Production of Biofuels for transport in Colombia: An assessment through sustainability tools

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August, 2014

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Glossary

Accronym	English Name	Original Name (Where applies)
1GBf	Fist Generation Biofuels	
2GBf	Second Generation Biofuels	
3GBf	Third Generation Biofuels	
4GBf	Fourth Generation Biofuels	
ACCEFYN	Colombian academy for physics and natural sciences	Academia Colombiana de Ciencias Exactas, Físicas y Naturales
ACPM	Oil fuel for engines	Aceite Combustible para motor
ANCAP	Fuel, Alcohol and Cement National Bureau	Adminsitración Nacional de Combustibles, Alcohol y Pórtland
ASOCAÑA	Colombian Sugarcane Growers Association	Asociación de Cultivadores de Caña de Azúcar de Colombia
B100	Neat bioethanol	
BOD	Biochemical Oxygen Demand	
BOD	Biochemical Oxygen Demand	
CAN	Andean Community	Comunidad Andina de Naciones
CAP	Common Agricultural Policy	
CBA	Cost Benefit Analysis	
CBI	Caribbean Basin Initiative	
CC	Climate change	
CDM	Clean Development Mechanisms	
CED	Cumulative Energy Demand	
CENICAÑA	Colombian Sugarcane Research Centre	Centro de Investigación de la Caña de Azúcar en Colombia
CENIPALMA	Colombian Research Centre for palm oil	Corporación Centro de Investigación en Palma de Aceite
CFC's	Chlorofluorocarbon gases	
CIAT	International Research Center for Tropical Agriculture	Centro Internacional de Agricultura Tropical
CNE	Chilean National Energy Commission	Comision Nacional de Energía
CO2	Carbon dioxyde	
COD	Chemical Oxygen Demand	
COLCIENCIAS	Colombian Administrative Department of Science, Technology and Innovation	Departamento Administrativo de Ciencia, Tecnología e Innovacion de Colombia
CONPES	National council for Economic and social policy making	Consejo Nacional de Política Económica y Social
COP	Colombian Pesos	
CORPODIB	Industry Development of Biotechnology and Clean Production Corporation	Corporación para el Desarrollo Industrial de la Biotecnología y la Producción Limpia
CPI	Consumer Price Index	
CUE	Consortium University-Private sector	Consorcio Universidad Empresa

CV	Climate variability	
DAMA	Environmental Administrative Department	Departamento Administrativo del Medio ambiente
DANE	National Administrative Department of Statistics	Departamento Administrativo Nacional de Estadistica
DAP	Diammonium phosphate	
DNP	National Economic Planning Bureau	Departamento Nacional de Planeación
DOF	Law of Promotion and Development of Bioenergy products	Diario Oficial de la Federación
DOM	decomposed organic matter	
ECOPETROL	Colombian Corporate group focused on petroleum, gas, petrochemicals and alternative fuels	
EF	Ecological Footprint	
EIA	Energy Information Administration	
ENSO	El Niño –Southern Oscillation	
EtOH	sugarcane-based ethanol	
EU	European union	
FAG	Agricultural and Guarantee Fund	Fondo Agropecuario de Garantías
FAME	Fatty Acid Methyl Ester	
FAO	Food and Agriculture Organization	
FAOSTAT	The Statistics Division of the FAO	
FARC	Revolutionary Armed Forces of Colombia	Fuerzas Armadas Revolucionarias de Colombia
FEDEPALMA	Colombian Federation of Palm Oil Growers (Bussiness association)	Federación Nacional de Cultivadores de Palma de Aceite
FEISEH	Ecuadorian Investment Fund for the Energy and Hydrocarbon Sectors	Fondo Ecuatoriano de Inversión En Los Sectores Energético E Hidrocarburífero
FEPA	Sugar Price Stabilization Fund	Fondo de estabilización del precio del Azúcar
FFB	Fresh Fruit Bunches	
FFV	Flex-Fuel Vehicle	
FI	Factor: Input	Factor de Entrada
FLU	Factor: Land use	Factor de uso del suelo
FMG	Factor: Management	Factor de Manejo
FSM	Financial Social Model	
GDP	Gross Domestic Product	
GHG	Greenhouse Gas	
GIS	Geographic Information Systems	
GWP	Global Warming Potential	
IBI	Index of Biotic Integrity	
ICR	Rural funding incentives	Incentivo de capitalización rural

IDB	Inter-American Development Bank	
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies of Colombia	Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia
IGAC	Agustin Codazzi Geographical Institute	Instituto Geográfico Agustín Codazzi
iLUC	indirect land use change	
IMESI	Domestic Specific Tax	Impuesto Específico interno
IPCC	Intergovernmental Panel on Climate Change	
ISC	Selective Consumption Tax	Impuesto selectivo al consumo
Kwh	Kilowatts per hour	
LAC	Latin American and Caribbean	
LCA	Life Cycle Analysis	
LCI	Life Cycle Inventory	
LCIA	Life Cycle Impact Assessment	
LUC	land use change	
MADR	Ministry of environment and Rural Development	Ministerio de Ambiente y Desarrollo Rural
MAVDT	Ministri of Environment, Housing and Territorial Development	Ministerio de ambiente, vivienda y Desarrollo territorial
MGSM	Macquarie Graduate School of Management	
MIDAS	More investment for the sustainable alternative development	Mas inversion para el desarrollo alternativo Sostenible
MJ	Megajoules	
MTBE	methyl tertiary butyl ether	
NEST	Without translation	Núcleo de estudios de Sistemas Térmicos
NGO´s	Non-governmental organizations	
O&GJ	Oil and Gas Journal	
OAS	Organization of American States	
PA	Positional Analysis	
PM	Particulate matter	
PNAB	National Policy of Agrienergy and Biofuels	Política Nacional de Agroenergía y Biocombustibles
PNBs	National plan for sustainable Biofuels Development	Plan Nacional para el desarrollo sostenible de los biocombustibles
PROALCOOL	Brazilian National Alcohol Program	
PROBIOCOM		
PROBIODIESEL		
PSF	Price Stabilization Fund	
RBD	refined, bleached and deodorized palm oil	
RED	European Renewable Energy Directive	
RED	Renewable Energy Directive	
RFS	Renewable Fuel Standard	

RNP	National Records for the Palm oil industry	Registro Nacional Palmero
SITM	Massive Integrated Transportation Systems	
SOC	soil organic carbon	
SQCB	Sustainability Quick Check for Biofuels tool	
UCTE	Union for the Coordination of the Transmission of Electricity	
UK	United Kingdom	
UNEP	United Nations environment programme	
UNFCCC	United Nations Framework Convention on Climate Change	
UNODC	United Nations Office on Drugs and Crime	
UPME	Mining and Energy Planning Unit	Unidad de Planeación Minero Energética
VAT	Value Added Tax	
VEETC	Volumetric Ethanol Excise Tax Credit	
VOC’s	Volatile organic compounds	
WB	World Bank	
WMO	World Meteorological Organization	
WWW	World Weather Watch	

Abstract

Bioenergy has emerged as a potentially sustainable alternative to the use of fossil fuels for transport and industrial uses. Developing nations, such as Colombia, can seize the advantages of modernizing rural areas by using cleaner energy and having more economic opportunities with bioenergy initiatives, provided the trade-offs between fiber, food, feed and fuel can be managed. This Thesis examines the bioenergy program now under way in Colombia, where comparative advantages (shared with other tropical countries) in production of sugar cane and palm oil are being built on. While the technologies associated with use of these feedstocks are well known, nevertheless their scaling up in a country like Colombia poses considerable environmental, social, economic and business challenges.

The thesis poses two fundamental questions based on current Colombian conditions, namely (1) can the Colombian biofuel industry produce bioethanol and biodiesel under sustainable guidelines; and (2) to what extent is it possible to expand energy crops for biofuels production purposes without jeopardizing sustainability goals? A sustainability approach based on recognized techniques such as Life Cycle Assessment (LCA) allows for a comprehensive social, economic and environmental analysis of the whole cradle-to-grave progress of the bioenergy value chain. An original LCA analysis is conducted for the Colombian bioenergy sector, with results indicating that considerable savings in GHG emissions are achieved while producing sustainable and competitive bioenergy products. Nevertheless expansion of sugarcane and palm oil crops is possible but constrained by biophysical, legal, ecological and socio-economic conditions, established to safeguard sustainable production. Utilising Geographic Information Systems (GIS) some maps were created which clarify the potential for bioenergy expansion in Colombia. The Thesis thereby engages with the bioenergy capabilities of Colombia, and drawing on the literature from other tropical and Latin American countries, provides original estimates of the country's biopotential as well as needed policy settings to bring Colombia to its full capacity.

To sum up, this document argues that sustainable production and use of biofuels is feasible and would meet expected market demands over time.

Key-words: Bio-based energy, Energy, Biofuels, Sugarcane Bioethanol, Palm oil Biodiesel, First Generation Biofuels

Thesis statement

The author hereby indicates that the presented work has not been submitted for a higher degree to any other university or institution. Within the following document all the sources for external information have been fully acknowledged. This thesis document did not require any Ethics Committee approval, as was informed in the Annual Progress Reports, given that the information provided here does not violate any confidentiality agreement, nor have any hazardous experiments on animals or humans been carried out to reach the conclusions.

Carlos Ariel Ramirez Triana

This work is dedicated to my pretty, lovely and patient wife Diana and to the joy of my life, my son, Tomás

Acknowledgments

The writing, designing and final delivery of this document has been possible only with the enormous support of several people.

Firstly, I want to highlight the huge help received by these two institutions, who made possible the completion of this really long and exhausting journey: MGSM and Politécnico Grancolombiano. Staff at the MGSM and Macquarie University were very supportive during my stay in Australia and also in long distance assistance.

The cornerstone of this thesis was the expertise, knowledge and generosity from my supervisor, Professor John Mathews, and despite the short time that we shared, his advice was always precise and accurate.

Also, in Colombia I received special support from the former and current Deans of the School of Management, Economics and Accounting Science, Dr. Jurgen Chiari and Dra: Deisy de la Rosa, and from the Head of Research of the University, Dra. Sandra Rojas.

Of course, this thesis could have not been completed without the special collaboration of several private and public entities that took part directly or indirectly during the research process. In particular, I want to mention FEDEPALMA, ASOCAÑA, FEDEBIOCOMBUSTIBLES, CUE, IGAC, IDEAM, UPME, CENICAÑA, CENIPALMA, and CORPODIB.

On a personal note, I want to thank my patient wife Diana, my parents, my sister and my family and friends in general. I am fully aware that I have stolen plenty of good time from our lives, but it is my intention to return it in both quality and quantity.

Many more people that were close to me during these last 5 years deserve a special mention for making this burden less heavy. Unfortunately, space is quite limited and I can only say to you all, I cannot thank you enough.

1. INTRODUCTORY CHAPTER: BIOENERGY, SUSTAINABILITY AND COLOMBIA

Developing countries are becoming more aware about the role of fossil fuels as being one of the highest barriers against developing their industrialization process. On the other hand, industrialized countries constantly emphasize the need to create new alternatives to energy, generate renewable energies, or to break or relieve their dependence on oil and hence avoid being subject to oil price fluctuations. In addition, global warming and greenhouse gas (GHG) emissions have been holding world attention (A. P. C. Faaij & Domac, 2006). Answers to this problem so far include international agreements, national policies, industry and academic research, and new technology.

One of the possible answers being presented is Bioenergy, energy from biomass. Bioenergy can bring environmental improvements through carbon neutral (or even negative) emissions during the production process (J. Mathews, 2008a, 2008b). Additionally this alternative fuel source, besides providing a close substitute for gasoline and diesel and alleviating oil dependence, can also be used as a source of local employment and income from exports(Schuck, 2006).

Nevertheless, Bioenergy projects should be handled carefully. The Brundtland Commission has set a high standard through the Sustainable Development concept, one that will be difficult to achieve. The ideal status claimed by the Brundtland Commission, through the Sustainable Development concept, has imposed a high standard. Growth is possible, but some guidance should be provided in order to reap the benefits. Sustainable production around the bioenergy industry has become a real challenge for Latin American and Caribbean (LAC) countries; of course alternative energies create opportunities but at the same time bring along significant consequences that should be fully understood, addressed and corrected if possible, before a full implementation with undesirable results is carried out.

Sustainable development accounts for three basic aspects:

1. the social aspect - involves creating opportunities for local people around the project, hopefully improving living conditions;
2. the economic aspect - which not only raises income for the investors but also for the surrounding community,
3. the environmental aspect - that implies to produce alternative fuels in a considered way in order to preserve or improve natural resources for future generations.

When bioenergy is produced several factors can influence or pervert the path leading to the achievement of these sustainable goals. In the LAC region some literature, especially among business sectors and policymakers, has been published encouraging public and private investment. In some cases, biofuels in particular are shown as a great alternative to overcome a number of difficulties faced by the whole region (some worse than others). However, there are some sensible publications, most of them from an academic point of view, that warn of the possible adverse effects related with this sort of energy; of course they cannot be ignored.

It is fair to say that the discussion mentioned above should not be analyzed as black or white. Among the LAC region it is possible to find a wide gray area. Some similarities can be found between South and Central American countries in term of natural resources, for example: excellent sunlight, good soil conditions, and an extensive agricultural sector, probably underused (Dominik Rutz et al., 2008). However, many social features are also common, such as: poverty, corruption, undernourishment, social fragmentation, etc. The region as a whole could be an interesting base for internal and even external bioenergy supply. Conversely not every country has adequate conditions to take the risk with its energy future and rely on biomass, not to mention the risk to develop an export industry based on bioenergy.

Subtle differences among these LAC nations allow identifying some particular weakness and strengths. In that way, potential bioenergy producers and exporters can be highlighted, and threats and opportunities can be pointed out. The aim of this paper is exactly that, but focusing on the noteworthy Colombian case.

