth, burning of firewood, common components for heat + electricity / CH
Turbine	3.47E-04	Cogeneration unit 6400 kWth, burning of firewood, components for electricity only / CH

Source: CUE based on data field

Transport

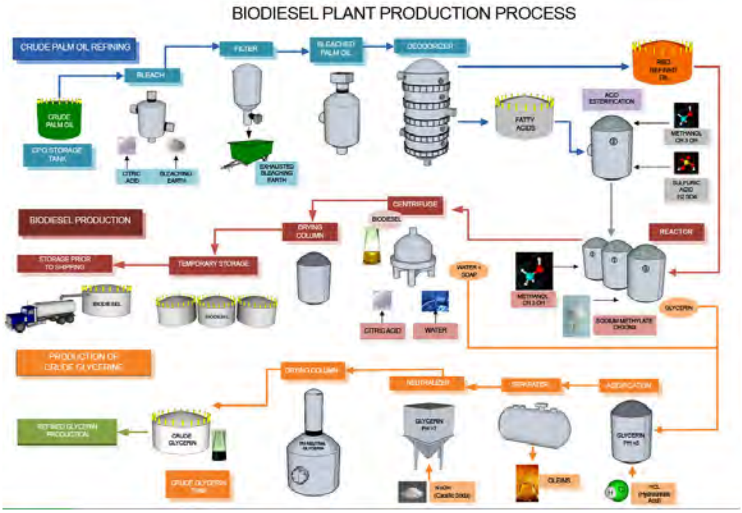
Transportation of FFB’s from the crop field to the extraction plant is already considered in the cultivation stage. Transportation of machinery and equipment is embedded within the set of data for infrastructure.

Refinery and biodiesel plant

Description of the system

The following figure presents a schematic summary of an average biodiesel plant in Colombia. Processing includes crude oil refining, transesterification, and biodiesel purification.

Figure 6.30. System characterization for palm oil refining process



Source: (Manuelita website, 2012)

The following table presents a detailed description for each step of the process.

Table 6.52. Processes description of palm oil refining and biodiesel processing

Process	Description
1. Refinery	Crude oil is filtered, bleached and deodorized (refined, bleached and deodorized palm oil, or RBD) by employing citric acid and bleaching earth.
2. Diesel production	Refined oil might be employed for biodiesel production. In the transeterification process, esters are transformed by employing methanol and a catalyst with the aim of producing biodiesel and glycerol as a by-product.
3. Refined Glycerol production	Glycerol can be used crude or refined up to a specified technical standard, regarding the intended market. For its use in the cosmetic or pharmaceutical industries, it must be refined until USP level.

Source: Fedepalma (2009)

Raw materials and energy demand

The following two tables present entry materials for biodiesel refining and production processes per ton of palm oil-based biodiesel.

Table 6.53. Inputs and energy requirements of a palm oil refinery to produce 1 ton of biodiesel

Input	Unit	Average and optimized scenarios
Crude palm oil	ton	1.04
Citric	kg	0.77
Bleaching earth	kg	5.01
NaOH	kg	0.34
Electricity from the grid	kWh	14.09
Water	kg	179.24
Steam	kg	477.27

Source: CUE based on data field

Table 6.54. Inputs and energy requirements for the biodiesel plant needed to produce 1 ton of biodiesel

Input	Unit	Average and Optimized scenarios
Refined oil	ton	1,0
Methanol	kg	108,65
Sodium metoxide	kg	18,15
Acetic acid	kg	0,63
Citric acid	kg	0,68
Sulphur acid	kg	0,18
Chlohydric acid	kg	7,69
Sodium hydroxide	kg	0,48
N2 gas	m3	2,23
Fatty acids	kg	11,92
Electricity from the grid	kWh	28,18
Steam	kg	361,42

Source: CUE based on data field

Production process and by-products

The next two tables present the outputs from the biodiesel refining and production processes per ton of palm oil-based biodiesel. The resulting products of the refining process (refined oil and fatty acids) are used in the biodiesel process, while residual waters and bleaching earth are treated and disposed respectively.

Table 6.55. Outputs from the refining oil plant per 1 ton of oil (kg)

Output	Average and optimized scenarios	SD
Refined oil	1003.47	24.52
Bleaching earth	6.85	0.83
Fatty acids	35.87	3.52
Residual waters	146.99	104.39

Source: CUE based on data field

Biodiesel plant does not only produce biodiesel, but also raw glycerol and other by–products, such as soaps.

Table 6.56. Outputs from the transesterification process per 1 ton of palm oil biodiesel

Output	Average and Optimized scenarios	SD
Biodiesel	1000	0
Output	137.4	40.3
Soap	50.8	47.4
Residual water	76.2	66.8
Sediment	1.3	0.7
Methanol loss	0.4	0.7

Source: CUE based on data field

Energy generation

The steam generated in the process of transesterification has an average pressure between 1000 to 1500 kPa and an average temperature of 300 °C . Energy consumption is close to 900 MJ per ton of biodiesel.

In this document it is assumed that the steam for transesterification and refining processes comes from coal. In this sense, and with the purpose of calculating the optimization potential, it is considered that biofuel production uses steam that comes from agricultural organic wastes (fibers and shells).

Infrastructure and machinery

Infrastructure for the refining and transesterification process data were taken from the Ecoinvent database under the name of "vegetable oil esterification plant". Having an expected lifespan of 50 years and the given installed capacity, it used 9E-07 pieces per every kg of biodiesel.

Table 6.57. Transportation distances for palm oil refining and transesterification (in ton/km)

Product	Transport Vehicle, truck > 32 t, Euro 3	Cargo Ship
Crude palm oil	70.1	-
Refinery inputs	3.6	10
Refined oil	-	-
Inputs for transesterification	67.6	771.7
Total	141.3	781.7

Source: CUE based on data field

Transportation distances

Distance from the extraction plant to oil refining facilities is on average 68 km. Usually, oil is transported by truck that have a capacity higher than 32 tons. Inputs employed in the refining process are transported, in general, covering huge distances (by instance, bleaching earth is imported), but in comparison with the transesterification process the amount of chemical inputs employed per ton of palm oil–based biodiesel are very low. Due to the fact that the refinery is placed next to the oil processing plant facilities, oil is not transported in trucks.

Application of residuals on the ground

The cob-like waste, ashes from the boiler, and sometimes to a minor extent, a small portion of fibers and shells are used for compost production, or applied directly to the crop field. This study assumed direct application to the field, given that is the most common practice.

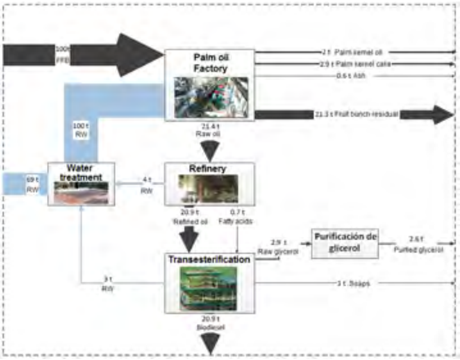
General vision of the inventory and allocation process

The following section will present data referred to as "main flows of materials, prices and energy values". This collection of data, in turn, determines allocation factors.

Mass flow in the biodiesel value chain

Based on the data extracted from the production activity in the field, in Colombia, 20.3 tons of biodiesel per every 100 tons of FFB's are produced. In addition, it is possible to produce 2 tons of palm kernel oil, 2.9 of palm kernel cakes, and 2.9 of crude glycerol. To end up, small amount of soaps come out from the biodiesel process.

Figure 6.31. Mass flow for biodiesel production (per every 100 tons FFB)



The chart only includes the main mass flows coming in and out of the system related to palm oil processing. Therefore, some products that are used within (embedded in) the system, such as shells and fibers, are not depicted in the figure. Furthermore, the graphic representation reflects the generalized situation in Colombia, so specific diagrams of visited plants might differ slightly from the information presented here. For instance, just 2 factories have glycerin purification plants.

Allocation factors

As is shown in the previous figure, biodiesel value chain consists of several sub-chains with multiple exits, therefore by-products must be allocated. Allocation of the different by-products will be implemented economically. Thus, it takes into account the average price of 2009 and the first semester of 2010.

Allocation factors are calculated by multiplying the amount of an output with its price (economic allocation) by the amount of its energy content (energy allocation), and afterwards the value of all outputs are determined (in percentage) for both cases.

Economic allocation

In order to obtain the allocation factors mentioned in the table were used the following economic values.

Table 6.58. Economic value of those by-products from fresh fruit bunches (FFB)

Product	Value	Unit	Description	References
Palm kernel oil	1878	COP/kg	Average price from 2007 to 2009	Annual Statistics (Fedepalma 2009)
Palm kernel cake	266	COP/kg	Average price from 2007 to 2009	Annual Statistics (Fedepalma 2009)
Biodiesel	2463	COP/kg	Average price from 2007 to 2009	MinMinas
Crude glycerol	419	COP/kg	Average price from 2007 to 2009	Website icispricing
Purified glycerol	2063	COP/kg	Based on market international prices from 2007 to 2009	Website icispricing
Soap	150	COP/kg	2011	Personal communication with BioSc
Cob-like residual	152	COP/kg	2011	Personal communication with Cenipalma

Source: CUE based on data field

Energy allocation

The following data is used for the sensibility analysis of results, when the energy allocation is used:

Table 6.59. Energy value of those by-products from FFB (MJ/kg)

Product	Value	Notes	References
Palm kernel oil	37		Personal communication with Cenipalma
Palm kernel cake	19.1		(O'mara, Mulligan et al 1999)
Biodiesel	37.2		Ecoinvent
Crude glycerol	25.3	The highest value of crude glycerol it is explained due to the presence of methanol and biodiesel (trazas) within the sample	www.esru.strath.ac.uk
Purified glycerol	19		
Soap	37		
Cob-like residual	16.8		CUE report

6.2.4 Transport to the service station

The set of data includes fuel transportation from processing plant to service station in Bogotá, taking into consideration actual distances and type of vehicles. Data was collected by employing standard distance tables and interviews with experts.

Transport of sugarcane-based ethanol to service station in Bogotá

Ethanol is mixed in an ethanol plant to a level of 2% of regular gasoline and the remaining portion of ethanol (i.e. E98). Afterwards it is transported to the blending facilities in Bogotá (Puente Aranda). Average distance of transportation is 490km and for this purpose tank trucks are used (the reference in Ecoinvent is: Transport, truck with capacity superior to 16 tons, average fleet / RER U).

Furthermore, fuel distribution to service stations in Bogotá's downtown. Therefore, it also used as a reference the standard process from Ecoinvent "regional distribution, oil products / RER / IU". It also considered the operation of both storage tanks and the gas station itself. It also includes evaporation emissions and effluents treatment.

Transportation of palm oil-based biodiesel to Bogotá

Biodiesel is normally transported in a tank truck. Moving distances from a specific biodiesel plant to the blending station in Bogota (Puente Aranda) are presented as follow:

- Biocombustibles Sostenibles del Caribe (Santa Marta): 960 km
- Oleoflores Codazzi, Cesar: 814 km
- BioD, Facacativá: 46 km
- Aceites Manuelita, San Carlos de Guaroa 171 km.

Transportation of sugarcane-based ethanol to California

Ethanol can be transported from Buenaventura, Colombia to Los Angeles, California (USA). In the first place, different ethanol plants require an average transportation distance by truck close to 129 km all the way to the Buenaventura port. Transportation distance from Buenaventura port to Los Angeles is 5669km. Transportation distances from the maritime port to the final gas station was calculated to be approximately 100km.

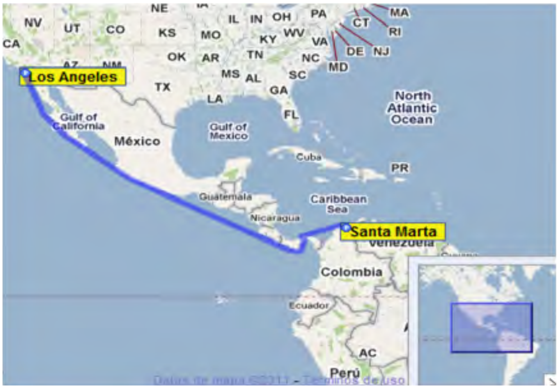
Figure 6.32. Distance from Buenaventura port to Los Angeles

Source: (www.searates.com)

6.2.5 Transport of palm oil Biodiesel to California

Palm oil-based biodiesel must be transported from Santa Marta, Colombia to Los Angeles (6176 km). The first portion of the journey must be carried by road from the production plant in Codazzi, Santa Marta, and San Carlos de Guaroa.

Figure 6.33. Distance from Santa Marta to Los Angeles



6.2.6 Use of fuels in vehicles

Selection of Vehicles

In order to establish a comparison of use of different biofuels reference vehicles are required. Obviously it is not possible to compare directly a km of operation of a light and efficient vehicle (just like a compact car in a city) with a km of operation of a heavy and inefficient vehicle (like a light truck, or pickup truck) because the amount of required fuel will be very dissimilar in absolute terms. However, if relative environmental impacts are compared between fuels and biofuels in the same vehicle, a comparison of results is absolutely valid.

The report presented by consortium proposed to choose a reference standard vehicle according to Ecoinvent guidance (Hischier et al., 2010) for common use in Colombia and other countries. Data of this inventory rest on information provided for a Volkswagen Golf, which is a vehicle that runs on Colombian roads but is not a very common one. For this reason, in this study the most representative vehicle in Colombia was chosen, a Renault Logan.

Fuel use and consumption of a Renault Logan

System description

Renault Logan was selected as a representative vehicle for the Colombian market. Renault Logan is a medium-class vehicle designed for 5 passengers (including driver) and with a boot capacity of 510 liters (See appendix 9.15).

Renault Logan is manufactured in the plant of SOFASA in Medellín / Envigado whereas single pieces are imported from the Renault/Dacia Plant in Rumania.

In Colombia, the Renault Logan has been sold, so far, with gasoline engines (1.4 L 75 HP and 1.6 L 90 HP). Nevertheless, the same model in some other countries is sold with diesel based engines. Under given circumstances these engines comply with emission class Euro4. In this document, it is supposed that energy consumption for Renault Logan is:

Gasoline Model: 1.6L 90HP: 7.56 l/100km under a regular blend in the "real world" it reaches 50 km/gal

Diesel Model: 1.5 cDi 85HP: 5.29 l/100km under a regular blend in the "real world" it reaches 72 km/gal

The notation of "real world" makes reference to the event that actual consumptions are, in fact, higher than the ones suggested by the automobile manufacturers. These specifications are based on assessments on standard conditions in the test lab. In comparison with some other vehicles, Renault Logan is relatively light weight, for both the gasoline version (980 kg) and the diesel one (1065 kg).

Inventory is based on the composition of Renault Logan with both gasoline and diesel engines. The inventory of data was based on the technic specification provided by Renault on its website (www.renault.com) and data from the inventory from Ecoinvent when it was needed to complete the data set (for instance for emission profiles).

Chassis of the gasoline and diesel models are identical, whereas transmission systems are modeled individually. The lifespan of the studied vehicles was adapted from 150.000 km to 300.000 km with the idea of reflecting more accurately Colombian conditions.

Emissions were modeled in accordance to the last version of Econinvent (v2.3), which includes values for biofuels. The inventory of emissions was adapted in regards to the energy consumption of the vehicles employed in this study.

Vehicle for international comparison

The chosen vehicle for comparison purposes with an international reference —was a vehicle that runs in California based on fossil fuels— and was proposed by Ecoinvent (Hischier et al., 2010). The set of data (Inventory for passenger cars /RER/I U') is based on the Volkswagen Golf 4 which is frequently used for international comparisons for LCA studies, and therefore it allows a clear reference. In comparison with Renault Logan, this vehicle is 100 kg heavier, and it exhibits a higher fuel consumption and a shorter lifespan (150.000 km in USA and 300.000 km in Colombia).

Gasoline-based vehicle: Energy consumption and emission profile for gasoline-based vehicle matches with the description given by Ecoinvent: “operation, passenger automobile, gasoline, average fleet 2010 L/km/RER”. Fuel consumption is 0.060202 kg/km (8.03 L/100 km) in comparison with 0.0567 kg/km (7.56 L/100 km) for the gasoline based Renault Logan.

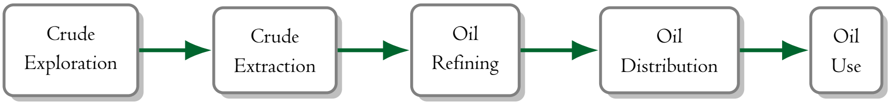
Diesel–based vehicle: Energy consumption and emission profile for the diesel-based vehicle matches with the description given by Ecoinvent: “operation, passenger automobile, diesel, average fleet 2010 L/km/RER”. Fuel consumption is 0.055828 kg/km (6.65 L/100 km) in comparison with 0.0444 kg/km (5.29 L/100 km) for the diesel based Renault Logan.

Regardless of the created emissions per fuel consumption (CO2, CO), profiles of emission of the vehicle in California and Colombia present similar performances. Colombian vehicles create lower emissions (for instance NOx) because of the applied standard, which obeys the EURO4 regulation.

6.2.7 Fossil fuels

Within this section is described the inventory of the life cycle of production and transportation of fossil fuels and gasoline in both Colombia and California (USA). Therefore, it models the chain value of actual blends in Colombia and California, taking into account all the steps of the life cycle (figure below). In addition, modeled values for fossil fuels in Colombia and California are contrasted and validated based on the values presented in publications and opinions of experts.

Figure 6.34. Chart of the LCA for fossil fuels



Gasoline and Diesel production in Colombia

Specific references to fossil fuels in Colombia are gasoline and diesel (also known as ACPM in the local market —Aceite Combustible para motor— Oil fuel for engines). For GHG's emissions those values provided by the in depth study undertook by Ecopetrol (section 6.3.8.6) were used. However, for some other sort of environmental impacts there is no inventory data, nor impact values. In such cases, they were adapted from the available set of data provided by Ecoinvent for Colombia and they were used to calculate some other environmental impacts different from global warming.

Crude oil extraction

Colombia is considered as a continuous but marginal oil exporter in the international market, but still important in comparison with some other countries from the LAC region. According to the International Energy Agency, Colombia can be considered as a net crude oil exporter, and it manages a small amount of refined products (gasoline and diesel) (IEA, 2011)

Table 6.60. Fossil fuels production in Colombia (in 1000 tons)

Item	Crude oil	Engine type	
		Gasoline	Gas/Diesel
Production	273465	3164	4395
From other sources	0	0	0
Imports	401	1	285
Exports	-11681	-363	0
Bunkers of international cargo ships	0	0	-367
Bunkers of international airplanes	0	0	0
Change in stocks	502	200	-109
Domestic supply	16567	3002	4204

Source: IEA (2007)

In 2009, national reserves reached a level of 1.9 billion barrels of oil. Average crude oil production in 2009 was approximately 670,000 barrels per day and for some years this trend has been growing gradually (EIA, 2009b). Evolution of crude reserves and their corresponding production are shown in the following table.

Table 6.61. Colombian crude reserves and oil production

Year	Crude (Million barrels)		
	Reserves	Annual production	R/P
2000	1,972	251	7.9
2001	1,842	221	8.4
2002	1,632	211	7.7
2003	1,542	198	7.8
2004	1,478	193	7.7
2005	1,453	192	7.6
2006	1,510	193	7.8
2007	1,358	194	7.0
2008	1,668	215	7.8
2009	1,988	245	8.1
2010	2,058	287	7.2
2011	2,259	334	6.8
2012	2,377	346	6.9

Source: Compiled by the Author. Data source ANH website

Crude oil extraction technology

Extraction of crude oil in Colombia is implemented onshore; whereas there is only one oilfield in deep waters (offshore) that has been named "Chuchupa" which is located 15 km away from Rioacha heading northeast, and from which natural gas is extracted. In general natural gas that comes from the oil crude extraction process is burned The process described in Ecoinvent as "Crude oil, production/ RME U" was employed for the Colombia conditions (Jungbluth et al., 2007).

Oil Refining

In Colombia near to 74% of crude oil is refined in the refining plant located in Barrancabermeja, Santander. Refinery plants in Colombia operate at 95% of the installed capacity (UPME, 2009). Recently Ecopetrol inaugurated a water treatment plant in the Barrancabermeja's refinery, with the purpose of producing diesel and gasoline of 50 and 300 ppm of sulphur correspondingly.