Within this chapter the reader will find an overview to those aspects that lead the discussion throughout the entire document. The analysis herein is broken down in to four sections, presented as follows:

- The first section shows basic concepts around bioenergy production; starting with the role played in the world by bioenergy and biofuels among the different alternative energies. It also summarizes biofuels classification and production processes.
- The second section is a general overview on the definition of sustainability. Once this term is clear, in light of this particular study and after a proper literature review, an explanation of the importance of sustainable production in the bioenergy sector can be inferred.

- The third section explains briefly the importance of Life Cycle Analysis (LCA) as contribution of the environmental component within sustainability studies[1]. This instrument provides an insight to understand the proper extension of energy crops taking into account highly controversial topics such as carbon emissions and expansion in tropical areas.
- The fourth section will offer a general idea of the biofuel industry in Colombia, and the potential role that it plays in the global bioenergy scenario.

Note: These sections will be developed in detail in further chapters.

1.1 **Bioenergy and sustainability: general overview**

Renewable energies, in particular bioenergy, can provide interesting substitutes for fossil fuels. The following section offers a brief overview of the definitions, importance, processing methods and possible impact of this alternative energy source in terms of sustainability.

1.1.1 Bioenergy situation in the global energy scenario

The world is trying to reduce its dependence on fossil fuels. Not only because the price of oil continually rises as it becomes more scares, but also because of the environmental burden related with GHG emissions (carbon dioxide mainly) and their effects on global warming.

For that reason, energy alternatives are starting to play important roles in energy consumption today. Some of those, such as nuclear energy, have the potential to cover part of the energy need at a competitive cost. However the radioactive waste management, the constant threat of nuclear material for use in weapons manufacture, and the reported scope of fatal accidents (the most famous ones being Middletown, Pennsylvania, USA in 1979, and Chernobyl, ex-URSS in 1986) create resistance among the population and in the general international political community.

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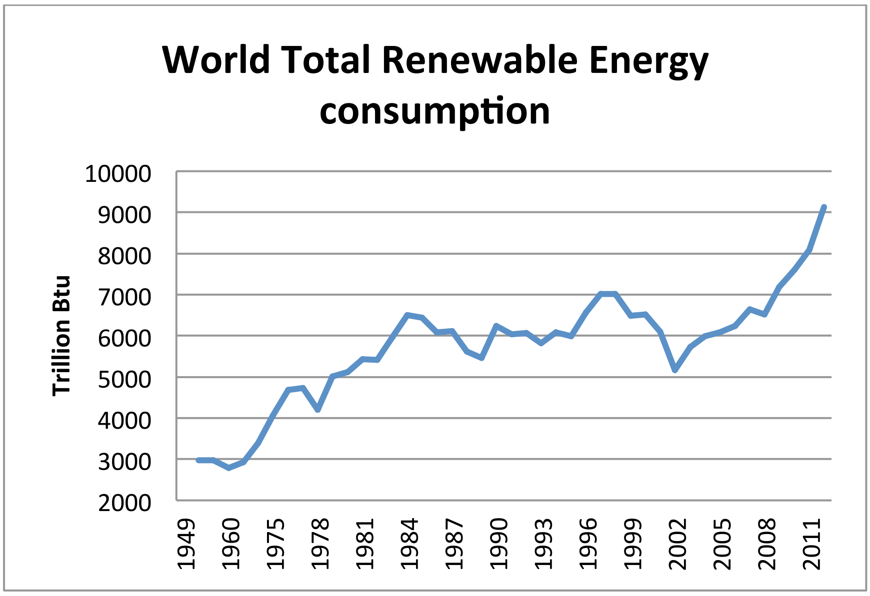
[1] It is importand to recognize that LCA does not provide a comprehensive analysis in terms of sustainability under a holistic perspective because it does not cover social nor economic aspects. It focuses rather on the so-called environmental sustainability (Čuček, Klemeš, & Kravanja, 2012); however, LCA does make part of the set of methods to measure sustailability (at least partially), as do other alternatives such as Social LCA, Life Cycle Cost Analysis, Ecologycal footprint, environmental sustainability index, among others. Čuček et.al make reference to some important limitations that can be found in the LCA application, such as the enourmous amount of information required and the availability of that data, and the resource and time intensities of LCA. Nevertheless it is interesting that LCA studies were not very frequent in developing countries (Hauschild, Jeswiet, & Alting, 2005), but nowadays they are being used for decision-making processes for private or public initiatives.

Renewable energies have been available for a long time and they are advancing on many different fronts. In general, it can be seen that renewable energy use has been increasing (See **Figure 1**). However, since 2001, there has been a noticeable upsurge in its consumption, with an average growth rate of 5.9%, but it is still uncertain if the cycle observed during the 90's will be repeated.

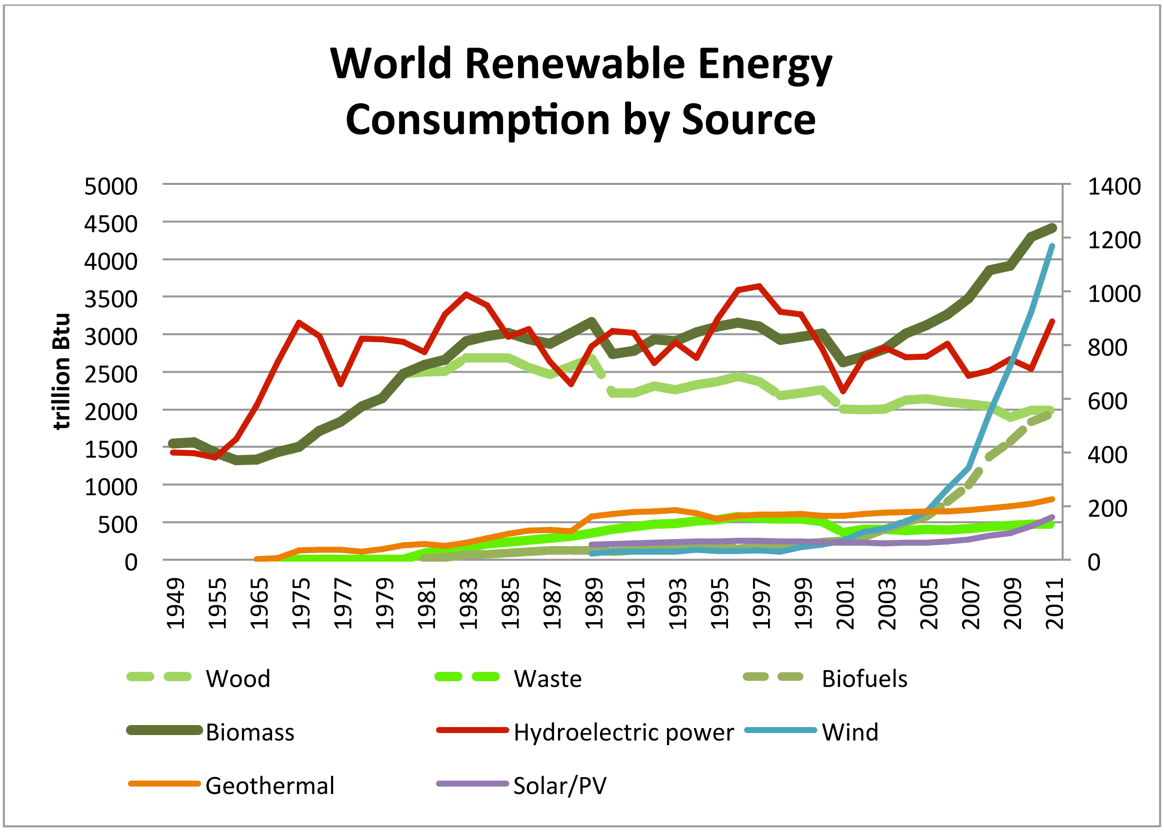
Figure 1 World renewable energy consumption



Source: (EIA, 2012)

Nevertheless, this evolution can be separated by source, as is shown in **Figure 2**. Here, it is seen that some sources of renewable energy (RE) have experienced a substantial growth: it is noteworthy the case of Solar/PV, but even more noticeable, in terms of dimension, the growth exhibited by Bioenergy (particulary modern bioenergy represented by biofuels). . Bionenergy covers nowadays nearly 10% of total global primary energy supply (i.e. 50EJ). However, a big share of all bioenergy applications (62%) is represented as traditional fuelwood for cooking and heating (Lamers, Junginger, Hamelinck, & Faaij, 2012). In the last decade the upsurge of modern biofuel applications has been substantial: within the period of 2000 to 2009 biodiesel production has move from 30 PJ 572 PJ, while bio-ethanol started with 340 and ended ud with 1540 PJ (Lamers, Hamelinck, Junginger, & Faaij, 2011). Use of wind power is still limited and the scale small (its highest point is less than one tenth that of Biomass used in the same period). An insignificant but stable part is played by both geothermal and solar power. Despite their enormous prospects they have not been embraced sufficiently by the market.

Figure 2 World renewable energy consumption by source



Note :Dotted green lines represent the contribution of three different sources of Biomass (Waste, Wood and Biofuels). The addition of the aforementioned souces.is shown in the green thick line (Biomass).Geothermal, Solar and Wind power are measured with the secondary axis. **Source**: (EIA, 2012)

On the other hand, a big share of energy production is driven by hydro, which actually describes most of the behavior of total consumption, but it has been particularly discrete since 2001 and explains part of the decrease experienced in 2007 in the previous chart (figure 1). However, as previously stated, since 2001 the aggregated use of renewable energy has been rising (showing a 5.4% growth rate) despite the fall presented by hydro – predominantly offset by increased use of biomass sources.

This Biomass study can be even more detailed if it is broken down by sector as is presented in **figure 3**. Biomass energy has traditionally been used (and it is still used) largely by industry, in the form of roundwood, wood byproducts and wood waste. Residential use is secondary to industry, and it has fallen constantly in the analyzed period, mainly due to conversion methods for cooking and heating in depressed regions, through substituting fuelwood and other sorts of biomass by kerosene, natural gas or gasoline[2].

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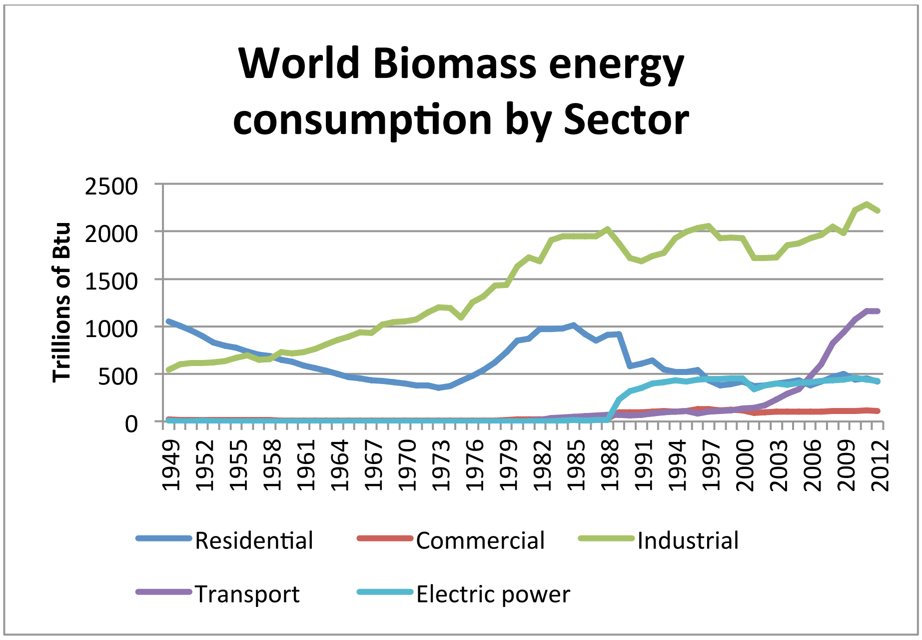
[2] Private-Public Initiatives are being developed to reduce the use of fuelwood indoors because of the risk that it represents to health, as the documented experience of alternative stoves in Philippines. Decision makers are

Figure 3 World Biomass energy consumption by sector



Source: (EIA, 2012)

The production of electricity associated with biomass consumption is utterly recent and it has remained relatively unchanged since 1991, with a little setback in 2000-2001. The initial growth of this energy shown in early 90's within this sector is practically immovable nowadays.

The occurrence of biomass energy in commercial power consumption is especially low, apparently because most of the commercial activity is located in urban areas, implying that this sector is mostly covered by other alternative energy in different national energy grids, so a small remnant in isolated areas is supplied by biomass.

Modern biomass has been expanding at considerable speed. The IPCC report shows that its use has been growing at 8%, 9.6%, and 11.3% per annum for the years 2008, 2004 and 2008 respectively. Energy carriers within this category (like liquid and gaseous biofuels) have experienced average annual growth rates of over 12%, in the period 1990 to 2008.

In 2009 biofuels provided 3% of road transportation fuel use. Together biodiesel and ethanol accounted for 90 billion litres for that year (IEA, 2010).

There have been some setbacks in the augmentation of bioenergy initiatives around the world. In the period 2007-2008 the use of biofuels had an escalation in OECD countries mainly. Such situation led to infrastructure investments that failed due to the economic environment

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addressing their policies to fight this situation. "Household use of traditional bioenergy locks people in the developing world, particularly women, into a cycle of poverty and ill health" See (UN-Energy, 2007).

that was present those days. The consequences were that some of the productive capacity was idle (by the time of the IPCC report) and some facilities were shut down. On the upside, Latin American and Asian (South pacific) markets are growing, therefore the decline in the use of biofuels can be offset for this fact (Chum et al., 2011; IEA, 2010).

Those active players in the current biofuel initiatives (with strong policy support) are expected to be the most benefited of the projected expansion for this market (From 2.1 EJ/y in 2008 to 16.2 in 2035) (Chum et al., 2011; IEA, 2010).

Finally, it is noticeable that the transportation sector is definitely driven by an active fuel substitution creation policy. In a very broad sense there have been identified policies (such as promotion of domestic production and consumption and trade boosters or barriers) that add dynamism to the sector (Lamers et al., 2011). Biomass energy used in transportation is basically concentrated in liquid fuels (bioethanol and biodiesel) and it has grown at an average rate of 20% from 2000 to 2012.