Figure 6.35. Loads to refinery and Barrancabermeja refining plant

Source: (Ecopetrol, 2009)

For the GHG's, were considered the emission factors provided by Ecopetrol. Nonetheless, some other environmental factor impacts are based on average data provided by Ecoinvent about a standard refinery in Europe ("diesel, low sulphur, in the refinery kg/RER U" and "gasoline, low sulphur, in the refinery kg/RER U ") (Jungbluth et al., 2007). It is guessed that transportation distances for crude oil from the extraction fields to the refinery plant are close to 493 km, via pipelines (Ecopetrol, 2011)

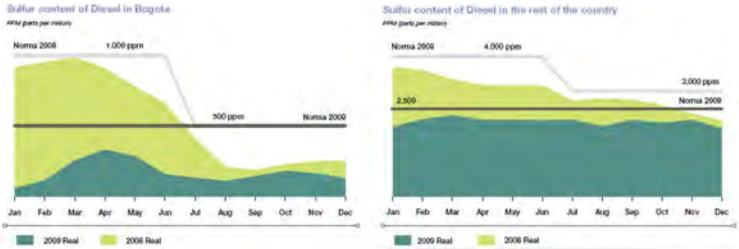
Transportation to the service station

Diesel is transported through pipelines from the refinery all the way up to the blending station in Puente Aranda in Bogotá. Transportation process from refinery is based on high quality data provided by Ecopetrol, GHG's emissions and the remaining emissions and entries were based on the default information registered in Ecoinvent. In accordance with Colombian conditions transportation distance to the service station was calculated to be 509.07 km (Ecopetrol, 2011). It is worth to note that the former is just a mere assumption employed within the LCA study, which does not describe completely the transportation process of those refined products given by Ecopetrol.

Ecopetrol continued its commitment of improving quality of available fuel, by distributing diesel of low sulphur content. In 2009, content of sulphur for diesel fuel in Bogota was less than 500 parts per million (ppm), thus is known as low sulphur diesel (LSD). In the rest of the country, from January 2009, sulphur levels were reduced from 3000 ppm to less than 2500 ppm. The following information describes the process that Ecopetrol inventory presented in 2008, in which it does not include water treatment plant. The hydro-treatment plant started operations in 2010, and as a consequence sulphur content dropped. Since 2008, official regulations on specifications for fuels changed (see figure 6.35). For instance, sulphur content in the first semester of 2008 was 4000 ppm, while in the second semester of 2008 it drop down to 3000 ppm;

but in contrast in 2010/2011 this item was 500 ppm of Sulpher, and in 2013 it is expected to be reduced to 50 ppm or less. Although, note that all big cities and massive transportation systems in Colombia have been employing LSD since 2011.

Figure 6.36. Sulphur content for Diesel (Colombia)



Source: (Dickey, Shelton, Jasa, & Peterson, 1985)

Study presented by Ecopetrol on GHG's emissions caused by fossil fuels

In 2010, Ecopetrol undertook a LCA study on GHG's emissions related to fossil fuel (gasoline and diesel only) in Colombia. This study was carried out for fuels with local specifications for the year 2008, presented below:

Table 6.62. Fuel specification regarding Ecopetrol study

Refined properties	Sulphur (ppm)	PCI (MJ/kg)	Density (kg/m^3)
Regular gasoline (average 2008)	610	45.14	742.2
Regular Diesel (average 2008)	2850	45.45	851.2

Ecopetrol's study quantifies GHG emissions such as carbon dioxide, methane and nitrous oxide, for different stages of the life cycle. Emissions were calculated from values assessed, and values that could not be assessed were calculated by using assessment protocols for the inventory of GHG in the industry of petroleum and gas. Life cycle stages can be broken down into:

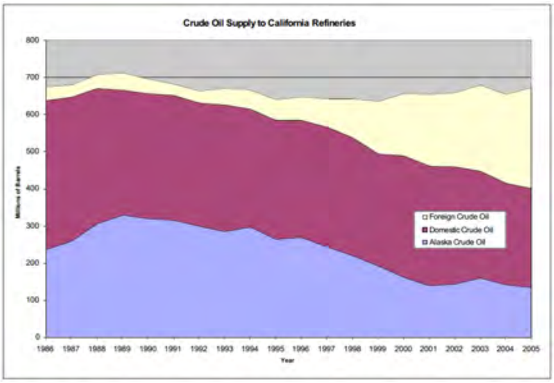
- crude extraction,
- transportation to refining facilities,
- refining and fuel transportation to blending station (Puente Aranda, Bogotá),
- Note: fuel distribution to final retailer's station and infrastructure (i.e. buildings and machinery) are beyond the scope of this study.

The impact of fossil fuel production was calculated based on the methodology proposed by the IPCC "for the global warming potential (GWP) for 100 years". Results show that regular gasoline in blending station exhibits a GWP corresponding to 10.3g of CO2 equivalent per MJ and for diesel the assessment draws 10.5g of CO2 equivalent per MJ. Furthermore, it shows that accumulated energy demand for diesel is 1.22 MJ per MJ and for gasoline is 1.19 MJ per MJ. These values will be used as a reference below.

Gasoline and diesel production in California

The chain value for gasoline and diesel that are consumed in California is mainly modeled based on the information from the Energy Commission of California (Sheridan, 2006). Refining capacity of oil and diesel exceed consumption levels, therefore it is assumed that all diesel and gas employed in California is refined locally. Nevertheless, due to present demand and reduced supply of local crude oil, more crude must be imported.

Figure 6.37. Crude oil supply to Californian refineries



Source: (Sheridan, 2006)

The following section describes the source of crude petroleum and the involved processes, thus the inventory is built it up.

Crude oil extraction

Close to 34% of the refined crude oil in California is extracted at national level, while 21% is imported from Alaska and 45% from other countries. Near to 7% of the national crude oil of California is in underground oilfields (Department of Conservation, 2010). In Alaska the situation is similar (Division of Oil & Gas, 2012). Crude imports come from Middle East and Latin America.

Table 6.63. Crude oil composition from California (including transport and process assumptions from Ecoinvent)

Source of crude oil	Share	Extraction technology	Transport (km)	Ecoinvent reference
California	34%			
California	32%	Inland production	200	Crude oil, Inland production / RME S
California	2%	Offshore production	200	Crude oil, Offshore production / GB U
Alaska	21%			
Alaska	16%	Inland production	3032	Crude oil, Inland production / RME S
Alaska	5%	Offshore production	3032	Crude oil, Offshore production / GB U
Overseas	45%			
Saudi Arabia	11%	Inland production	18357	Crude oil, Inland production / RME U
Iraq	8%	Inland production	21417	Crude oil, Inland production / RME U
Ecuador	8%	Inland production	5978	Crude oil, Inland production / CO U
Other	18%		6103	Crude oil, Inland production / RME U

Source: CUE

Refining

Due to the lack of data on specific process of oil refining in USA, average data from an average refining facility in Europe was taken, as a way of approximation from the database of Ecoinvent ("low sulphur diesel, to the refinery kg / RER U" and "low sulphur gasoline, to the refinery kg / RER U") (Jungbluth et al., 2007).

Transportation to the service station

Refineries in California are located in the San Francisco Bay area, Los Angeles zone and Central Valley. Average distance was assumed to be 100 km.

6.2.8 Electricity production

Inventory of electricity at low, medium and high voltage in Colombia is calculated based on the report published by the International Energy Agency (IEA 2008) and the impact on the transmission. For electricity and transmission processes the reference of Ecoinvent are taken as valid for the UCTE (Faist Emmenegger et al., 2009; Frischknecht et al., 2007).

Table 6.64. Electricity matrix for Colombia

Energy carrier	GWh	%	Reference Ecoinvent
Coal	3045	5.4%	Electricity, coal, energy plant / UCTE U
Liquid fuels	151	0.3%	Electricity, liquid fuels, energy plant / UCTE U
Gas	5781	10.3%	Electricity, natural gas, energy plant / UCTE U
Biomass	590	1.1%	Electricity, bagasse, sugarcane, in refinery/ BR U
Hydro	46403	82.8%	Electricity, hydropower plant / CH U
Wind	54	0.1%	Electricity, wind power plant / RER U
Total	56024		-

Source: IEA (2010)

The values of electric energy emission in Colombia were adapted through the inventory of Ecoinvent and are presented here.

Table 6.65. Emission factors for generation and transmission of electricity used in this study

Category of impact	Unit	Medium voltage	Low voltage	High voltage	Mix
IPCC GWP 100 years	kg CO2 eq	0,166	0,188	0,162	0,158

The current impact of the mix of electricity in Colombia depends of the daily generation in thermal generation plants and hydroelectric plants. Carbon emissions are calculated based on the electric energy data published on a daily basis by XM Expertos (XM expertos, 2010). Taking into account coal daily consumption, diesel and natural gas, as well as transmission losses, emission factors fluctuate between 0.035 and 0.44 kWh. On average, emission factors are between 0.13 and 0.18kg of CO2 equivalent per kWh, which is accurate with the emission factors presented in the table 6.65.

6.3 IMPACTS EVALUATION

As it was mentioned earlier, the GWP was evaluated, which is defined as the impact of human emission in the heat radiation absorption from the atmosphere. This model is known as Global Warming Potential (GWP), created by the IPCC in 1990, which turn emission data of some gases, created during a life cycle studied in this document, to Kg of CO2 equivalent, through characterization factors.

Likewise, the accumulated demand of energy, as is expressed by its name, represents the addition of non-renewable sources and/or nuclear energy, and is expressed in thermal units (MJ) (a mode detailed explanation can be found by (Frischknecht et al., 2007; Jungbluth et al., 2007).

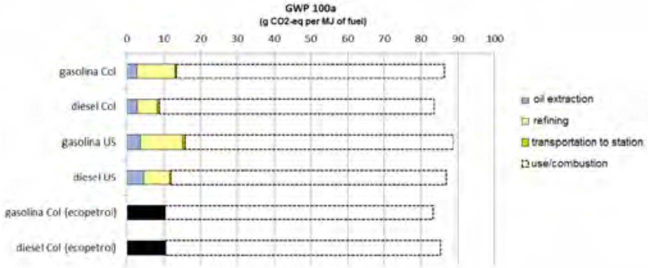
Midpoint indicators such as acidification eotriphication, ecotoxicity and particulate matter are discussed in appendix 9.4

6.3.1 Fossil fuels

Global Warming potential

The figure below shows GHG emissions for fossil fuels in both Colombia and California, in grams of CO2 equivalent per MJ of fuel from the oil-well to the tank. In order to produce and use (only combustion) fossil fuels, it emits between 83 to 89g of CO2 equivalent. Most of the emissions of GHG are caused during the combustion process (84% - 89%). Beyond that, emissions are related with the refining process (7% - 12%) and crude oil exploration and extraction (3% - 5%), while fuel transportation to the service station is negligible. In general, diesel refining releases less GHG in comparison with gasoline refining (because diesel required less energy).However, fossil diesel accounts for higher emissions of CO2 equivalent per MJ of fuel, during use.

Figure 6.38. GHG emissions for fossil fuels per MJ of fuel



Source: CUE

Results from the detailed study from Ecopetrol are similar to the ones presented here. Environmental impact, slightly under the one reported by Ecopetrol, might be explained by the fact that it did not include the infrastructure impact and the fact that modeled fuel had with higher sulphur content.

The following table, summarizes compared results with different standards of GHG emissions. In general terms, values reported by the norms are similar to the ones reported here. Details can be explained by the different assumptions and process considered in the individual standards.

Table 6.66. Comparison of CO2 emissions from fossil fuels from different studies

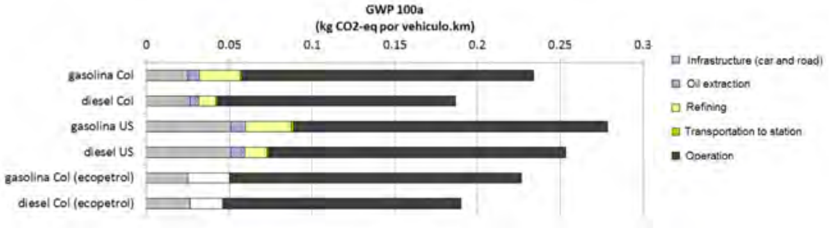
Country	GHG's emissions (g CO2/ MJ fuel). Without combustion		GHG's emissions (g CO2/ MJ fuel). With combustion	
	Gasoline	Diesel	Gasoline	Diesel
Colombia	13.43	8.73	86.39	83.5
Colombia (Ecopetrol data)	10.3	10.5	83.23	85.26
USA (California)	-	-	88.7	86.77
UK	-	-	85	86
USA (California) (CARB 2009)	-	-	94.71	98.86
EU (EC 2008)	-	-	83.8	87.64

Given that diesel combustion is more efficient than gasoline (more km per MJ of fuel) a comparison with scientific validation must take place in this case: Therefore, the figure below presents GHG emission assessment related to all LCA (from well to wheel), taking into account road infrastructure and vehicle manufacture. As was noted, a diesel fed vehicle emits less CO2 per km.

Furthermore, Colombian fuels used to propel a Renault Logan, emit less GHG than a standard automobile in California. There are several reasons for that, including:

1. the Renault Logan has a higher efficiency than an average car in California.
2. the lifespan of a vehicle in Colombia is nearly twice as much as it is in California, therefore production and final disposal for vehicles in Colombia are relatively low in comparison with the Californian standard.
3. associated emissions with fuel production are slightly above Colombian case.

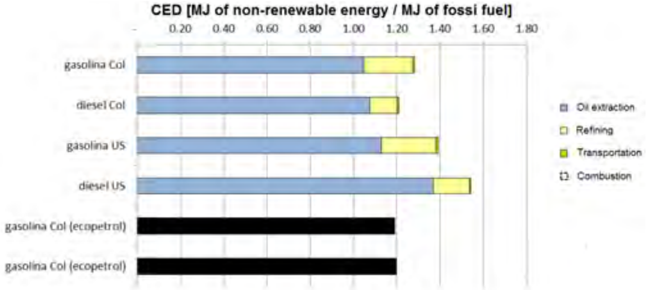
Figure 6.39. GHG emissions for fossil fuels per v.km



Cumulative energy demand

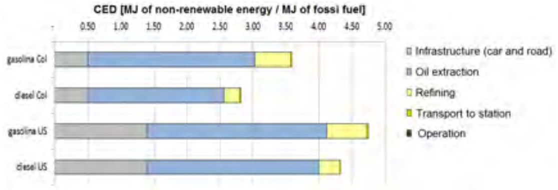
As it is shown in the figure below, production of 1 MJ of fossil fuel requires an entry of 1.2 to 1.5 MJ, depending on the mix of crude oil and the chosen transformation path (technological treatment).

Figure 6.40. Cumulative non-renewable energy demand per MJ of fossil fuel



The figure 6.40 includes the load of infrastructure per vehicle km. Once more, the lifespan of the Colombian reference vehicle improves the energy balance from 2.8 to 3.6 MJ per vehicle km. for Colombian conditions and 4.3 to 4.7 MJ per vehicle km. in USA (see figure below).

Figure 6.41. Cumulative non-renewable energy demand per v.km

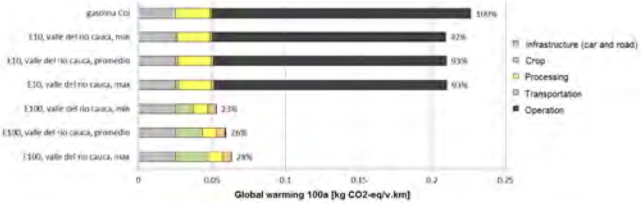


6.3.2 Sugarcane – based ethanol

Global warming potential

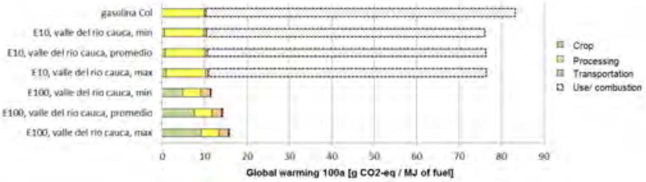
In a very broad sense, sugarcane-based ethanol production and use, emits less GHG in comparison with regular fossil-based gasoline. Per vehicle km. it emits between 53g to 63g of CO2 equivalent in comparison with fossil fuel (226g of CO2 eq. per v.km). If E100 is employed it is possible to reduce to about 72% to 77% GHG emissions. Apart from infrastructure impact (construction of roads and highways), cultivation stage contributes a major proportion to GWP.

Figure 6.42. Global warming potential of sugarcane ethanol in CO2 eq v.km



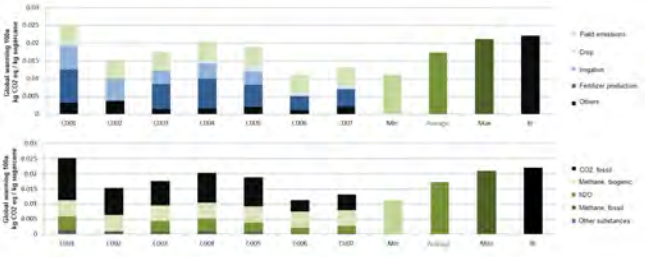
The figure below reveals impacts of ethanol transportation to the service station in Bogotá and they are shown in g per MJ. Each MJ of fuel (excluding infrastructure) composes between 12g to 16g per MJ. The GHG emissions of the ethanol production are superior to fossil fuels production, but the former creates a high contribution of gases during combustion. Notwithstanding, if combustion is taken into the account the figure 6.43 appears again.

Figure 6.43. Global warming potential of sugarcane ethanol per MJ of fuel



Underneath is shown the performance of studied locations, and it is presented as kg of CO2 equivalent per kg of harvested sugarcane. Predominant impacts are linked to production and application of fertilizers, which are very energy-intensive activities, creating a big burden in the agricultural stage. In addition energy consumed in irrigation tasks creates significant impacts.

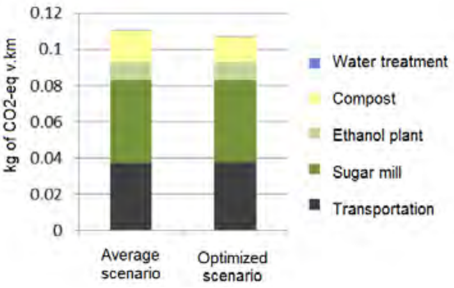
Figure 6.44. Global warming potential for sugar crop in CO2 eq per Kg of sugarcane



The impact is broken down into process (upper panel) and substance (lower panel). Furthermore the minimum, maximum and weighted averages (in function of the area) are compared with the data set from Ecoinvent for the Brazilian case.

GHG emissions associated to sugarcane processing (ethanol production) are caused mainly due to ingenio's activity (41%), transportation of sugarcane from plantation to manufacturing plant (34%) and composting activities (16%). Composed of a volatile impurity residual called flemaza, filtered mud and some other sources of organic material, causes methane emissions, which as it has been told, have a great impact on global warming. As it is shown in the figure below, environmental performance might be improved lightly through much more efficient systems (boiler and turbine) in the processing plant and if CO2 in liquid form is sold.

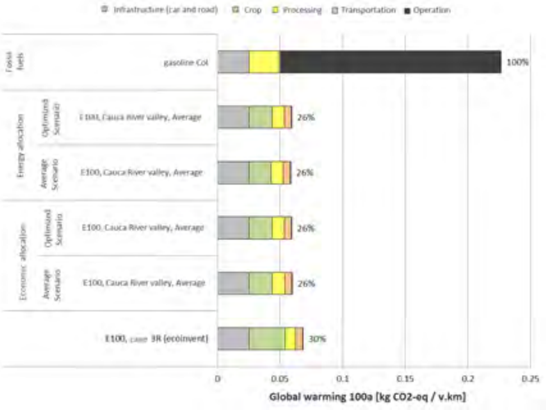
Figure 6.45. Global warming potential for sugar processing divided by process



Sensitivity analysis: Allocation factors

Below are presented the different methods of allocation of GHG's emissions of Colombian ethanol from sugarcane (economic allocation factor for ethanol is: 22% energy allocation factor: 22%). Due to the fact that both economic and energy allocation factors are similar, results are also similar. Therefore, even if current prices are used, results are indifferent to the allocation method.

Figure 6.46. Sensitivity analysis of the allocation method for ethanol

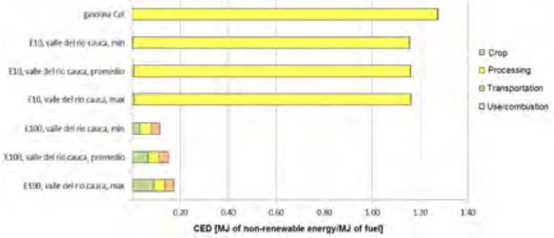


The figure above exhibits impacts on the economic and energy allocation for the average national scenario and also for the optimized one in comparison with fossil fuels.