So far, Brazil, the EU and the US have been the main consumers and in major extent producers of liquid biofuels for the last decade, however more countries are emerging as potential producers and exporters of biofuels.

1.1.2 Bioenergy/biofuels production

Among different sources of renewable energy, bioenergy is highlighted by its scope and versatility. In contrast to other possibilities, like wind, hydro and solar power, it goes beyond electrical production and furthermore is capable of providing an attractive answer for transportation requirements. . Biomass is understood as any non-fossil material of biological origin such as energy crops, forestry, residues and organic wastes[3] and it can be used or transformed in an energy carrier. This can be extended to include fuels produced directly or indirectly from biomass. Some of these kinds of fuels are known as biofuels[4] amongst which the

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[3] These wastes comprise of agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials. See http://www.energy.gov/energysources/bioenergy.htm

[4] There is a debate around the term biofuel instead of agrofuel. It seems using the prefix "bio" gives an environmental or benevolent connotation. "Agro" on the other hand specifies big monoculture procedures such as sugarcane, soy, etc. However, the *biofuels* definition used in this article is referring exclusively to its biological origin. See discussion in Honty and Gudynas, 2007, Pistonesi et al., 2008.

most remarkable examples are, bioethanol, biodiesel, and biohydrogen[5]. Some other examples of bionenergy products can include fuelwood, charcoal and methane[6].

Biofuels are also responsible for generating the most controversial debates in terms of sustainability, however, some references regarding biogas will be made below in the Colombian case study and supplementary research will be done as part of this project to understand the effects of bioenergy that come from different natural sources.

1.1.2.1 Types of biofuels (by natural physical state)

Biofuel can be classified by their natural physical state, i.e. solid, liquid and gas (as shown in figure 4). Solid biofuels come from non-standardized material, like: branches, dung, irregular firewood, bark, among others; and are exposed to mechanical processes to transform them into regular shapes such as pellets or briquettes, making storage, commercialization and use less problematic.

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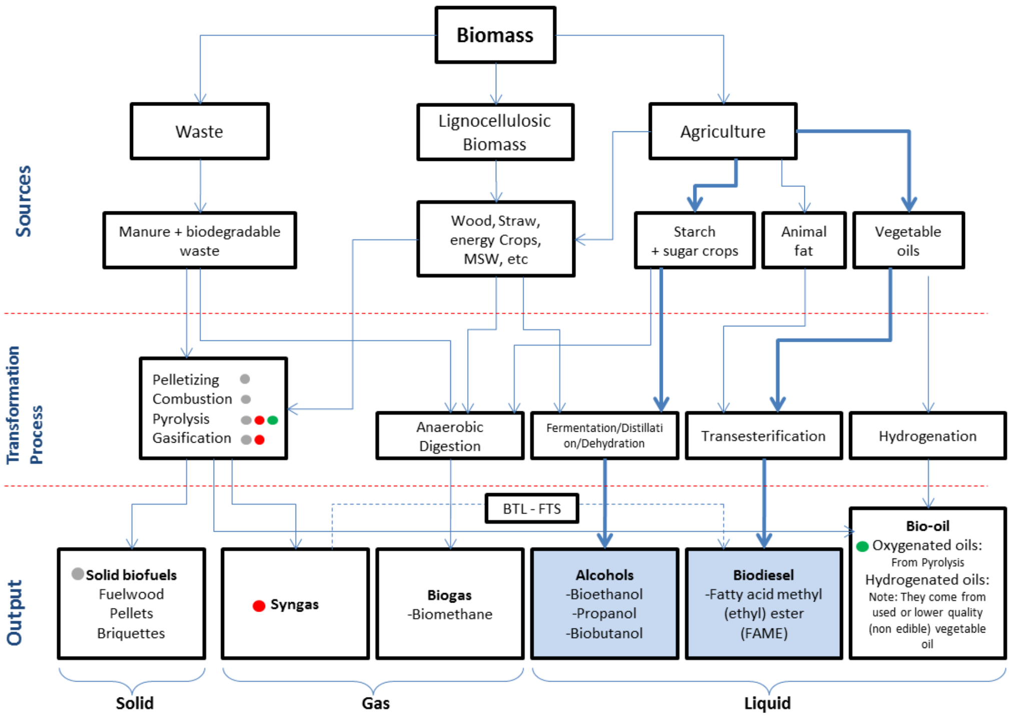
[5] The whole document, places special attention on energy crops used to create biofuels as most of them can be created deliberately and rapidly, which is not the case for forestry or waste-based processes, unless indicated otherwise.

[6] In a broad sense fuel is any material capable of storing potential energy and that usally releases such energy as heat. Having said that some other bioenergy products (such as firewood or methane) can be considered themselves as fuels. However the literature has coined the term biofuels mostly for those products in liquid state that are employed for transportation purposes.

Figure 4 Route from biomass to biofuels



Note: *The first transformation process gathers all technologies via thermochemical transformation. Different products can be obtained using such pathway: solid biofuels (grey dot), syngas (red dot) and oxygenated oils (green dot), based on the chosen route.*

There is also the possibility to put biomass through torrefaction (pyrolysis), which involves exposing the material to temperatures between 200 and 320°C in the absence of oxygen. Two main products are obtained: a solid material called *biochar,* and a gas called syngas or synthesis gas. Biochar can be used as a more concentrated firewood, but it has greater positive effect if it is used in agricultural practices, creating a negative net effect in terms of carbon emissions to the atmosphere, i.e. absorbing carbon instead of emitting it (J. Mathews, 2008a). In the case of syngas, it can be used directly as fuel or it can be used as source material to produce gasoline and diesel (through the Fischer-Tropsch process) (A. Demirbas, 2007).

Another source of bio-gas fuel is methane that comes from wastes, landfills or dung (Schuck, 2007). The most frequent use of such a source is for heating and electricity production. A solid by-product also results through the use of this technology, but in most cases is used as fertilizer rather than being used as fuel.

Liquid biofuels, which are the core of this document, are represented by alcohols and oils, and among them the most recognized and used ones being bioethanol and biodiesel. Alcohols, such as ethanol, butanol and propanol, are used to complement or substitute for gasoline fuel. They come mainly from feedstocks rich in starch (for instance potato, cassava, maize, or wheat), but they can also be produced from natural sugar sources, like sugarcane or beetroot. It is also possible to manufacture alcohols by using complex technological routes that are able to process biomass rich in lignin and cellulose (Schuck, 2006). These substances are present in the exterior layer of plants and are often used for paper and cardboard production.

The inclusion of such technologies brings an amazing potential to the bioenergy stage, due to the fact that other materials, for example: Poplar, Willow, Eucalyptus, Miscanthus and Switchgrass, can be considered as a source for biofuels manufacture (Mathews, 2009). Likewise, wastes from other industries can be used: from timber processing industries sawdust, branches and barks, can be employed, and some seed shells from food processing industries. Smeets argues that technology improvements per-se are not able to provide large potentials, but the former are hinging from a proper agricultural and livestock management as well as strong governance on land policies (Edward Smeets, 2008).

Unfortunately, these technologies are still under development and commercial scales are still not available due to cost and technical complexity.

Oils, on the other hand, complement or substitute diesel fuel. Feedstocks have animal (fat or tallow) or vegetable origin (oleaginous seeds, such as: rapeseed, castor oil, soybeans, and palm oil among others). These materials go through a process called transesterification (a blending process of fatty component with an alcohol), in order to separate glycerol (by-product highly used in pharmaceutical industry) from FAME (Fatty Acid Methyl Ester), commonly known as biodiesel.

It is also possible to employ residual oil from frying processes, or wastes from oily animal fodder. However, the commercial experience with this product is not as wide as the FAME one (Evans, 2007), nor as homogenous in terms of product quality. It is also possible to use non-edible oily seeds such as Jatropha Curcas, which is not very demanding in terms of soil conditions, so it can be planted in degraded or marginal lands.

From now on in this document, the term biofuel will make reference to any liquid fuel produced from biomass and used for transportation purposes. On that basis, it is possible to go deeper in to the classification of biofuels:

1.1.2.2 Types of biofuels (by technology generation)

Bioenergy has been present in human life since men were able to master fire, and during thousands of years not many changes in technology were presented. However within the last century this aspect has faced several modifications (S. C. Trindade, Cocchi, Onibon, & Grassi, 2012), turning the sector in a core of constant innovation.

Bioenergy uses several types of feedstocks to manufacture different kinds of products. Transformation of neat biomass into energy carriers (modern solid, liquid and gaseous presentation) can provide more efficiency in economic and energy terms, and can have more applications that in its original version. Technology complexity varies accordingly with the kind of feedstock to be processed, and so do the costs associated with the chosen technological path (Chum et al., 2011).

According to the type of technological route that is employed to obtain biofuels, these can be classified in four different generations (Carlos Ariel Ramírez Triana, 2010):

First generation biofuels (1GBf): they are also called agrofuels and they come from crops that are employed for food, or fodder for animals. The complexity of technology to process them is relatively low, given that accessing the sugars is relatively easy through the addition of yeast (for alcohols), and breaking the lipid chains, through transesterification, in the case of oils. Within this category are sugarcane, corn, cassava, and beetroot ethanol and butanol; and palm oil, rapeseed and soybean based biodiesel. Due to their relatively low costs first generation biofuels have successfully been produced commercially since the First World War.

In 1GBF only a small fraction of AGB is used for biofuel production, within the remaining fraction being processed for animal feed or lignocellulosic residues. For the Colombian case, which so far produces mainly sugarcane-based ethanol and pal oil-based biodiesel, is implemented the use of bagasse and palm fruit residues to produce heat and power to cover the needs of processing needs. Such practice likewise occurs in Brazil, leads to positive environmental footprints for these biorefinery products (Chum et al., 2011).

Second generation biofuels (2GBf): they emerged as a response to the most critical issue faced by 1GBf: the fuel vs. food dilemma. Lignocellulose sources are the base for 2GBf, so more materials can be employed as mentioned before. The yield that can be obtained with 2GBF exceeds regular feedstock results by a factor between 2 and 5, and the requirements of agrochemicals is less intensive in comparison with 1GBF (Hill, 2007). Biodiesel production uses Jatropha, Castor oil and some bushes such as Pongammia Pinnata and Callophylum Inophyllum. Lignin sources are also useful if they go through the Fischer Tropsch Synthesis. 2GBf can be obtained by using two paths:

- Biochemical extraction - using enzymes to break lignin fibers and release the required sugars. It produces cellulosic ethanol.
- Thermochemical extraction of oil -mentioned in the syngas process, for further biodiesel processing. This technique is called biomass-to-liquid (BTL) (BioPact, 2007; Schuck, 2007).

Notwithstanding the impact of their production process on soil organic matter after the removal of stands is done has not been completely studied (Anderson-Teixeira, Davis, Masters, & Delucia, 2009; Wilhelm, Johnson, Karlen, & Lightle, 2007). Nowadays, current commercial feedstocks are mainly used to provide heat and power, whereas oily seeds, sugar and starch crops are used to produce liquid biofuels (with some conversion of residues into heat and power as well) (Chum et al., 2011).

Regarding 2GBf, several pilot plants have been built in Europe and are at the forefront in bioenergy literature, however, their cost remain prohibitive to their implementation in the LAC region.

Third generation biofuels (3GBf): 2GBf do not cover the issue of land competition. Agricultural land is becoming scarcer, and implementation of 1GBF and 2GBf also need this natural resource. So, in 3GBf some research has been undertaken to use algae and cyanobacteria for biodiesel production. Some initial tests were carried out in fresh water, but due to the shortage of this resource, research redirected efforts to maritime organisms. Yield results have proven a productivity 100 times better than palm oil (which is the best 1GBf feedstock for biodiesel), however, high costs and unpredictable biological conditions have slowed the pace of this research (Gressel, 2008). From a techno-economic perspective the use of algae *for energy purposes only* is not attractive. So far, capital costs, productivity energy consumption during cultivation, harvesting and conversion paths to bio-energy has prevented to make of this a competitive alternative (Jonker & Faaij, 2013).

Fourth generation biofuels (4GBf): Given the recent emergence of 4GBf, their literature references are ambiguous. On one hand they are presented as organisms genetically modified, in order to raise cellulose content and with low lignin content. This is the case of some tropical Eucalyptus and Dahuria Larch. The main feature of these species is that they exclude carbon, turning into carbon negative biofuels (BioPact, 2007; J. Mathews, 2008a). It has been argued that energy content can be enhanced with 4GBf in comparison with 2GBf, reaching calorific values close to regular fossil fuels (Mannan, 2009).

On the other hand, some authors present 4GBf as an extension of 3GBf, in which, through genetic modification, some algae are created and undergo enzymatic biochemical processes, to produce biohydrogen or bioelectricity (M. F. Demirbas, 2011; DNV, 2010; Gressel, 2008; Lu, Sheahan, & Fu, 2011).

Frequently, many authors combine 3GBf and 4GBf under 2GBf, therefore, it is not common to find much information about them. Their study and implementation are conceptually interesting, however, they need more time to reach a mature commercialization within the LAC region. For instance calculations have been made where is implied that some particular biofuels (methanol, ethanol, hydrogen and synthetic FT diesel) could cost between EUR 16-22 per GJ (with prices of 2006), however projections to 2030 indicate that through technology and a biomass supply cost of EUR 3 GJ such costs could drop up to EUR 9-13 per GJ.[7] (Hamelinck & Faaij, 2006). Thus, there are potential savings in production cost between 18% and almost 60%, which is very attractive to the industry.

Now that biofuels have been explained it is important to understand the linkage that they have with sustainability and the implications for developing nations such as Colombia.

1.2 Sustainable Development and energy

The concept of sustainable development (SD) was issued by the Brundtland commission in Our Common future report in 1987, but it has been present tacitly from the early 70’s. The main point behind SD is to create a harmonic plan of action which organizes human life in a planet of finite resources, where the needs (particularly of the poor) are covered and limits are set by the technology and availability of restricted natural resources (WCED, 1987). In order to do that several issues have to be tackled, such as securing of food, provision of materials for sustenance, and implementation water, land and energy management, among others.

The relationship between energy, environment and SD is very close, given that in the pursuit of SD a society has the obligation to look for environmentally-friendly energy sources. However, it is a fact that all energy sources have some sort of impact on the environment, therefore energy efficiency and conservation is encouraged to its maximum extent (nevertheless it experiences technical and institutional issues for implementation), and research on several alternatives is always welcomed (Dincer & Rosen, 1999). A proper energy management plays a key role in livelihood conditions, given that it allows consumers and producers to have access to affordable, reliable and clean energy on a permanent basis (UNPD, 2014). Diversification of energy sources and appropriate distribution build up energy security and mitigate adverse impacts on the environment (UNPD, 2014).

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[7] In some regions su as the former URSS and LAC region is possible to drop down such cost up to EUR 7-11 per $GJ_{HHV.}$

Development and technical progress on energy has provided solution to several problems but it has unleashed some others like the effect of road traffic and the pollutants that are released by locomotive alternatives (Omer, 2008). For that reason, the use of some other fuels, that eventually can fulfill the same needs without generating effects as severe as the ones occasioned by current alternatives, calls the attention of scholars, governments and the society as a whole and it triggers a series of dynamics (policy-design, international forums, research, financial supports, etc.) that aims to strengthen an energy provision more aligned with sustainability goals.

For energy can be applied the concept of absolut sustainability (where there is not depletion and no residues) and relative sustainability (where there is a comparison of two or more generation technologies, cities, etc.). Absolut sustainable energy can be achieved by some renewable alternatives. Bioenergy can provide a more sustainable option than fossil alternatives for transportation purposes.

1.2.2 Biomass production and sustainability

Biomass production carries a huge responsibility because important social, ecological and economical upshots are hinging on it. On the one hand, it is a source for fuel, construction, fodder, clothing materials, medicines and so on. On the other hand, trees, bushes and other vegetation types have to accomplish an environmental balance while maintaining soil, water and air quality. This results in a difficult predicament to use biomass for energy purposes and at the same time to fulfill the rest of the basic needs (Miller, Mintzer, & Hoagland, 1986).

Important consequences are linked with a non-responsible biomass production system. Environmental results could be: devegetation, soil degradation, deforestation, erosion, loss of biological diversity and climate change. In addition socioeconomic results could include: possible reduction of agricultural yields in some areas, uneven land distribution and forced displacement of local populations among others (Chum et al., 2011).

Literature about bionenergy has been vastly feed with both, positive and negative impacts on job creation, wealth distribution, and wellbeing performance (Coelho, 2005; Khatiwada, Pacini, & Lönnqvist, 2010; Pimentel, 2003) ; therefore, it is hard to assume a clear and absolute position abour biofuels in this matter.

However, global warming, high pollution and fossil fuel's non-renewable nature have presented biomass as an appealing option in the current energy scenario. The photosynthetic process has an superb capacity for capturing energy. Through early studies (Miller, Mintzer et al. 1986) it has been shown that every year plants accumulate up to 10 times as much energy as the world uses. In using plants to produce energy important goals can be achieved: withdrawing the remarkable reliance on oil, moving back or even changing trends on pollution levels through carbon sequestration (wastes exchange[8]), and providing foundations for development and growth through rural development and creation of export industries.

This excitement comes with both high controversy and concern: a constant increase in food prices[9], indirect effects such as tropical deforestation and GHG emissions generating a carbon debit due to inadequate land use[10], this could be direct or collateral effects that endanger sustainability aims. Pros and cons around biofuels demand urgent attention: thus both sustainability balance and goals are top priorities on the global agenda.

1.3 Life Cycle assessment (LCA) importance

Measuring and monitoring sustainability is a key factor if new alternatives are to be implementedIt is important to bear in mind that turning biomass into energy brings along input and output flows that may have impacts on the environment.Assessing Sustainable Development Production as a whole is, by definition, particularly hard, so indicators have been designed to reflect the desired "triple P" criterion. Some assessment methods applied to agricultural cases (Doherty & Rydberg, 2002) could include, Cost Benefit Analysis (CBA), Ecological Footprint (EF), Energy Analysis (EMA), assessment of Ecological Integrity/index of Biotic Integrity (IBI), Positional Analysis (PA). However, none are complete or sufficiently integrated. (Fehér & Lýdia, 2005).

Some of the studies that have been used to make a partial approach to sustainability assessment in bioenergy production are founded in the use of Life Cycle Assessment (LCA). This is not a new tool, given that has been explored for nearly 30 years, but it was during the period 1900-2000 where LCA studies took a standard shape as result of numerous workshops, guides and handbooks (Guinee et al., 2010).

The LCA methodology is a quite comprehensive cradle-to-grave analysis of a particular product, in terms of input requirements and output achievements. The evaluation starts with raw materials extraction, followed by a processing stage, and subsequently by distribution and commercialization phases. A complete LCA finalizes when the selected product reaches its disposal stage, but in most cases ends with its final use.

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[8] Morton (2008) says: "As far as photosynthesis is concerned, oxygen is a potentially problematic waste product; but to the biosphere at large it is a great gift". So, ironically a wastes cycle is faced between industrial development and nature.

[9] This position is argued by some scholars (Redclift, M and D. Goodman, 1991; Pimentel, D 2003) but refuted by some authors (Kline, K, et al, 2009)

[10] See discussion presented in Mathews, J and H, Tan (2009)

The use of LCA in bioenergy studies have been implemented for about decade and a half (Cherubini & Strømman, 2011), and it provides a complete and tangible insight in particular aspects, such as energy efficiency, greenhouse emission savings, among others; therefore they can offer information for decision-making processes in both public and private enterprises.

A good compilation/comparison of the most recent publications in such regard can be found in (Cherubini & Strømman, 2011). However it is fundamental to highlight that LCA does not cover completely a sustainability assessment, but it focuses mainly in the environmental performance. In the literature it is also mentioned, as a barrier of LCA implmentation, that some funds are conditioned to the results obtained by LCA studies, therefore there are cases where the methodological freedom of e.g. biogenic carbon balance and allocation are practically non-existent (Guinee et al., 2010). Some other obstacles that LCA studies must overcome are the lack of enough carbon footprint studies implement in geographic areas different to Europe and North America (so it is possible to provide more accurate results of the analysis), as well as turning the results into real-world enhancements, given that in several occasions LCA's cannot cover side-effects such as LUC, rebound effects, market mechanisms, etc.

Most of the LCA bioenergy analyses have been carried out in developed countries. Just recently a considerable amount of publications have shown productive systems in developing countries, particularly in Southeast Asia. There is not abundant research for biofuels by using LCA studies in Africa and South America (Cherubini & Strømman, 2011). There is comparative analysis of the Colombian and Brazilian case via LCA study, however deatails of the study are not provided in the publication (Yáñez Angarita, Silva Lora, da Costa, & Torres, 2009). As part of this thesis, within the Chapter 6 will be presented a complete LCA for sugarcane based ethanol and palm oil, where it will compare results with those presented by Yañez et.al[11] .

To end the current chapter an insight of the Colombian bioenergy panorama is presented in brief.

1.4 Colombia: country, energy needs, and bioenergy industry

Some progress (regulation and investment) has been made so far, but as is shown below, there are some task regarding social and environmental balance that still need consideration. An initial reference to the country's current situation is presented, followed by an energy analysis, in order to understand finally Colombia bioenergy performance at the present time.

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[11] It is important to highlight that the work presented here to assess sustainability is mainly focused on GHG and LUC effects of 1st generation biofuels (particularly on chapters 6 and 7).

1.4.1 General Information

Colombia is a country located in north-western South America with a population of over 45 million people evenly distributed by gender (See **Table 1**). It is possible to establish a density of approximately 38/km^2 (Crossing information with **Table 2**). Its territory (more than 114 million hectares) places it as the fourth largest nation in South America. More than 70% of the population is located in urban centers which are spread throughout the highlands of the Andes Mountains. However, Colombia also encompasses tropical grassland, Amazon rainforest, and both Caribbean and Pacific coastlines. In 2005, when bioenergy projects started in Colombia, more than half of its land was covered by forest, about 38% of the available land was suitable for agriculture, but was already predominantly used for livestock (above 90%), leaving only a small area for growing crops (see **Table 2**). That opens the door today to create a new scheme of intensive agriculture/ergoculture[12] and to restructure land activity distribution.

Table 1 Colombian Population Distribution Estimated for 2006 and 2013

Category (1000)	2006		2013	
	Unit (1000)	%	Unit (1000)	%
Total - Both sexes	43841	100.0%	48321	100.0%
Male	21594	49.3%	23759	49.2%
Female	22247	50.7%	24563	50.8%
Urban	32388	73.9%	36650	75.8%
Rural	11454	26.1%	11671	24.2%
Total economically active	21684	49.5%	25545	52.9%
Male	11662	26.6%	13562	28.1%
Female	10022	22.9%	11982	24.8%
Economically active population in Agr	3571	8.1%	3467	7.2%
Male	2700	6.2%	2597	5.4%
Female	871	2.0%	870	1.8%

FAOSTAT FAO statistic division 2013

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[12] Ergoculture concept (land to cultivate energy) developed by Mathews (2007)

Table 2 Colombia Land distribution 2006 and 2011

Elements	2006		2011	
	Area (1000 ha)	%*	Area (1000 ha)	%*
Country area	114175	100.00%	114175	100.00%
Land area	110950	97.18%	110950	97.18%
Agricultural area	42174	36.94%	43785.6	38.35%
Arable land and Permanent crops	3369.3	2.95%	3998	3.50%
Arable land	1904.6	1.67%	2098	1.84%
Permanent crops	1464.7	1.28%	1900	1.66%
Permanent meadows and pastures	38804.7	33.99%	39787.6	34.85%
Forest area	60903	53.34%	60398	52.90%
Fallow land	108.2	0.09%	114	0.10%
Other land	7873	6.90%	6766.4	5.93%
Inland water	3225	2.82%	3225	2.82%

* This percentage is the share of the element in the Total country area
FAOSTAT 2013

Since 2000, Colombia has had a positive growth in its GDP starting under 2% in 2001 and reaching almost 7% in 2007. In the same period of time a contrary tendency is seen in the inflation rate, decreasing constantly from almost 11% in 1999 until its lowest point in 2006 (4.3%) and increasing again in 2007 (5.54%).[13]

Table 3 South American socioeconomic facts

Item	Gross domestic product, current prices			Population			Gross domestic product per capita, current prices			Unemployment rate		
Unit	U.S. dollars (Billions)			Persons (Millions)			U.S. dollars (Units)			Percent of total labor		
Country	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
Argentina	444.61	475.21	484.60	40.57	41.03	41.49	10958.90	11582.48	11679.30	7.15	7.20	7.34
Bolivia	24.12	27.23	29.81	10.63	10.83	11.04	2269.35	2514.32	2700.53	6.50	6.43	6.35
Brazil	2474.64	2253.09	2190.22	196.66	198.36	199.88	12583.64	11358.54	10957.61	5.97	5.50	5.80
Chile	250.99	268.18	281.67	17.25	17.40	17.56	14551.69	15410.12	16043.10	7.12	6.43	6.18
Colombia	**330.76**	**369.02**	**369.23**	**46.05**	**46.60**	**47.15**	**7182.36**	**7919.17**	**7830.67**	**10.84**	**10.38**	**10.30**
Ecuador	76.77	84.04	91.41	14.42	14.63	14.85	5324.55	5742.65	6154.06	6.00	5.30	5.50
Paraguay	24.08	26.07	30.56	6.57	6.68	6.79	3666.30	3903.66	4499.21	5.60	5.80	5.40
Peru	178.37	198.85	210.35	30.01	30.47	30.95	5943.85	6525.36	6797.34	7.73	6.75	6.00
Uruguay	46.44	49.92	57.11	3.37	3.38	3.39	13784.56	14766.83	16833.65	5.99	6.03	6.70
Venezuela	316.48	381.29	367.48	29.07	29.52	29.99	10886.05	12917.52	12255.50	8.20	7.82	9.21

World Economic Database, January 2014

Due to its high population (second in the South American region), its GDP per capita in Colombia is below average in South America (See **Table 3**). A similar situation occurs in Brazil according to the ranking; however, its GDP per capita is over the average in the region by far, showing a big gap in productivity, dividing these countries into two groups:

- High productivity (Venezuela, Chile, Uruguay, Argentina and Brazil)

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[13] Data from IDB (Inter-American Development Bank) databases: http://www.iadb.org/countries/indicators.cfm?id_country=CO&lang=en

- Low productivity (Colombia, Peru, Ecuador, Paraguay and Bolivia)[14].

By 2006 the labor force reached around 50% of the total population in Colombia with participation growing trend for 2013 (nearly 53%). Close to 17% of the labor force (almost 8% of the total population) was participating actively in primary sector activities, but such item decreased by 2013 (to 13.5 and 7.2% respectively) (**Table 1**).

By February 2009 it could be established that 25% of the occupied people were working in the commerce, restaurant, and hospitality sectors (which is still the most active sector today). These facts seem to show that Colombia is on the developing path, changing its agricultural vocation as seen 15 years ago and moving towards the service sector. Nonetheless the picture is incomplete, because in 2009 the unemployment rate is at 12.5% and underemployment rate is almost in 40% (DANE, 2009). If violence and consequent migration are added it is easy to understand that the current social balance is negative; and farmers and agricultural non-trained workers are being sent to the cities to work in precarious and non-stable conditions, accelerating the effects of violence in the cities due to impoverishment and lack of opportunities.

It is fair to say that Colombia now has a better security situation which has brought investment confidence. Since 2002, under president Alvaro Uribe's administration, a new government plan started called "Democratic Security", characterized by providing an enforcement of the public force (Manson, 2003)[15], hence creating a trust climate and boosting direct foreign investment. But it is undeniable there still exists the effects of a 40-year-old civil conflict with the presence of guerrillas, paramilitaries, and drug dealers creating political instability, and generating grim effects such as forced displacement and irrational use of land.