Accumulated energy demand

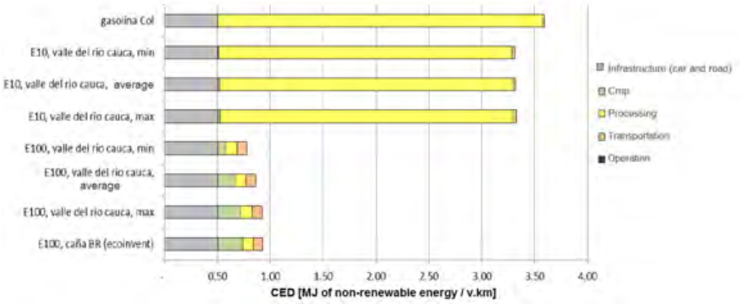
Accumulated energy demands of non-renewable energy for ethanol fuelled vehicles is less than the one presented by those fed by fossil energy (with a factor between 7 and 11). Energy return, assessed as the amount of MJ as output per every MJ used as input fluctuates between 6 and 8, depending on the plantation intensity and on the productivity.

Figure 6.47. CED of sugarcane ethanol in MJ of non-renewable energy per MJ of fuel



Per every driven kilometer a vehicle powered with ethanol consumes less than 3 MJ of non-renewable energy, in comparison with regular gasoline (see figure below). A high component (more than 50%) of the non-renewable used energy, to drive with ethanol is directly linked with infrastructure.

Figure 6.48. CED of sugarcane ethanol in MJ of non-renewable energy per v.km

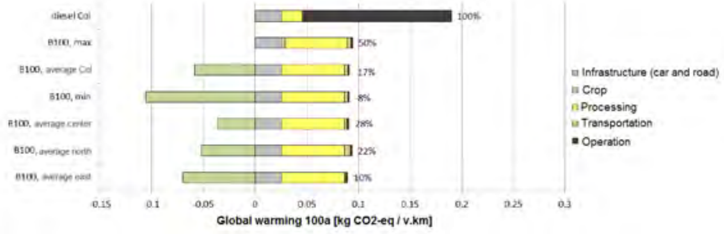


6.3.3 Palm oil biodiesel

Global warming potential

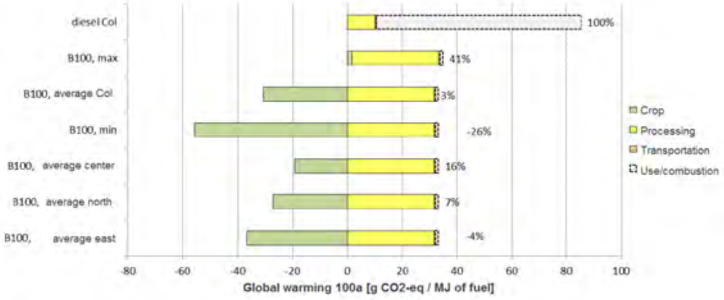
In a very broad sense, it is possible to assert that production and use of diesel from biological origin creates fewer emissions in comparison with its equivalent fossil substitute. Per vehicle km there is an emission between 14g and 94g of CO2 equivalent in comparison with fossil fuels (190g of CO2 equivalent per v.km.). If B100 is employed it is possible to reduce between 50% and 108% —on average 17%— of GHG emissions, depending on the LUC.

Figure 6.49. GWP for palm oil biodiesel in CO2 eq per v.km



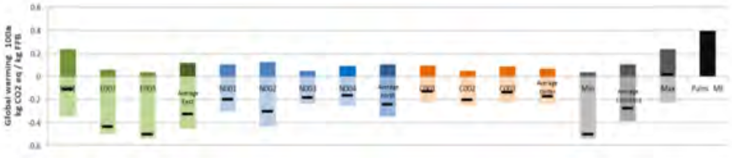
In the figure below the impact of biodiesel transported to the service station in Bogota are shown, is shown in g of CO2 per MJ of fuel. Per MJ of fuel and excluding the infrastructure, GHG emissions oscillate between 23 and 35 g of CO2 per MJ. GHG generation in biodiesel production exceeds the one corresponding to fossil fuels, which in fact emit most of the released CO2 in the combustion process. Nevertheless, if combustion is taken into the account, results are comparable to those presented in the figure above.

Figure 6.50. GWP for palm oil biodiesel by process in g of CO2 eq per MJ of fuel



Palm oil impact is dominated by direct positive effects in the LUC. Palm oil cultivation in zones with relatively low carbon reserves (i.e. agricultural lands and grazing lands) create an increase in the carbon reserves, therefore GHG emissions are avoided to some extent (as is shown in the following figure). Impacts of palm oil cultivation in Colombia are generally fewer than those presented in Malaysia, because in this country, most plantations are established in tropical forest.

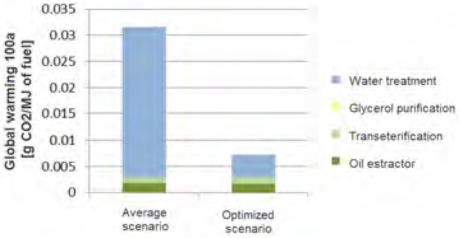
Figure 6.51. GWP for palm oil biodiesel in kg CO2 eq per kg of Fresh Fruit Bunch



The above figure shows impact in the LUC (light color) and the impact of the plantation (dark color), whereas the average is indicated with the black bar.

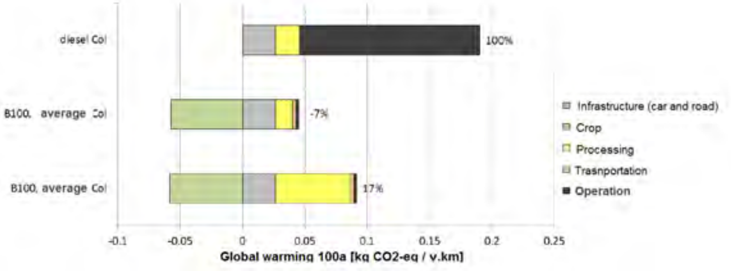
GHG emissions associated to palm oil processing (biodiesel production) are caused mainly by residual water treatment (90%), due to high emissions of methane. As is shown in the figure below, these impacts might be reduced 77% if the emitted biogas is captured and burned (therefore is emitted CO2 instead of CH4). These alternatives have been studied already by the palm oil agribusiness association, FEDEPALMA (Fedepalma, 2006b), and they will be implemented within the next few years.

Figure 6.52. GWP for palm oil biodiesel divided by process



In the next figure, the total impact of the optimized scenario is compared with the average scenario. The extent of the capture of methane emissions, through the treatment of residual waters, reduces substantially the GHG emissions (from 17% to -7%).

Figure 6.53. GWP for average and optimized scenarios in comparison with fossil fuels

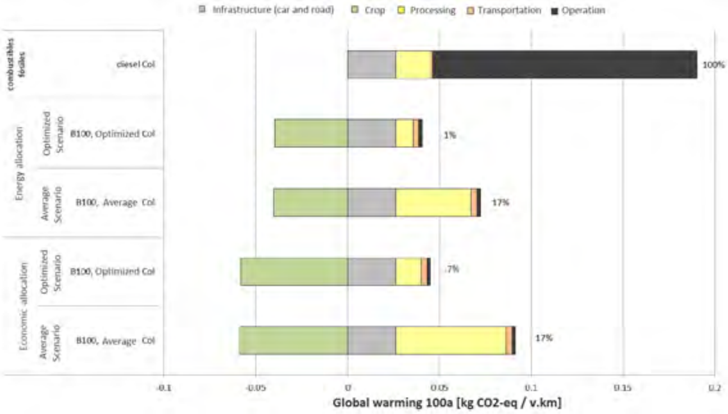


Sensitivity analysis: allocation factor

Below, are presented different allocation methods of GHG emissions for the palm oil-based Colombian biodiesel (economic allocation factor: 86%, energy allocation factor: 56%). In general biodiesel impacts are reduced if energy allocation factors are employed instead of economic allocation factors (this situation is valid to either positive or negative impacts). For the former situation, based on the average scenario, the effects of the energy allocation method leads to a situation in which the reduction of the positive impacts (in the agricultural stage) and reduces in the negative impacts (infrastructure, processing, transport and operation) can be balanced between themselves, therefore total impact remains as 17% of the impact of fossil fuels.

For the optimized scenario, GHG savings relative to palm crops are reduced significantly if energy application factors are applied; thus GHG savings can be reduced in between 99% to 107% in comparison with the fossil reference.

Figure 6.54. Sensitivity analysis of the allocation method for palm oil biodiesel

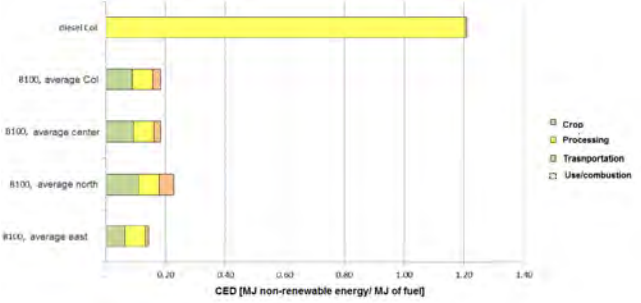


The figure shows the impact based on both economic and energy allocation for the two studied cases: average and optimized ones in comparison with fossil fuels.

Accumulated energy demand

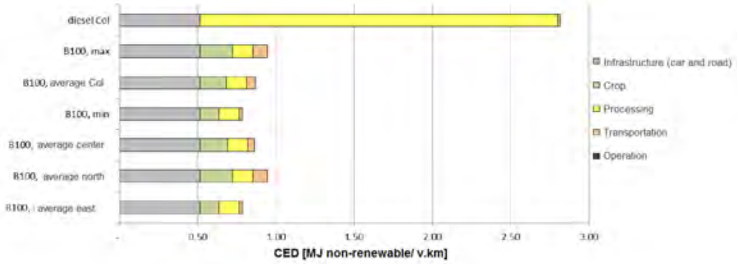
Accumulated energy demand for diesel fuelled vehicles is less than the one presented by those fed by regular diesel (with a factor between 7 and 11). Energy return, for the biodiesel case, fluctuates between 4 and 7, depending on the plantation intensity and on the productivity.