However, a high environmental price has been paid by Colombia in order to adopt the current development model. The uncontrolled growth of every city has left a huge legacy of environmental problems: atmospheric and noise pollution, and traffic congestion are endemic. Generalized respiratory issues and control policies are a consequence of that, diminishing the productivity in some cities[16]. Aquatic ecosystems, especially rivers close to development cores are extremely polluted.

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[14] Venezuelan case is particular because a big portion of its income comes from oil exports (and derivatives), but not from agriculture or manufacture products which is the case of rest of South American countries.

[15] Manson argues that notwithstanding the enhancement in economic issues due to Uribe's policy there is also a big concern among political opposition and some civil society sectors that the strategy has, at best, moved forward more aggressively on the military than on the institutional dimension, and, at worst, has restricted the democratic rights that it purports to protect.

[16] Daily respiratory hospital admission is highly correlated with air pollutant emissions. The result of this is: on one hand frequent work absence and on the other hand creation of taxes for emissions, restrictions over the use of vehicles, among others (Lozano 2004). In recent years Bogota, Pereira, Cali and Medellin have implemented restriction of the use of vehicles only during peak hours with effective results. Other cities are planning to follow that example. However, since the beginning of 2012 the Mayor of Bogota, Samuel Moreno, has imposed a very controversial full "No drive day" during two weekdays (taking turns according with the license plates on private vehicles), generating

Additionally coffee plantations, the traditional crop in Colombia with around 590 thousand hectares cultivated today[17], require intensive use of pesticides and fertilizers, and are highly demanding of lighting conditions, which means large scale clearances of shade trees, resulting in degradation of soil quality. Deforestation is massive and largely uncontrolled and is the outcome of undesired migration processes, thus increasing the desertification progression in the Andean ecosystem (O'Brien, 1997). Profits have been plunging and most of the added value is captured by international coffee processor, and benefits for small farmers are appalling.

Moreover, illegal coca leaf production, processing and posterior eradication when crops are detected by the Government, bring catastrophic results to the environment and society, including: rainforest clearance for starting the crops (most commonly burning), strong chemicals used to nurture the plants and to increase cocaine content, anti-personnel mines employed to protect the plantations, inflationary phenomena in local economies, violence, farmer evictions, and fumigation (without discrimination between illegal and subsistence crops) with potent herbicides used to eradicate these illegal plantations (Álvarez, 2001; Mejía & Posada, 2008).

Colombia needs to expand their agricultural horizons beyond coffee, and strengthen the primary sector to develop agricultural and ergocultural projects, leading to a better demographic distribution, and hence local progress. Moving from a weak tertiary sector to a potential strong primary sector would not necessarily mean involution, but opportunity.

1.4.2 Energy Information

Colombia has shown (so far) a relatively low energy import dependency due mainly to its use of hydro-power energy. Electricity in Colombia is based on hydro (close to 82%), gas (around 12%) and coal (approximately 7%). Nevertheless, due to transport and industrial needs for Colombia, oil is the dominant fuel, accounting for 34.4 % of 2007’s primary energy demand, followed by hydro (33.6%), gas (23.1%), and coal (8.8%) (BMI, 2008), so the remainder for biofuels and other renewable sources is low.

As the security situation is being improved, the number of attacks against Colombia’s energy infrastructure has dropped, but even today occasional sabotage is done by insurgent groups to the country’s pipelines and power lines (EIA, 2009a). According to Oil and Gas Journal (O&GJ) cited in EIA, Colombia had 1.36 billion barrels of proven crude oil reserves (as of 2009), the fifth-largest in South America. Production though, is at risk, attributed to lack of confirmed new oil

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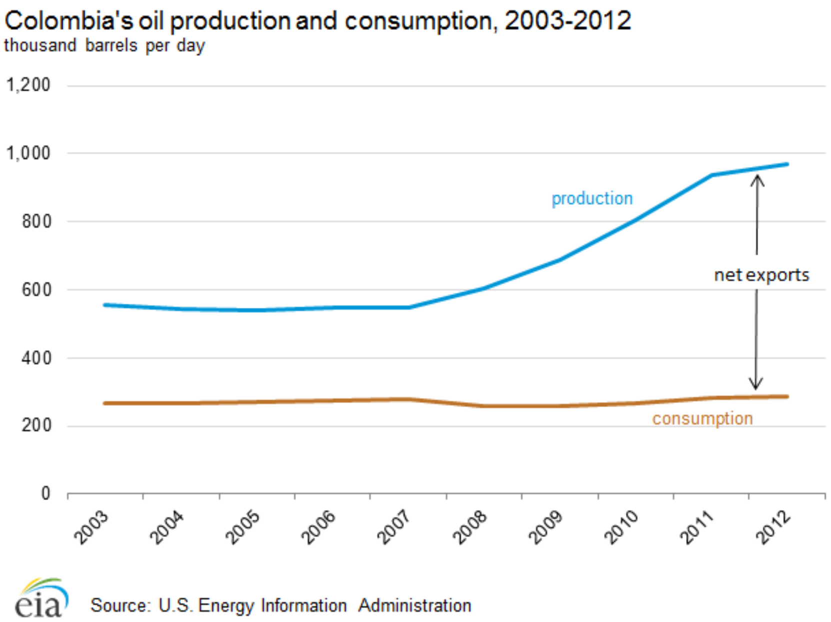
slowdown in business and creating analogous effects experienced by Mexico City, where a similar program appeared to have induced the purchase of a second vehicle, often older and more polluted. This law is under revision by city council in order to whether cancel or continue.

[17] FAO Data base. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor

reserves and uncertainty associated to investment flows for exploration and drilling activities (See **Figure 5**).

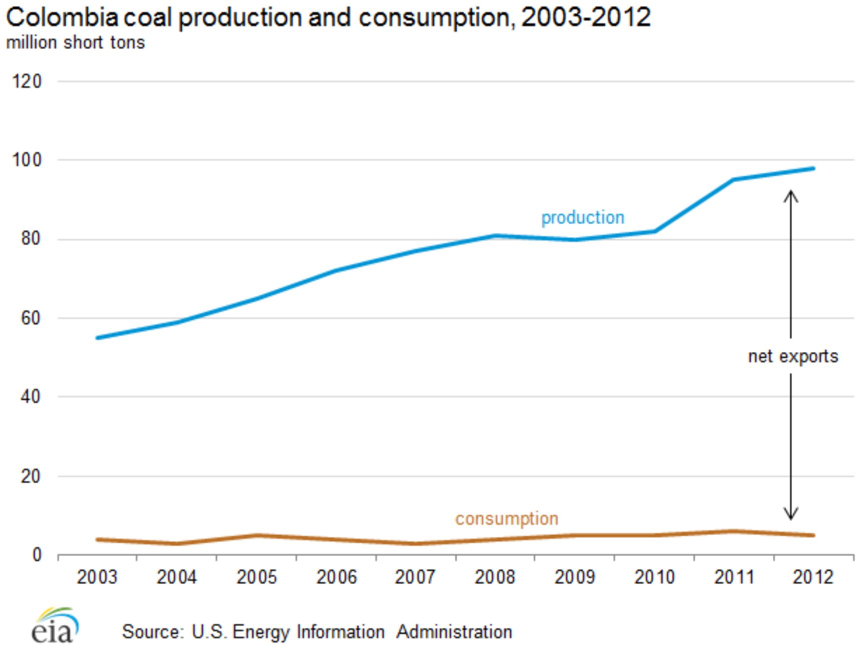
Figure 5 Colombia’s Oil production and consumption



Source: U.S. Energy Information Administration

Coal is one of Colombia’s strengths, with 7,670 million short tons (MMst) of recoverable coal reserves in 2006, but just a small amount is dedicated to internal consumption (See **chart 6**). Actually, its export levels place Colombia as fifth largest coal exporter in the world (EIA, 2009a).

Figure 6 Colombia's Coal production and consumption



Colombia counts on a diversity of energy choices, but none of them are absolutely sustainable in the long run. The country is running out of oil, hydro is highly threatened by possible droughts, and coal's share in internal industry is not heavy, not to mention high pollution contributions; hence investment in new alternatives, such as bioenergy, must be considered and welcomed, after proper studies and commitments to sustainable production standards.

1.4.3 Biofuels in Colombia

Colombia is starting to develop a complete proposal in order to seize the eventual economic compensation offered by the bioenergy industry, thus taking advantage of its land capacity and the potential of its agricultural sector. Colombia, with agribusiness entrepreneurs, government support, and international interest, has decided to step firmly into this market through a nascent legal framework, continuing with agricultural R&D focused on energy production and creating the adequate climate for foreign direct investment.

This section presents a review of the types of biofuels and the stages used to produce Bioenergy in Colombia. This information will be widened later on for sugarcane based ethanol and palm oil biodiesel. In spite of this, it is necessary to understand which factors are driving such a boom for this industry, so an explanation about R&D and the legal framework will be done.

1.4.3.1 Research and Development (R&D)

Colombia has been following the path of biofuels research for almost 30 years and it has accumulated several research groups that are working in several areas, including: basic research, agricultural projects, product transformation, biotechnology, engine applications and environmental impacts.

It is remarkable the interest of research groups born from private initiative, directly linked with agribusiness chains: CENICAÑA[18] for instance is the Colombian Sugarcane Research Centre, it was funded in 1977 and it is sponsored directly by ASOCAÑA[19] (established in 1959). The same happened with CENIPALMA (Colombian Research Centre for palm oil), which works since 1991 under supervision of FEDEPALMA[20], wich in turn was created in 1962. Despite this, research centers are not specifically designed for supporting the biofuel industry, their efforts are focused on these products because they concentrate R&D to point out efficient crop methods and biological varieties that increase yields per hectare.

Other independent R&D centers are also present around the Bioenergy industry. That is the case of CIAT[21] International Research Center for Tropical Agriculture. This center is leading cassava-based ethanol production in the LAC region, a pilot plant was recently built as is explained in **appendix 1**.

Some research projects are starting to be directed exclusively to bioenergy production. The Biotechnology Institute belonging to Universidad Nacional[22] just discovered a bacteria that is capable of eating glycerin (co-product of biodiesel and highly contaminating if it is not treated adequately) transforming this substance for further processing (La Rotta, 2009).

In order to enhance sustainable production of biofuels and to promote strategic lines for innovation and scientific research in Colombia US$ 1,180,000 was planned to investe from 2008 to 2012 (MEN, 2008; Rojas R, 2008). These funds were supposed to come from 'Inter-Americas Development Bank' (IDB) giving more than 40% of the total investment. The 'Knowledge Partnership Korea Fund for Technology and Innovation'[23] contributed US$350,000, and the rest

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[18] Centro colombiano de investigación de la caña de azúcar: www.cenicana.org

[19] ASOCAÑA Asociación de cultivadores de caña de azúcar de Colombia. Colombian sugarcane growers association. Website in Spanish: http://www.asocana.com.co/

[20] FEDEPALMA Federación Nacional de cultivadores de palma de aceite. National Federation of Palm Oil Growers. Website in Spanish: http://www.fedepalma.org/

[21] CIAT: Centro Internacional de Agricultura tropical. Website in Spanish www.ciat.cgiar.org/inicio.htm .

[22] The biggest public university in Colombia

[23] This contribution from the Korean government is part of a big help (US$ 50 million) to Latin American countries in order to strengthen their science and technology capacity. The inclusion of Korean Partnership was announced by Ciro de Falco, IDB Executive Vice-President in his opening speech for the Global Forum: Building Science, Technology, and Innovation Capacity for Sustainable Growth and Poverty reduction (January 2007).

being donated by 'Instituto Colombiano para el Desarrollo de la Ciencia y la Tecnología', 'Francisco José de Caldas' (COLCIENCIAS)[24](MEN, 2008). So far, there has been no report on the public light regarding this particular initiative.

1.4.3.2 Legal Framework

Regardless of longstanding interest in bioenergy/biofuels research, legislation around biofuels in Colombia only started some years ago with *Ley 693 de 2001*[25]. In this law the regulation indicates that gasoline and diesel must be blended with ethanol. Despite the advanced condition of the market at that, the standards were not clearly established. With a later resolution in 2003 this situation improved, by recognizing the importance of biofuels and the necessity to expand the supply. Initial it demand that cities with a population over 500,000 should mix regular gasoline with ethanol in a proportion of 10±5% to create what is known, nowadays, as regular oxygenated gasoline. Mandatory use started in September 2005. Some tax-exemptions in the commercialization chain were released to boost the production, and the prices would be controlled by the Government through the Ministry of Mines and Energy[26].

Biodiesel crops were given tax-exemption within a general law for agricultural development: *Ley 818 de 2008*. Law 818 of 2004 had some discrimination between crops and a lack of precision in the definition, so it was consequently corrected a few days later in Ley 939 de 2004. By doing so, crops used for creating biofuels for diesel engines (bioethanol, biodiesel, biomethanol, biodimetileter, Synthetic Biofuels, biohydrogen and vegetal oils), were tax exempt from the beginning of the production for the next (now standardized) 10 years. Further legislation has been published to fine-tune the standards in order to raise them, and hence improve quality and performance in engines.

1.4.3.3 Investment

In 2006, a consortium of Colombian companies announced that they would build three ethanol plants in the country, with a total production capacity of 5,600 bbl/d, however, that has not happened. Contrary to coffee, biofuels have to be processed domestically, so the export of unprocessed commodities can be avoided (J. A. Mathews, 2008), generating local development. These plants mainly target export markets, but will also sell some of their production domestically. ECOPETROL formed a joint venture in 2007 with local palm oil producers to build a biodiesel plant in the city of Barrancabermeja, with a capacity of 2,000 bbl/d. ECOPETROL aimed

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[24] Colombian Institute for Science and Technology Development

[25] Law 693 of 2001: decrees the rules for the usage of fuel alcohols, creates stimuli for their production, marketing and consumption, and also lays down other provisions.

[26] Resolución no. 180836 de Julio 25 de 2003. Resolution N. 180836 July the 25th of 2003: which defines the price framework for Regular Oxygenated Gasoline.

to blend most of the plant's output with conventional diesel fuel produced by its refinery in the city (EIA, 2009a).

The IDB is also planning to finance a US$20 million palm based biodiesel plant that will eventually produce up to 100,000 tons of fuel per year.

Some exotic varieties such as Jatropha are attracting the attention of investors in Colombia, trying to replicate the successful African experience. In particular, Oilsource Holding Group Inc. and Abundant Biofuels Corporation are eager to bid on Colombian soil with an estimation of US$45 million. It brings an appealing chance to diversify feedstock in Colombia bioenergy plans and partially avoid the food vs. fuels discussion.

1.4.3.4 Regarding biofuels: what is produced in Colombia and how?

Nowadays in Colombia, there are different sources of alternative energy: wind power is generated on the North coast in the Jepirachi plant in the Department of La Guajira, several hydro dams are located throughout Colombia supplying most of the electricity to the energy grid, and now it is the turn for bioenergy: today this South American country is producing ethanol and biodiesel, and there is a project for biogas.

1.4.3.5 Bioethanol

Bioethanol in Colombia is partially based on starch extracted from maize and cassava crops. Maize has the highest acreage among biofuel feedstock sources[27]. Maize crop area has been fluctuating substantially in the last 2 decades, but the current level is slightly lower than 20 years ago, close to 0.6 million hectares (See **figure 7**). Cassava is also a starch source and its area has practically remained constant from the early 1990's but has a remarkable production growth using the same area (its production has changed 66% in the analyzed period and the cultivated area has varied by 16%, see **figure 8**).

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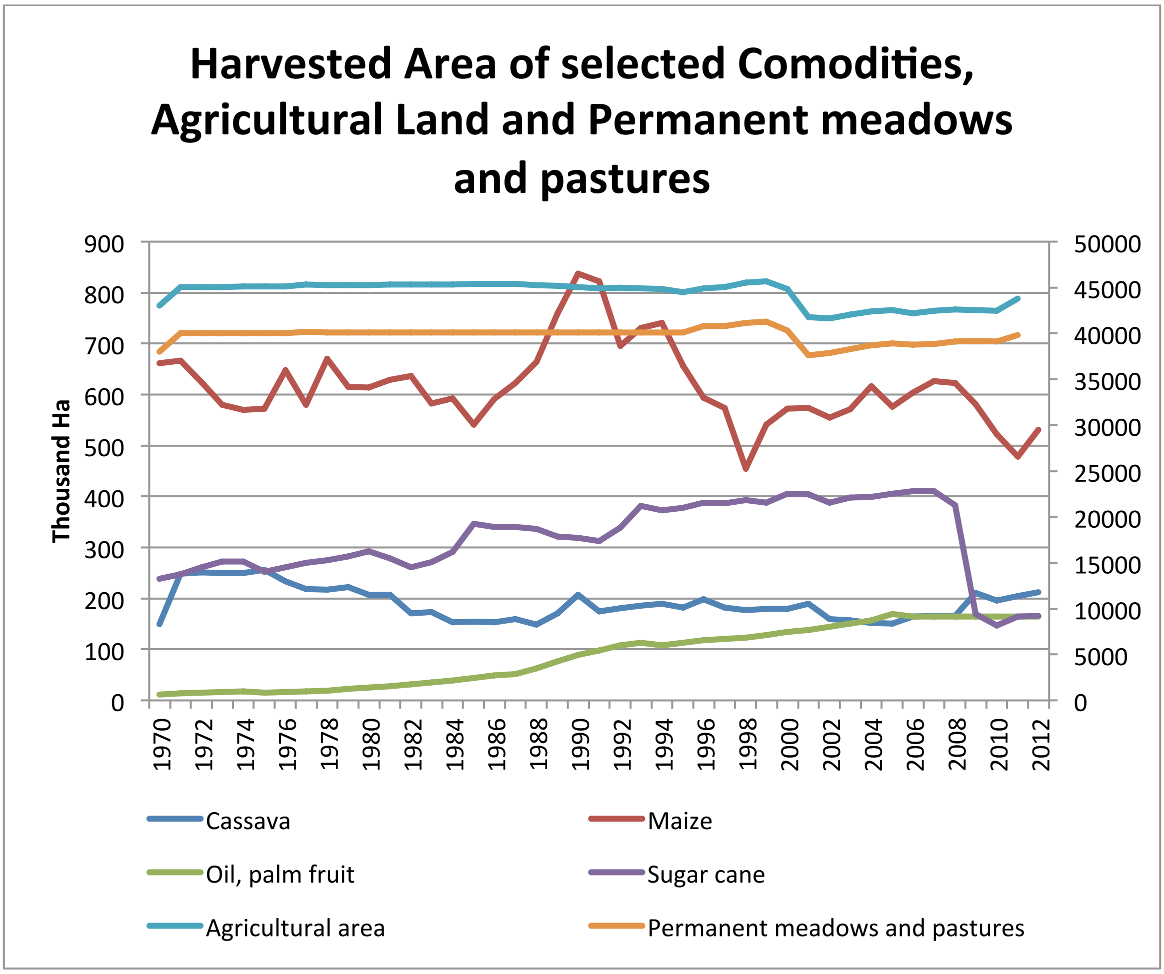
[27] This acreage refers to total commodity cultivated for different proposes including feed and food, and other industrial aims.

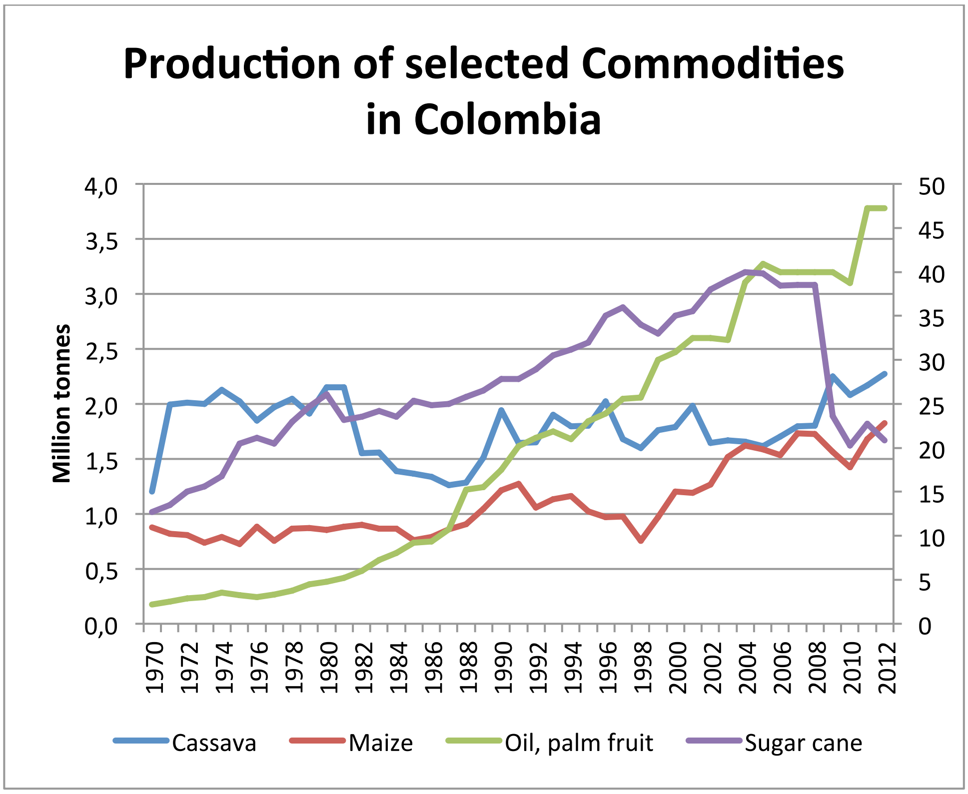
Figure 7 Land indicators of selected Comodities

Harvested Area of selected Comodities, Agricultural Land and Permanent meadows and pastures



Note: Agricultural area and Permanent meadows and pastures are measured in the seconday axis
FAOSTAT | © FAO Statistics Division 2013 | 11 December 2013

Figure 8 Production of selected Commodities in Colombia



Note: Sugarcane is measured in the secondary axis.

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Currently, most of the ethanol industry in Colombia is alcohol-based, hence sugarcane is the preferred input due to its high productivity[28], reaching levels of 90 ton/ha, which is approximately 8 times cassava productivity (See **figure 9**). It is estimated that between 37,000 and 50,000 sugarcane hectares (8.2% and 11.1%) and 3000 cassava hectares (16%) are dedicated to producing ethanol (Rothkopf, 2007).

By 2007, Colombia had 5 processing plants to produce sugarcane-based ethanol and it was able to produce 730 thousand liters(Honty & Gudynas, 2007). Recent data published by *Fedebiocombustibles* shows no change in the number of plants, however there was an increment in the productivity, which can be seen by an increase of the installed capacity reaching 1’250.000 l/d.

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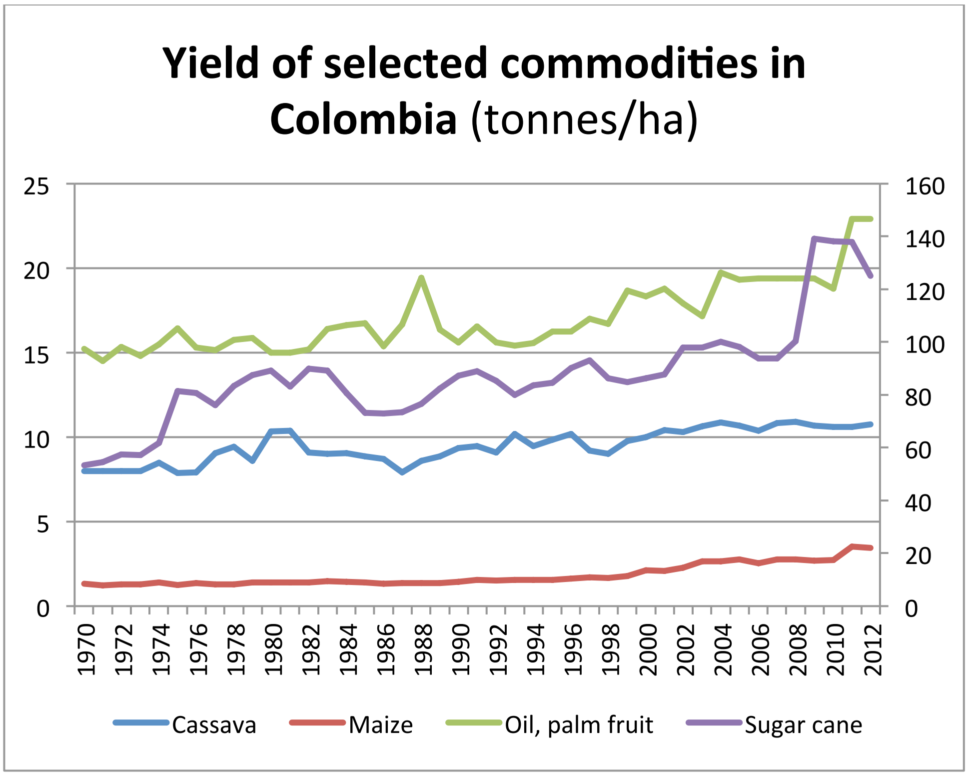
[28] Colombia is placed in world top 10 sugarcane producers

Figure 9 Yield of selected commodities in Colombia



Note: Sugarcane is measured in the secondary axis.

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Most of sugarcane production in Colombia is concentrated in the *Cauca Valley* (Southwest). At the present time, further growth has been hampered by unavailability of land in the zone. For that reason CENICAÑA, recommends creating intensive crops and a big extension of land is planned to this end (see figure 3). This land was chosen because currently it is used for low density livestock pastures (Toasa, 2009). It is important to stress the risk in the aforementioned: Colombia has several biodiverse hotspots, therefore, an indiscriminate implementation of energy crops cannot be made without putting these at risk. In chapter 7 this expansion potential will be explained in more detail.

Processing technology to treat sugarcane in Colombia is being brought from India and it has some advantages, including: it produces a low volume of vinasse[29] and allows them to be further processed and deliver fertilizer to market. In addition ethanol plants in Colombia use about one-third of the water of Brazilian plants and about half of the energy (Toasa, 2009). However the sugarcane variety used in Colombia needs heavy irrigation which is avoided in Brazil.

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[29] Vinasses are a big threat for water sources and for soil conditions.

Table 4 Differences between Brazilian and Colombian ethanol industries

item	Brazil	Colombia
Vinasse (l)/ethanol (l)	15 a	1 - 2 a
Tons of sugar cane (million)	588 b	38 c
Cost (USD/GJ)	14 d	18.2-21.5 a
million l/y (2012)	23216 b	333 e
price Usc/l (2012)	63 f *	121 e *

a Toasa
b Sugarcane.org (2014)
c Faostat
d Chum et. Al . 2011
e Fedebiocombustibles website
f (Barros, s. 2012)
* calculated based on the source

Additionally, sugar mills in Colombia are energy self-sufficient, using burned bagasse as a power source. In fact, the energy produced is higher than the required amount for the factories, for that reason surplus is sold to the national energy grid.[30]

In spite of counting with higher yields in terms of tons of sugarcane per ha, Colombia handles higher productions costs and prices, and this is mostly due to the fact that in Brazil alcohol industry has been from the mid 70's, whereas in Colombia is just starting to mature.

Literature does not provide detailed reference regarding maize ethanol production, but there are some notes around exotic cassava production in the country (See appendix 1).

1.4.3.6 Biodiesel

Biodiesel production in Colombia is derived from palm oil[31], because other oleaginous sources have been reduced and are not competitive (Honty & Gudynas, 2007). Contrarily, palm oil crop areas and production have increased rapidly (on average 13% and 11% respectively yearly, See charts 7 and 8).