Figure 6.55. CED for palm oil biodiesel in MJ of non-renewable energy per MJ of fuel



Per driven km, a diesel-fed vehicle requires less than 2 MJ of non-renewable energy in comparison with fossil diesel, as is shown here. A high percentage (54% to 66%) of non-renewable energy in the use of biodiesel is associated with infrastructure (road construction, vehicles, maintenance and final disposal).

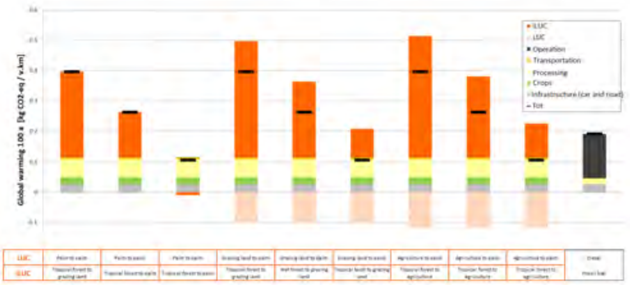
Figure 6.56. CED for palm oil biodiesel in MJ of non-renewable energy per v.km



6.3.4 Indirect land use changes (iLUC)

Those results that have been presented so far just take into account those direct land use changes (LUC). Most lands that are being used or are planned to be used for cultivation of feedstocks for biofuel production are currently occupied for other purposes (for instance agricultural or grazing lands). Based on the assumption that the demand of food products (from either agriculture or grazing activities) remains, the displaced products due to new palm oil plantations must be placed somewhere else. The loss of the production area can be offset by either intensification processes or expansion of natural areas. These indirect effects are rather complex and surrounded by a great deal of uncertainty. So, considering only direct effects and putting aside the iLUC there can be created what it is called here the “best possible case”. From this point onwards, this document will consider the “worst possible scenario” of iLUC assuming the expansion of natural systems with the purpose of illustrating the maximum potential.

Figure 6.57. Potential effects of iLUC caused by palm crops in Colombia

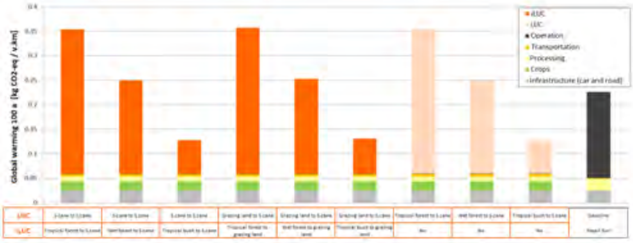


The figure 6.57, shows the potential iLUCs, for palm oil cultivation case, if crops are held in grazing or agricultural lands. The mentioned displacement entails pressure on natural lands (tropical forests, wet forests and bushes). Depending to what extent the natural system is affected, the iLUC has a significant impact on the carbon reserves and therefore on the GWP.

If the indirect displacement takes place in tropical or wet forests, the GWP of biofuels is even higher than in comparison with fossil references. On the contrary, if the displacement occurs in bushes or scrubland, the extent of impact will be less and the GHG balance of biofuels will be positive in comparison with fossil fuels.

A similar situation is presented for the case of sugarcane, as is illustrated in the figure 6.58. In this chart the iLUC of implementing sugarcane crops in general, the LUC of switching from sugar production to ethanol manufacture (LUC from sugarcane from sugarcane), and the implementation of sugarcane crops in pasture lands and other natural areas are compared.

Figure 6.58. Potential effects of iLUC caused by sugarcane crops in Colombia



In any case, a LUC of natural forests creates a natural impact even higher than the one created by fossil fuels. As was mentioned formerly, a direct displacement to agricultural or pasture lands might create an indirect pressure in natural areas. So, if feedstock for biofuels production is cultivated on agricultural or grazing lands, displaced products should be produced through intensification process or in scrublands. In Colombia there is potential for maintaining intensive livestock farming programs, using, for instance, forest grazing or silvopasture techniques.

The core of this sensitivity analysis of the iLUC is that not only direct effects, but also indirect effects must be considered when a new crop is planned. With the rationale of maintaining the land use change effects (either direct or indirect ones) in an acceptable range, detailed studies are required on land requirements, land availability and LUC planning mechanisms.

6.3.5 Blending options and exports to California

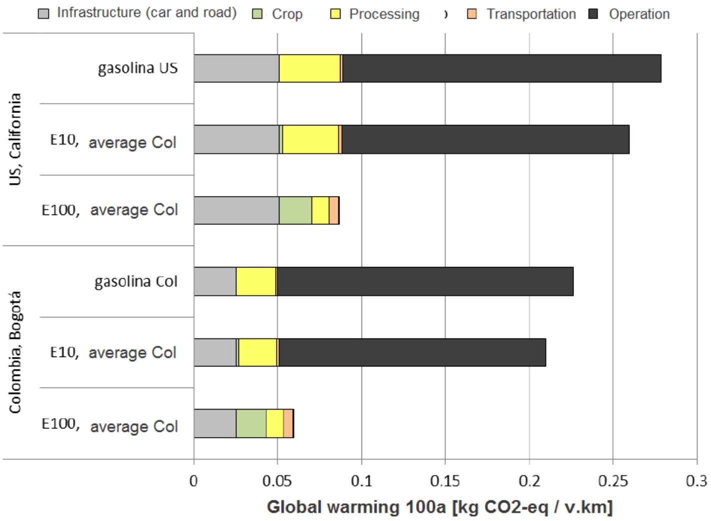
Global Warming Potential

The next two figures show the global warming potential (GWP) for neat ethanol (E100) and a regular blend of ethanol with gasoline (E10) based on sugarcane. The information also includes the palm oil-based biodiesel employed in both California and Bogota.

In general the environmental impact of a standard vehicle in the USA is higher than in Colombia, due mainly to the fact that in the Northern country vehicles are heavier, therefore the distance performance is reduced. On the other hand, infrastructure also has a higher impact in the USA, given that both roads and vehicle fleet have a lifespan shorter than in Colombia. However, the environmental impact of fuel transportation is marginal compared to their production and use process. This is particularly true for water transportation methods, even if the distance is long.

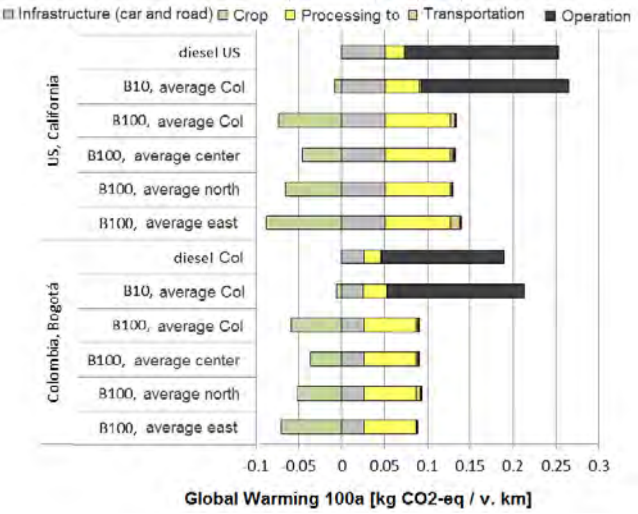
For ethanol produced in the geographic valley of Cauca River the impact of transportation is marginal, regardless of the destination (either Bogota or Los Angeles), as is presented.

Figure 6.59. GWP for Ethanol (Colombian Average E10 E100). Ethanol used in Bogota and California



The GHG balance can be marginally affected by biodiesel transportation. Nevertheless, the extent of the impact of transportation is susceptible to reduction based on the location. For instance, it is friendlier in environmental terms to carry biodiesel (produced in the Caribbean coast) via ship to California, than move this kind of biodiesel to Bogota. On the other hand, the idea of carrying palm oil-based diesel from the Department of Meta to export ports does not have any effect in environmental terms.

Figure 6.60. GWP for biodiesel (Colombian Average B10 B100). Biodiesel used in Bogota and California



In addition, blends do not alter impact, given that reductions are proportional to the amount of blended fuel.

6.3.6 Comparison of Colombian biofuels with some other biofuels

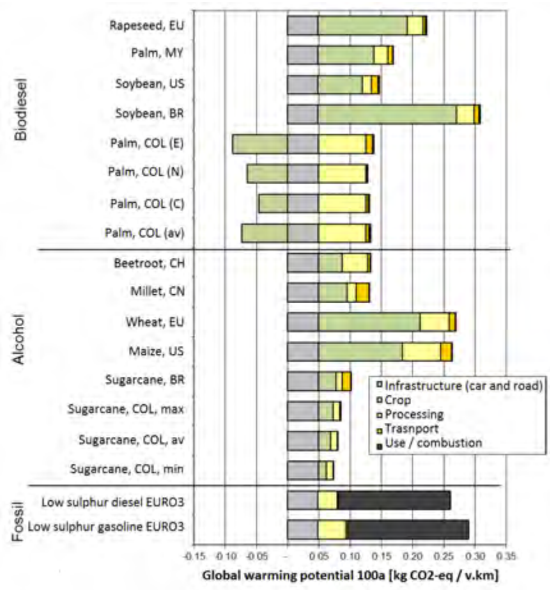
Global warming potential

The figure below shows the global warming potential (GWP) of Colombian biofuels in comparison with different value chains of biofuels known internationally, and reference fossil fuels (diesel and gasoline). Impact of international biofuels is based on the study of (Zah et al., 2007). In addition, the impact of Colombian biofuels was calculated by employing same infrastructure impact and the same standard vehicle, regarding Zah's method, in order to provide consistency. These minor adaptations and the fact that the Swiss gasoline mix is taken as a relative comparison (100%) do not marginally change the environmental impact of biofuel from Colombia, as was stated before.

In a study presented by Cherubini.et.al (2009) is possible to find that sugarcane-based ethanol could have GHG emission per unit of output between 0.05–0.75 CO2eq (kg/pkm) and a performance of other crops (corn, beetroot, wheat) between 0.1 and 0.195 CO2eq (kg/pkm). Lignocelullose ethanol fluctuates between 0.025 and 0.05 CO2eq (kg/pkm) (under laboratory conditions). For biodiesel was found that biodiesel based on sunflowers, rapeseed and soy could be between 0.08 and 0.14 CO2eq (kg/pkm), whereas experiments under Fischer-Tropsch drew results between 0.015 and 0.055 (Cherubini et al., 2009). The case of palm oil, regarding GHG emission is no analysed in Cherubini's study.