Colombia counts three producing regions that are able to provide nearly 1.7 million liters/day, and 5 recognized processing plants. In chapter 6 a complete description of the Colombian biodiesel production will be presented.

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[30] Some incentives are being created in order to attract investors to create 230 MW. Nowadays the industry is able to produce 90MW. Expanding capacity requires about US$100 000 and government support.

[31] Colombia is among the world top 5 palm oil producers (being the premier one in LAC region).

1.4.3.7 Opportunities and threats

The Colombian bioenergy industry brings a dual challenge:

On one hand, it has the chance to develop an enormous comparative advantage. To develop alternative energies that not just implies a decrease of oil imports but opens the possibility of a nascent exporting industry, beyond just agricultural commodities that have been usually commercialized as raw materials or as products that face high levels of competition in international markets or with low added value (e.g. raw sugar, unrefined oil) (See **appendix 2**).

The boost of this industry can have collateral impacts on other social aspects, such as job creation and income distribution. The biofuels industry is manpower-intensive, so it can have a positive impact on the labor market. In 2004 the palm oil industry contributed to employment with the creation of more than 30,000 direct jobs and about 60,000 indirect ones (Fedepalma, 2004). Sugarcane, by 2008, provided 36,000 direct jobs and 216,000 indirect (Toasa, 2009). If more agribusiness projects are implemented in this industry, economic well-being can be boosted and social conditions as well.

The implementation of biofuel regulations contributes to a positive environmental balance in major Colombian cities, expressly: with the use of biodiesel, pollution emitted by low quality diesel used in the nation will eventually diminish.

The Colombian bioenergy industry is growing up, but to reach its maturity it has to develop internally, reaching a solid position through adequate infrastructure and offering big and small producers an equal chance to play. After that, it can think about export possibilities. The establishment of a Biofuels industry has impacts along the whole chain, not just the processing component. For that reason, current distribution is suitable and requires only small changes in pump stations. However, the transport fleet will require major engine tuning to work properly with proposed blends. In addition to this consumption factor, it is fundamental to demand stimulation starting from inside. Today ethanol covers 80% of Colombian territory using a blend of 10% ethanol and 90% gasoline. However this market will grow substantially with the introduction of Flex-fuels vehicles (Guzman, 2009)[32].

The goal is try to cover 100% of national territory with an E10, and once a bigger supply is developed, the content of ethanol in the mix will be increased up to 20%. After that exports will come onto the agenda.

Colombia demonstrates a robust legal framework, showing a strong government commitment to the industry. Of course, it has paid off with almost twelve bioenergy functioning

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[32] According to Hernán Martinez, Minister of Mines and Energy, the decree 1135 of March 2009 claims that from 2012 all assembled or imported vehicles must have the possibility to work with blended fuels up to 85% ethanol in the mix.

projects since law 693 was released in 2001. Investors and agribusiness sectors are encourage to keep working on and enhancing productive capacity.

Nonetheless, it seems that some connections between politicians and agribusiness leaders has created big doubts about the transparency of policies: in June 2008 ethanol price in Colombia was COP$4496.88 per gallon, (approximately US$2.15) in April 2009 this price has increased to COP 7698.39 (US$3.75) due to a price calculation scheme proposed by the government (Chacón & Gutiérrez 2008)33. That means a rise of 71% in 11 months.

A debate is currently being held about this topic: Agribusiness and producers argue that the modifications try to cover failures that generate losses in the near past, due to Colombia just starting and developing the industry and some support is needed to keep operating in the market. However, some senators, such as Jorge Robledo, and economic analysts, such as Salomon Kalmanovitz, say that it is a perverse distortion from international prices and it does not allow the country to reduce general prices. They point out that the sector is today highly patronized by the government with tax exemptions (40% deduction from income tax over fixed asset investment) plus low credit and other incentives (CEET, 2009).

According to the government, the formula used to calculate the price was designed to encourage ethanol suppliers and boost the quantities produced, in order to reach the proposed goals to cover most of the country, but it has recognized that some errors could have been made and should be corrected.[34]

Finally, multinationals are accused of hiring or creating paramilitary groups, with hidden government approval, with the intention of securing their investment and to cover it from

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[33] The calculation scheme is based on opportunity cost: The mechanism calculate the price based on the amount of sugarcane needed to produce a quintal of sugar (45 kg). The previous one indicated that it was possible to produce 29.2 liters of ethanol but the current one says that just 21 liters can be made out of it.

[34] Based on the resolution 181232 (29/07/2008), issued by the Ministry of Mines and Energy, the Sales Revenue for alcohol fuel producers (IPAC(t)) is defined by the following formula:

IPAC(t) = max [COP$4696.88, EqAC(t)1, EqAC(t)2]

Where IPAC(t) refers to the Sales Revenue for alcohol fuel producer, as the result of the sale of such product (expressed in gallons and in standard conditions, i.e. at a temperature of 60°F).

COP$4696.88: Expresses a minimum price per gallon and it has to be paid to the producers if some other conditions are not convenient. This value has to be adjusted by use of the price producer index (IPP) (70%), and the official exchange rate (TRM). The price is fixed and adjusted by technicians at the Ministry.

EqAC(t)1: Is the value of a gallon of bioethanol assessed by its equivalent of white sugar in international markets. This value represents the average of exporting parity of refined white sugar values, based on the No 5 contract at the London Futures Exchange (LIFFE), using the first 25 days of the month. The whole formula can be seen in the reference.

EqAC(t)2: Is the value of a gallon of bioethanol assessed by its equivalent of Colombian gasoline in international markets. This value represents the average of exporting parity of Colombian gasoline using the first 25 days of the month. Some adjustments are applied to the value taking into the account octane rating enhancements and sulfur diminishments. Some fine tuning is also implanted by the decrease in commercial value of the oxygenated gasoline by its corresponding decrease in energy content in comparison to regular gasoline. The whole formula can be seen in the reference.

All the acronyms have been left in Spanish and they can be found in the List of Acronyms.
The whole formulation is found in Spanish here: (Ministerio de Minas, 2008)

possible attacks from insurgent groups such as FARC guerrilla or other criminal organizations. On the contrary, the military capacity of these paramilitary groups have been used against local small farmers in order to displace them and grab their land (See **Appendix 3**), and used against union leaders to control and scare the population.

This fact is not exclusively linked to the bioenergy industry, but should be monitored by NGO's and the government in order to improve local population conditions and also facilitate commercial agreements.

Environmental studies done by research centers linked with agribusiness organizations usually address harvest productivity and resource efficiency. Good results have been obtained with R&D such as vinasses-fertilizer conversion, innovative cassava inclusion in the LAC region and glycerin post-production handling; so private and public financing sources are fundamental and still needed. However, considerations have to be taken into account to avoid environmental impacts in ecosystems previously selected for new crop implementation. The Government has to be careful with land allocation and permission for bioenergy development- the Amazon forest area has to be preserved, and Andean and Pacific biodiversity should be safeguarded as well.

According to the government, alimentary security in Colombia is not imperilled by bioenergy development- there are 7.5 million hectares suitable for biofuels (PROEXPORT, 2013).This area have been calculated by experts of the Minsitry of Agriculture, but there is not discrimination of the method employed, in order to identify if such land represent a baseline potential or the maximum achievable without compromising alimentary related crops. Therefore, although this is an appealing option, poverty and undernourishment are a reality in the country so wealth distribution has to be one of the goals of the industry.

However, according with FEDEBIOCOMBUSTIBLES, in Colombia the area used for both sugarcane and palm oil is less than 1% of the agricultural area within the national territory (21.46 million ha). In addition ethanol production use nearly 40.000 ha out of 223.905 that are employed for sugarcane plantations. In the production of biodiesel it is utilized an area of 160.000 ha out of 430.000 ha of palm oil crops (USCO, 2012) Based in the aforementioned, there is little prospect of bioenergy crops in Colombia representing (under curren conditions), a threat to food security.

So far in Colombia, biofuels production focuses on 1GBF, where sugarcane and palm oil are the main feedstocks. There is no biofuels of more advanced technologies commercially available, but research efforts have been conducted in order to explore academic knowledge, and technological and financial capabilities. These progresses allows to reduce the gap with those producers that are located in the forefront of technologies, and albeit it is not possible to deploy such initiatives due to costs, it keeps updated the Colombian scientific community around production possibilities (see further information in the final appendix).

Colombian bioenergy industry has now taken off with a clear goal of becoming a major player in the global industry. This can be seen as the result of the congruence of several factors such as dedicated efforts of R&D, important financial contributions of both private and public sectors, and a legal framework that ease the conformation of a mature domestic market, which in its initial stage counts with a strong support of the government through a favourable legal framework.

Risks are present in this path, such as public order conditions and weather uncertainties that are not possible for the producers to control. Research efforts do not always draw positive results in the short run, and it is required continuity, at this stage, in the governmental support and patience and attention from private investors.

Government efforts are needed to promote an institution that, from a political and technical perspective, leads and control production and trade processes and safeguard all-parties' interest, to prevent abuses and guarantee sustainable results.

1.5 Conclusions and general comments

Worldwide the search of alternative energies has become imperative, and of course developing countries such as Colombia are not isolated in this matter.

Colombia has several energy sources that allow it to remain temporarily independent in the energy market; nonetheless its oil reserves have been decreasing and, thus imminently, the country will become a net oil importer.

Hydro provides a good backup for electricity production, but transportation and other industrial needs are not within its scope. Not to mention the possible risk associated with droughts. Developing an alternative, such as bioenergy/biofuels, brings opportunities and responsibilities. If land availability and institutional willingness are merged in a project of sustainable production of biofuels, undesirable consequences for population and the environment can be avoided, then, on the contrary Colombia can accompany, rather than compete, with other countries i.e. Brazil and become a key supplier of bioenergy in the future.

Sustainable certificates, hopefully under multilateral support, can help market forces to find a win-win solution for human kind and nature, but sustainable production conditions must be studied, exposed and implemented, as a policy in the short run, but preserved in the long run.

Colombia has already started its biofuels industry, but, it is important to establish to what extent Colombian biofuel production can be considered sustainable, and what is its potential in a domestic market and also on a global scale

In the economic aspect Colombia requires a result where can be demonstrated that biofuels production not only bring new dynamics to rural development, by increasing income of farmers and feedstock processors, but also by opening foreing markets to agricultural commodities.

In the environmental part is it mandatory to preserve biodiversity hotspots and maintain or improve conditions of natural resources. This implies good practices in land and water management and also positive reponses in air quality assessments. In general this has to be achieved by reducing overuse of agrochemicals (fertilizers and pesticides), as well as by improving technological routes (which either enhance the performance of current feedstocks, or enable the use of new materiasl to be converted in bioenergy products), and by achieving attractive energy balances[35], like those reached by forefront bioenergy players. The GHG emissions must be reduced through the implementation of bioenergy for transportation, having into the account LUC effects.

In the social aspect, there is the need of improving housing, health and education conditions for the nearby population affected by the establishment and processing of energy crops. Processing companies need to be engaged with responsible practices, and by respecting labor laws and by working under fair production standards. Expansion cannot lead to force displacement of vulnerable communities. Land distribution, proprietorship and use regarding bioenergy requires close up scrutiny to guarantee a complete sustainable biomass-based product.

Is it possible for Colombia to get there? Is it walking in sustainable bionenergy track (despite that its bioenergy industry at present day is supported by 1GBf technologies)?. The anticipated answers to such questions are positive, and in addition, it can be said that bioenergy projects count on boundaries for expansion possibilities. Colombia counts on a set of climatic, edaphic, social, economic, environmental, infrastructural (among others) conditions, that led to understand that energy crops cannot be employed indiscriminately to comply with ambitious targets. However, this document present an assessment where an increase of the cultivated area for the main two feedstocks to produce liquid biofuels in Colombia is analised under the

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[35] Ramirez Triana argues that there is no reason to undertake an active support to a bioenergy industry if the latter is not capable to lower the amount of fossil fuel needed to propel vehicles without incurring in major modifications to the existing transportation fossil fuel-based fleet.Therefore an attractive energy balance is such where the Output/Input energy ratio draws results substantantially higher than 1, indicating that the number of equivalent units of bioenergy than can be produced out of 1 unit of fossil energy (See: (C.A. Ramírez Triana, 2011)).

light of restrictions of different order, representing the bounds of such mentioned limits, as it is explained further down.

However, in order to prove the aforementioned to be true, the upcoming chapters will try to answer several questions which are at the core of this thesis document[36]. Those questions will be focused in the ongoing industry, i.e. first generation biofuels, based on sugarcane and palm oil mainly, due to the short and midterm conditions of investment in the Colombian bioenergy policy agenda.

Main questions:

1. The panorama for Colombia has already been presented in this chapter, but what are the current biofuel production conditions in other countries that can be considered similar and used as a reference, i.e. which countries from the LAC region? What issues emerge in producing and using biomass based fuels?
2. What are the environmental problems that are faced by a nation such as Colombia? What kind of relationship exists between them and biofuel production and implementation?
3. Within the domestic market, how are cost and price conformed? Which actors play a role along the production chain regarding price/cost formation?
4. How is the whole production chain from feedstock production to final consumer organized?
5. How sustainable are sugarcane based ethanol and palm oil based biodiesel under a LCA perspective?
6. To what extent is it possible to expand current energy crops in the Colombian context? Taking into account biophysical, legal, ecologic, and social restrictions explored formerly?

In order to clarify the scope of the thesis is important to indicate that this document do not intend to present potential for biomass production including potential future developments of food demands neither production and improvements in agricultural and livestock management, but rather focus on current production conditions in order to assess its sustainable performance and its expansion potential under a sustainable production path.

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[36] From chapter 2 to chapter 5 most information was gathered from the public literature and provides a descriptive and updated background of the biofuel industry in Colombia and the LAC region, whereas the information presented in Chapters 6 and 7 comes from CENICAÑA and CENIPALMA

2 BIOFUELS IN THE WORLD AND THE LATIN AMERICA (LAC) REGION

The aim of this section is to provide a comparison of the future Colombian case with its immediate neighbors within the LAC region, but also with some global examples. In summary here will be reviewed biofuels production, and use management regarding policies impacts on the environment, socioeconomic impacts, and finally food security. By doing this the reader will be able to understand the main drivers behind each particular scenario and the degree of development of such goals under those achievements reported in the literature.