Using a broad view, biofuels in Colombia exhibit a fairly good performance if they are compared with some other biofuel value chains. Ethanol produced in Colombia from sugarcane emits slightly less GHG's emissions than ethanol produced in Brazil from the same feedstock. Biodiesel creates less GHG's emissions in comparison with the biodiesel produced in Malaysia, mainly due to the increase in carbon reserves due to LUC.

Figure 6.61. GWP of Colombian biofuels in comparison with other biofuels value chains



The biggest share of GHG's emissions come from the agricultural crop (figure above, green) through the use of machines, fertilizers and pesticides, and also in form of direct emissions (such as nitrous oxide). The most relevant factors for the GHG, in agriculture, are productivity per area (which is very high in the case of sugar beet in Switzerland, sugarcane in Brazil and Colombia, low in the case of wheat in Europe), emission of nitrous oxide (30% in the case of maize in USA) and deforestation process (which has been excessive in the case of palm oil cultivation in Malaysia and soybean oil in Brazil).

The case of palm oil in Colombia is the opposite (increase of carbon reserves), creating savings in GHG's (negative emissions of GHG).

Fuel production itself (yellow part in previous chart) creates on average less GHG's emissions in comparison with agricultural cultivation. Biodiesel emits low emission only during extraction and esterification processes. However, anaerobic conditions during residual waters plant treatment (which exhibits high chemical oxygen demand) in the palm oil industry releases vast amounts of methane. During bioethanol fermentation, emissions can fluctuate vastly due to the fossil energy carriers employed within the whole value chain (for instance corn-based ethanol produced in the USA creates high impact in this regard), they can also vary depending on to what extent agricultural wastes are re-introduced into the manufacturing process as energy generators (in this case the use of bagasse for sugarcane industry in Colombia and Brazil has proven to diminish those impacts).

Fuel transport per se (orange section in previous chart) from the production locations to the service station usually accounts for less than 10% of total emissions and it plays a secondary role from the environmental perspective, if intercontinental freight is undertaken via maritime routes or even via pipelines.

Current operation of the reference vehicle (dark grey) is carbon neutral when biofuels are completely pure, due to the fact that all CO2 that is released from the combustion process is absorbed during the growth of the plant.

Production and maintenance of vehicles, and construction and maintenance of roads (light grey) were included in this study. In any case, it was assumed an identical vehicle and same annual distance for all considered cases, producing the same increase in all the variations. In the case of alternative efficient fuels, such as bioethanol from sugarcane, such increments might comprise more than 50% of the GHG's emissions (Hischier et al., 2010; Zah et al., 2007).

6.4 DISCUSSION AND CONCLUSIONS

The goal of a Life Cycle Analysis (LCA) is to evaluate environmental impact of the most relevant biofuels within the Colombian context (sugarcane-based ethanol and palm oil-based biodiesel), overall in contrast with the performance presented by fossil references (particularly gasoline and diesel fuel). The average environmental impact of the evaluated biofuels was compared with international standards of sustainability, which provide a first approach on a key factor in regards to the export potential for Colombian biofuels. In addition, the critical and sensitive factors that have some sort of incidence within the environmental performance are determined and assessed for its further enhancement.

The evaluation of the average environmental impact for Colombian biofuels is based on the data collected in the field (feedstock production locations and processing / manufacture plants). Data was validated by experts and complemented by references in literature and the data base from Ecoinvent.

Within the following section will be argued and summarized the impact of ethanol made out of sugarcane and biodiesel made out of palm oil in terms of the GWP and the non-renewable accumulated energy demand. Some final remarks and conclusions are also presented.

6.4.1 Sugarcane-based ethanol

Global Warming potential of sugarcane-based ethanol As is illustrated in the next table and figure below, Colombia ethanol made out of sugarcane is generating close to 26% of GHG's emissions in comparison to pure fossil gasoline, without taking into account direct nor indirect effects on the land use change (LUC and iLUC) (see figure, step 1). The favorable balance of GHG is mainly due to the relatively low emissions produced in agriculture. Enhanced agricultural practices and advantageous climate conditions along the basin of the Cauca River, could greatly improve productivity and resource efficiency.

Results are independent of the allocation method, given that both energy and economic allocation factors are very similar. In addition, the possibilities of technological improvement (efficient co-generation and liquid CO2 recovery) do not influence significantly the GHG emitted per vehicle km.

The table and figure compile results from:

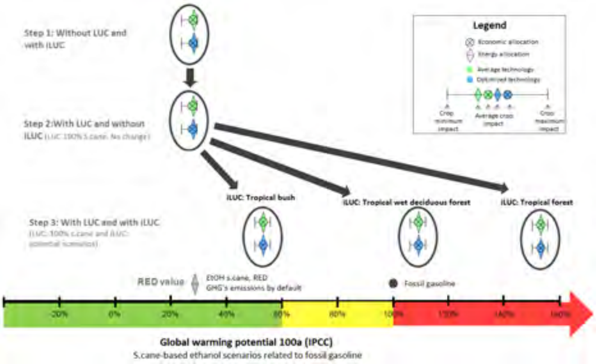
- different allocation factors (economic and energy ones),
- different technologies (average and optimized ones),
- different cultivation methods (minimum impact, average impact and maximum impact),
- changes in land use (either direct or indirect)

and they indicate those by–default values regarding the renewable energy directive (RED).

Table 6.67. GHG's emission potential. Different scenarios of sugarcane-based ethanol

GHG's emissions		Economic allocation		Energy allocation		Fossil gasoline
Scenario	**Unit**	**Standard tech**	**Optimized Tec**	**Standard tech**	**Optimized Tec**	
Scenario 1 Without LUC/ With iLUC	kg CO2 eq / v.km	0.06	0.059	0.059	0.059	0.226
	% (compared with fossil fuel)	26%	26%	26%	26%	100%
Scenario 2 With LUC/ Without iLUC	kg CO2 eq / v.km	0.06	0.059	0.059	0.059	0.226
	% (compared with fossil fuel)	26%	26%	26%	26%	100%
Scenario 3 With LUC/ With iLUC (tropical forest)	kg CO2 eq / v.km	0.354	0.354	0.345	0.345	0.226
	% (compared with fossil fuel)	156%	156%	152%	152%	100%
Scenario 3 With LUC/ With iLUC (wet tropical forest)	kg CO2 eq / v.km	0.249	0.249	0.243	0.243	0.226
	% (compared with fossil fuel)	110%	110%	107%	107%	100%
Scenario 3 With LUC/ With iLUC (bushes)	kg CO2 eq / v.km	0.128	0.128	0.125	0.125	0.226
	% (compared with fossil fuel)	56%	56%	55%	55%	100%

Figure 6.62. GWP of Colombian sugarcane based ethanol in comparison to gasoline (100% impact)



Source: (MME, 2012)

In environmental terms, the most critical stage of ethanol production corresponds to the agricultural stage, and therefore the mentioned GHG's emission savings can only be reached if best agricultural practices are applied and pressure on natural areas is avoided. Pressure on land might be either direct or indirect.

Due to the fact that sugarcane cultivation in the geographic valley of the Cauca River were established before year 2000, which was used as the reference year for this study in terms of the LUC analysis, the LUC effects were not included within this report (previous figure, step 2).

However, before ethanol production started in Colombia, the existing sugarcane was employed for sugar production, and the one that was dedicated for ethanol manufacture was formerly used for export to international markets. Reductions in sugar exports might be offset by an increase of sugarcane plantations in some other places. If that is the case, it might be expected to have some indirect effects on land (iLUC) if the cultivation area is expanded in some other suitable area (agricultural land or pasture land) in Colombia (figure, step 3). The indirect effects might go from no iLUC (best scenario, step 2) if no additional land is required due to intensification methods up to a complete expansion into natural ecosystems (worst case, step 3). Depending on the affected natural ecosystem (bush, wet tropical forest, jungle), the ethanol balance in comparison to fossil gasoline is close to 26% (if no iLUC is generated), and 156% (if wet tropical forest are affected). Results from the sensibility analysis pointed out that those results of the GHG's emission balance are highly sensitive to the iLUC effects. Nonetheless, the iLUC effects are complex and are directly related to local environment, society and markets dynamics. With the intention of avoiding indirect effects in natural areas and the consequent carbon debt, as was discussed in (Fargione, Hill, Tilman, Polasky, & Hawthorne, 2008), it is required to evaluate the local potential of the mechanisms, to implement careful land use planning and to establish mitigation if the case leads to that situation, as is referred to by other scholars as well as (Mathews & Tan, 2009b). These measures can include the intensification of remaining pasture lands or agricultural areas, or the expansion of areas with low carbon reserves as bushes.

In general, fuel transportation does no play a predominant role in regards to environmental impacts, but only if fuels are not moved long distances using terrestrial routes. Therefore, ship transportation does not have a significant impact on in the GHG's emission balance (between 3% and 7%).

A high environmental impact is related with construction, maintenance and disposition of ways and vehicle infrastructure used for transport. Besides, the decision of the final user in regards to the kind of fuel and type of vehicle (i.e. fuel consumption) influence significantly the total balance of GHG. Nevertheless, this set of conditions represents a general feature of mobility and it is not directly related to biofuels.

Colombian ethanol and fulfillment of the GHG's emissions standard defined by the RED

Several countries have implemented policy tools with the purpose of supporting biofuel production and use. However, this support is frequently associated to sustainability criteria in order to maintain environmental and socio-economic impacts within certain boundaries (CARB, 2009; CEN, 2009; EPFL, 2008; EU-Comission, 2010). Biofuel sustainable threshold regarding GHG savings having as reference regular fossil fuels is close to 40%. Despite the fact that the methodologies defined for GHG calculations present several discrepancies, it is very likely that Colombian biofuels comply with GHG criteria.

Energy efficiency of Colombian ethanol

Biofuels do not substitute fossil fuels completely, given that biofuel production is partially based on fossil fuels (for instance the use or manufacture of the required equipment or the chemicals used in the production process). Despite all that, biofuels production consumes 60% less non-renewable energy in comparison with fossil fuels. Efficiency is around 0.15 MJ of non-renewable energy per 1 MJ of bioenergy (in this case bioethanol), depending essentially on the agricultural practices and the use of agricultural wastes.

There is the potential of augmenting energy levels, which can be generated from by-products of extraction and field (plantation) residuals. Through the installation of more efficient boilers and turbines, even more fossil energy demand and electricity from the power grid can be reduced. With the aim of improving system efficiency, it is suggested using bagasse and other crop's residuals as energy sources (Isaias C. Macedo et al., 2008).

6.4.2 Palm oil biodiesel

Global Warming potential of Colombian palm oil–based biodiesel

The performance of biodiesel made out of palm oil in terms of GHG depends mainly on resource efficiency within the agricultural stage, land use change, and processing technology. The relative influence of these factors and of the GHG's emissions compared with fossil diesel is illustrated and discussed in this section.

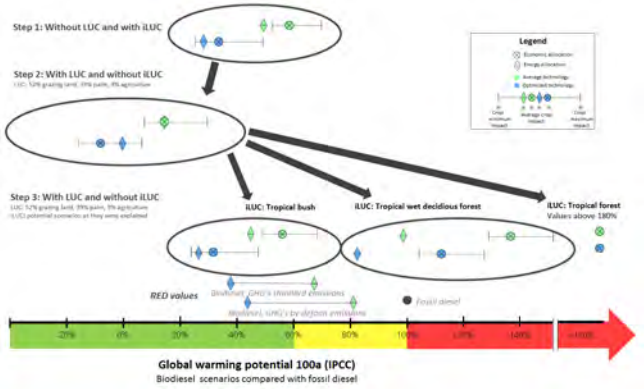
The following table and figure gather results for:

- different allocation factors(economic and energy),
- different technologies (average and optimized ones),
- different cultivation methods (minimum impact, average impact and maximum impact),
- land use changes (either direct or indirect, LUC and iLUC)
- and by-default values regarding the Renewable Energy Directive (RED).

Table 6.68. GHG's emission potential. Different scenarios of palm oil-based biodiesel per v.km and relative to 100% fossil diesel

GHG's emissions		Economic allocation		Energy allocation		Fossil gasoline
Scenario	Unit	Standard tech	Optimized Tech	Standard tech	Optimized Tec	
Scenario 1 Without LUC/ With iLUC	kg CO2 eq / v.km	0.114	0.067	0.087	0.056	0.19
	% (compared with fossil fuel)	60%	35%	46%	29%	100%
Scenario 2 With LUC/ Without iLUC	kg CO2 eq / v.km	0.033	-0.013	0.033	0.001	0.19
	% (compared with fossil fuel)	17%	-7%	17%	1%	100%
Scenario 3 With LUC/ With iLUC (tropical forest)	kg CO2 eq / v.km	0.393	0.343	0.275	0.244	0.19
	% (compared with fossil fuel)	207%	180%	145%	128%	100%
Scenario 3 With LUC/ With iLUC (wet tropical forest)	kg CO2 eq / v.km	0.259	0.211	0.185	0.154	0.19
	% (compared with fossil fuel)	136%	111%	97%	81%	100%
Scenario 3 With LUC/ With iLUC (bushes)	kg CO2 eq / v.km	0.104	0.057	0.081	0.049	0.19
	% (compared with fossil fuel)	55%	30%	42%	26%	100%

Figure 6.63. GWP of Colombian palm oil based biodiesel in comparison to diesel (100% impact)



Source: MME(2012)

Approximately 40% of GHG emissions per vehicle can be saved by using current technology and average cultivation practices, in comparison to fossil diesel alternatives (step 1, considering neither iLUC nor LUC effects). Nevertheless, GHG emissions may increase or decrease by 10%, depending on the resource efficiency during the cultivation stage (mainly in the inputs for fertilizers and pesticides). Likewise, the allocation method to determine to what extent the impact of the main products might influence the obtained results (particularly if energy allocation is applied, the positive and negative impacts present a wider variation).

The main optimization potential for palm oil production in terms of GHG's emissions is to improve treatment through residual waters, which emits significant amounts of methane. GHG's emissions of the production stage are capable of being reduced by 75% when methane is captured as is indicated in the umbrella CDM project of Fedepalma (Fedepalma, 2006a)(See in the figure "optimized technology").

Palm oil tree cultivation is able to store relatively great amounts of carbon in comparison to other use of lands (particularly if they are compared to agricultural or pasture lands). If the direct land use changes (step 2) are taken into account, the carbon balance has a propensity to be enhanced even more, up to 83% (using average technology) and up 107% (if advance or optimized technology is employed), due to the fact that most palm trees plantations took place in areas that formerly were destined for grazing purposes or agricultural production. Notwithstanding, some indirect changes in land might be caused by these actions as well (step 3).

In general, if biofuels are not transported by terrestrial roads over large distances, such fuel transportation does not represent a great impact in terms of environmental effects. Therefore, maritime transportation of biodiesel to the USA market has a marginal impact on the GHG's balance (in between 3% and 7%). As in the ethanol case a higher impact it associated to construction, maintenance and final disposal of road infrastructure and the vehicle used for transportation. Even more, the choice of the final user regarding the type of fuel used and the kind of vehicle driven are prone to strongly influence the total GHG balance. Nevertheless, these factors are mobility factors and are out of the scope of this study.

Colombian biodiesel and fulfillment of the GHG's emissions standard defined by the RED

It can be asserted that Colombian biodiesel made out of palm oil provides good performance in comparison with some other biofuels produced internationally and it accomplishes 40% of GHG's emission savings defined by several international standards (CARB, 2009; CEN, 2009; EPFL, 2008; EU-Comission, 2010).

Energy efficiency of Colombian biodiesel

The non-renewable accumulated energy demand of diesel-fed vehicles is greatly reduced (by a factor of 5 to 8 times) in comparison to those vehicles that work on regular diesel fuel from a fossil nature. The recovered energy, assessed as the produced MJ of bioenergy per every MJ of fossil origin introduced, fluctuates in between 4 and 7 (with an average of 5), depending mainly on the crop intensity and productivity.

The non-renewable energy demand for biofuels based on highly productive crops (as for the palm oil crop) is considerably less in comparison to other biofuels, especially when lingo-cellulosic biomass is used to provide energy in the processing facilities. It is important to note that if the lingo-cellulosic is used for second generation technologies a more efficient result might be reached as well, in terms of fuel generation but co-generation potential and the creation of compost will be affected negatively. In any case, the use of residuals (for instance the emptied palm fruit) might reduce the energy demand even more. However, the impact transference (such as the nutrients recycling) must be evaluated carefully.

6.4.3 Final conclusions

There is evidence that, if ethanol made out of sugar cane and biodiesel from palm oil are used instead of fossil fuels, GHG's emissions can be reduced by up to 74% and 83% respectively. If all existing biofuel producing plants work at their maximum capacity, it is possible to save 1.8 million tons of CO2 eq per year. That is equivalent to 3% of the total emissions of CO2 in Colombia in 2008 or 8% of those emissions caused by the Colombian transport sector (UN, 2012).

Compared with some other international biofuels, Colombian biofuel exhibits good performance and it achieves 40% of minimum GHG's emission savings, suggested by several bioenergy fuel standards (CARB, 2009; CEN, 2009; EPFL, 2008; EU-Comission, 2010). Therefore, biofuels exported from Colombia can be favored by various mechanisms for subsidies in "sustainable" international markets for biofuels. However, a sustainability assessment should be applied for each producing firm and plantation in an isolated way, given that the present study provides only an insight for the average Colombian case, and evaluates its range of impacts. Thus, it is required that recommendations presented in this study be validated at a local level in order to establish to what extent each plantation and facility complies with the standards.

In general, it can be assured that the GHG's emission balance is quite sensitive to the agricultural stage, particularly regarding the efficiency in agricultural handling and managing practices, and also land use changes (LUC and iLUC). Those GHG's emission related to biodiesel range between 60% and 17% if the LUC effect is taken into account (using economic allocation factors). The enhanced GHG balance is mainly due to the relatively high carbon reserve that is contained in soil under palm plantations in comparison to any other agricultural products, or to livestock growing purposes. Nevertheless, the act of using productive soil for planting sugarcane or palm oil might cause indirect land use changes (iLUC), given that replaced crops could be established in some other location. This way of acting can induce to either intensification processes, or soil expansion activities, the latter clashing with some natural areas. If the "worst case scenario" regarding expansion in the agricultural frontier is considered, the GHG's emissions can double compared to the ones produced by fossil alternatives. Therefore, the amount of GHG produced is highly susceptible to current and potential land uses. Given that these effects follow mechanisms of high complexity and they account for elevated levels of dependency on local conditions, it would be a great contribution to undertake a detailed study on the local conditions and to develop a land planning scheme in term of potential uses, including mitigation proposals (such as silvopasture techniques) for the forecasted biofuel plantations.

In the palm industry, particularly, residual water treatment can be improved in the oil facilities' effluent (very intensive in Chemical Oxygen Demand, COD), which emits vast amounts of methane. The implementation of the CDM "umbrella project" proposed by Fedepalma is a step in the right direction.

For ethanol made out of sugarcane and palm oil-based biodiesel, it has been established that both require 5 times less non-renewable energy carriers in comparison to fossil fuels. The relatively low demand of fossil fuels for sugarcane-based ethanol and palm oil-based biodiesel is explained by the fact that most of lingo-cellulosic material is employed for co-generation. The demand for fossil fuels can be reduced even more, through improvement of the efficiency of both boilers and turbines, and also the use of waste biomass that come from the plantations and harvesting process. However, in the future the transfer of impacts regarding costs and interruption of the nutrients cycle must be evaluated.

A dominant effect in the sugarcane crop is the burning practice before the crop harvest, which contributed to summer smog (caused by CO emissions). Despite all this, the effect of the burning practice before the harvesting season, has been, and still is, the subject of several academic and health debates. Some studies reveal that there is no significant effect from the sugarcane burning practice on the local or nearby population (Jose Goldemberg, 2007), while other references indicate that there are negative impacts, which manifest as respiratory diseases in children and elderly people that receive treatment in local hospitals (Nicolella & Belluzzo, 2011). There are some ongoing studies regarding the potential hazardous effect of the sugarcane burning practice on human health, but research and additional monitory controls are required to obtain conclusive results on the possible carcinogenic outcomes from such procedures.

Finally, the selection of vehicle on the Colombian roads affects directly fossil fuel consumption and therefore the impact caused by biofuels production stage. Policy tools and regulations that aim for greater vehicle efficiency, and for the provision of transport alternatives (i.e. use of efficient public transportation) should be included within the guidelines for the production, distribution and use of fuels of biological origin, at least as a mid-term energy opportunity.