2.4 Policies and regulation for biofuels implementation at a global level

The Biofuel industry owes its current development and diffusion to the existence of several ambitious policies that have been government-oriented, rather than market-oriented. In most countries around the world it is evident that some kind of political support to bioenergy projects, and in consequence some economic mechanisms, emerge to underpin those initiatives. Among the main features, either qualitative or quantitative, is the presence of a combination of mandates, direct subsidies, tax exemptions, and technical specifications around biomass production, biofuel processing, bioenergy final use and international trade.

In the same way that biofuel manufacturing processes and markets have gained more ground and have become more mature, the related supporting policies have evolved along with these changes. Initially, most of the policies were basically directed to the creation of subsidies. However, nowadays the policy agenda needs to go beyond fiscal tools, and demand a more interactive and effective international market scope. Therefore, it requires a policy more focused in not only supporting domestic production, but also penetrating foreign markets. This variation of strategy obeys the high costs that are implied in a continuous subsidy program, that it is paid mostly from general public funds. In the case of mandates, most of the financial burden rests on the end user.

As these kinds of bioenergy products provide an alternative to regular fossil fuels, any attempt to define to what extent these policies are sound (from an economic perspective) depend on the current and future oil price. The lower the oil price, the higher is the cost of an economic measure in favor of bioenergy.

Additionally, some of these policy proposals have turned out to be too ambitious, so they have required revision and adjustment from the initial schemes. The majority of policies also depend on the political climate that is in place. For instance, part of the financial aid that was directed to bioenergy initiatives had to be directed to other ends, given the crisis faced by some members of the EU which count on a profoundly reduced fiscal budget.

Nevertheless, there are a big number of both industrialized and developing nations that have implemented or are implementing different sorts of policy tools that aim to boost biofuel market development. The regulations of some countries in the EU or USA have been under revision and have undergone some modifications. For instance, the USA biofuel policy reduced the initial target of producing 100 million gallons of cellulosic ethanol, to only 6.5 million (Gibson, 2010). Amendments of this nature emerge because there is not enough domestic capacity to reach such goals under first generation technologies, and there have been several setbacks in the availability of second generation technologies, in regard to what was initially projected (Hebebrand & Laney, 2007). The discussion on targets has been permeated by the debate on the impact of biofuel production on food prices, thus a mere strategy promoting economic efficiency is not enough, and responsible criteria need to be considered. As consequence, more sustainable production is now on the current national bioenergy plans.

2.4.1 Main regulations

2.4.1.1 United States of America

The American policy framework has a long history, and different nuances, around two strategic targets: energy security and rural development.

As a consequence of the oil crisis that took place in the 1970’s there was an initiative to support production and use of alcohol fuel for transportation purposes. Under this scenario it was provided a 100% tax exemption on oil retailed price, which reached 1.05 cents per liter.

During the 1980’s another crisis hit the USA, however, this time it was related to the agricultural sector, particularly with the corn agribusiness sector, so ethanol production was an opportunity to bring back the sector to its former prosperity. Thereafter, ethanol gained more ground due to the prohibition of lead in regular gasoline, and given favorable octane rating of alcohol. In addition, some amendments of the Clean Air Act in 1990 established a program of oxygenated fuel, where any oil product for transportation with high contents of carbon monoxide must have at least 7% of oxygen. After some other regulations, finally in the early 1990’s extensive use of biofuel reached its consolidation (Dufey, 2006).

Later, came the Biomass Research and Development Act of 2000, which provided a framework to “facilitate consultations and partnerships among Federal and State agencies, agricultural producers, industry, consumers, the research community, and other interested groups to carry out program activities relating to the Initiative” (U.S. Congress, 2006).

After this, the 2002 Farm Bill was a governmental attempt to strengthen the agricultural economy over the long term, and design a specific chapter to nurture all these biobased projects. Thus, some funding plans were created to sponsor construction of biorefineries, biomass research, biodiesel education programs. Such plans illustrate the linkage of bioenergy projects in the context of renewable energy grants (House of Representatives, 2002).

Under the American Jobs Creation Act formulated in 2004, the Volumetric Ethanol Excise Tax Credit (VEETC) was created. With this tool ethanol production was subsidized and it was worth US$6 billion a year. This policy was highly controversial, because it became a trade barrier with other international and more competitive alcohol sources, and it was felt to be expensive by several taxpayers. It finally, after several modifications, came to an end in 2011 (Lyutse, 2011). Additionally, the USA currently has a surtax of 14.27 cents per liter on bioethanol imports over the regular ad valorem tax of 2.5% (Tyner, 2008).

Biodiesel production was favored with the VEETC policy as well. Those biodiesel manufacturers that use energy crops as feedstock (e.g. soybean) are candidates to receive a subsidy of 26.42 cents per liter, whereas those that produce biodiesel from oil waste can be granted some credits of up to 13.21 cents per liter.

The Energy Policy Act of 2005 takes a general overview about energy production, distribution and use, and the policy breaks down according to the variety of energy sources and carriers. There is a special section on renewables and for all bioenergy. Section 942 of that document also put on the table ambitious targets - on one hand to redirect renewable energy research funds to bioenergy applications, and on the other, to boost biobased product commercialization, particularly those of second generation technologies. For instance, the document mentions the production of one billion gallons of cellulosic ethanol per annum by the year 2015. Another important goal is to guarantee that by the year 2015 biofuels are cost competitive with regular fossil fuels, i.e. gasoline and diesel. Finally, there is a social goal that was not evident in former policies - It is important to “ensure that small feedstock producers and rural small businesses are full participants in the development of the cellulosic biofuels industry” (U.S. Congress., 2005). From that Energy Policy Act emerged the Renewable Fuel Standard (RFS) and its subsequent amendments. Within it is established that every fossil fuel produced in the USA must have a minimum content of renewable fuels. It is also the milestone for the American energy security strategy in terms of biomass use for energy production. Environmental concerns for the future are also tackled in this regulation, by mandating that the volume of renewable fuel required to be blended into transportation fuel will be increased from 9 billion gallons in 2008 to 36 billion gallons by 2022 (EPA, 2010). The direct implication of these biofuel implementations on the environment would represent a substantial mitigation of the GHG’s, tested under LCA’s: 20% for corn-based ethanol, 50% for advanced biofuels, except for cellulosic ethanol that will comply with a rigorous reduction of 60% of GHG´s (FAO, 2008).

From this regulation structure it is evident the strong role that cellulosic biofuels play in the American energy agenda, focusing research efforts into enhancing yields and promoting the use of biorefineries. Nevertheless, this experience has overestimated the capacity of research on the cellulosic front. Based on the setbacks regarding the availability of this kind of fuel, the USA government decided to reduce the cellulosic ethanol production target from 100 million gallons to 6.5 million of equivalent bioethanol (Gibson, 2010).

2.4.1.2 European Union

The EU was experiencing a decline in the agricultural sector during the 1980’s and the rural livelihood was starting to have a crisis. At the same time the energy needs of Europe were soaring, thus, these conditions together were the main drivers to promote biofuels production in the EU, particularly biodiesel.

Notwithstanding, it was only in the late 1990’s when the biodiesel market was fully developed. Similar to the American case, in Europe the policies were formed by a combination of mandates, subsidies and trade barriers.

Biofuel regulation in Europe has evolved as a result of changing targets, technologies and market opportunities, hence the set of norms, laws and standards have been moving along with the current and potential circumstances that bioenergy has faced until now, and the possible scenarios that they would have to deal with (Johnson & Roman, 2008).

Among all the regulations within the EU there are three pillars that define the great extent the European Bioenergy guidelines.

The first one is Directive 2003/30/EC about the promotion of the use of biofuels or other renewable fuels for transport. In the first place, this directive recognizes the potential of biomass material for bioenergy purposes, using agricultural and forestry products, and residues and waste from forestry and agrifoodstuffs industries. It also calls attention to the share (30%) that transportation takes from the final energy consumption total, and biofuels implication in the reduction of carbon dioxide emissions and energy security enhancement. The directive reminds us of the initial purpose set on the Green Paper “Towards a European strategy for energy security” where it is established that by the year 2020 20% of the conventional fuels used in road transport should be substituted by alternative fuels, but competitiveness and availability need to be guaranteed. Finally it sets a reference goal of using a blend of at least 2%[37] of biofuels with conventional fuels for all the members of the EU. This target was due on 2005. Later on the target was raised to 5.75% and it was supposed to be reached by 2010 (EC, 2003d).

The second milestone in the bioenergy biofuel policy is Directive 2003/96/EC, which stresses the field of taxation of energy products and electricity. The document recognizes the importance of taxes in the conformation of energy prices, and the impact of the latter in transport and environmental policies. The directive acknowledges that although taxation is necessary, it is an important support to alternative energy sources and for that reason it is recommended to implement discretional tax exemptions or reductions per country for renewable forms of energy (EC, 2003b). Under this directive specific actions were established by France, Italy and the United Kingdom. The French government asked for permission to apply reductions in excise duties from 2003 to 2009: these reductions "shall not exceed EUR 35.06/hl or EUR 396.64/t for vegetable oil esters, and EUR 50.23/hl or EUR 297.35/t for ethyl alcohol derivatives used in the mixtures". However, these reductions can be revised at any time to avoid extreme market distortions.

In a similar way, Italy decided to apply for differentiated rates of the excise duty on mixtures used as motor fuels containing 5% or 25% of biodiesel until 30 June 2004. Like the French case, Italy left the door open about a possible revision and adjustments.

The British case, just like the Italian one, is aimed at the biodiesel industry. The UK applied for differentiated rates of excise duty for road fuel containing biodiesel and biodiesel used as pure road fuel, until 31 March 2007.

Finally, the third pillar on the bioenergy policy is represented in Directive 2003/17/EC, which refers to the quality of petrol and diesel fuels. The document establishes a limit of at least 5% bioethanol content in regular gasoline due to environmental reasons, however that measure is being reviewed to be raised to 10% (EC, 2003c).

Those directives became the backbone of European bioenergy policy, but they were reinforced by a set of other instruments as explained below. Biofuels were supported by the Common Agricultural Policy (CAP) from the European Union. This plan, formulated in 2003, is an incentive to those that possess energy dedicated crops. Under the CAP appears a figure of "carbon credit", which pays EU$45/ha to those that use crops for energy purposes and have a land extension no greater than 1.5 million hectares. This credit is available to any kind of agricultural crop, except for sugarbeet and hemp, if, and only if, they are employed in approved energy uses and are under a production contract that benefits such a purpose. Any new energy

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[37] This percentage is given in terms of equivalent energy content.

crop harvested in former agricultural production land is not eligible for carbon credit. (EC, 2003a)

Another form of support received by the bioenergy industry was the Renewable Energies Directive (RED), which was approved in 2008. This directive establishes an ambitious target, where by it mandates by the year 2020 the general energy consumption of the EU, , is to be supplied by renewable energy sources, and in addition the share of this kind of energy for road transport purposes should be at least 10% (in the mixes of both gasoline and diesel) (Johnson, 2011). Later on, in 2009, such target had to be modified because of environmental concerns and questions on food security issues, if first generation technologies were to be implemented to great extent. Thus, Directive 2009/28/EC established that the initial goals were to be implemented but under two special conditions:

1. biofuels were to be produced following sustainable standards,
2. second generation biofuels has to be commercially available.

This directive started to work as a sustainable filter, because some minimal criteria were established to those biofuels produced either domestically or imported. Specifically, it was demanded that biofuels must guarantee a reduction of GHG's emissions of 35% and energy crops cannot be located in forestlands or wetlands (EC, 2009).

The entire European policy framework institutes a reference target for the region; however, every member has the discretion to choose the corresponding strategy to achieve it. In some cases, national targets go beyond these general goals, as occurs in Germany. Nevertheless, the reality of the market is a boundary that holds back these ambitious targets in terms of economic feasibility or sustainability soundness, and that is the reason why sometimes plans need to be restructured as was shown before.

2.4.2 Trends in biofuel policies and regulation in Latin American and Caribbean countries

Except for the Brazilian case, and other isolated cases including to a minor extent the countries that belong to the Caribbean Basin Initiative (CBI), the modern bioenergy, and in particular, biofuel development has been relatively recent among LAC countries. As a matter of fact, based on the successful Brazilian experience and the continuous upsurge of oil prices (predominantly the alarming escalation exhibited between 2004 and 2008 where the crude oil price more than tripled from a price of US$34/barrel to more than US$133/barrel) the LAC region started to rapidly and aggressively develop a biofuel industry with the aim of tackling energy security issues, reduce fuel import as a fiscal strategy, and agricultural promotion.

All these efforts have been shaped as indicative or mandatory targets, using cases just like the former American and European examples, i.e. introductory mixtures of regular fossil fuels with biofuels, along with other sorts of incentives. Nonetheless, it is quite important to understand that there is no such thing as a regional policy on this topic. Every country has designed its own strategy and tool set in approach to this energy option.

The next section has an overview of the LAC region policy framework, with the exception of the Colombian case, which was explained in chapter 1 and it will be reviewed in the following chapters.

2.4.2.1 *Argentina*

The biofuel sector started to be promoted in 2006, with the production and use of alcohol fuel, biodiesel and biogas. The strategic bioenergy product in the Argentinian case is biodiesel (Mathews & Goldsztein, 2008; Dominik Rutz et al., 2008). The Biofuel sector is framed under the Law 26.093 of 2006. This Law has been entitled "Régimen de Regulación y Promoción para la Producción y Uso Sustentables de Biocombustibles" (Law of regulation and promotion for sustainable biofuel production and use) and it establishes a 15 year plan to regulate and promote the biofuels industry, including the description of taxation benefits. Within this law was created the National Advisor Biofuel Commission and it was comprised of several representatives from rural sectors, technology and innovation developers, small and medium enterprises delegates, sustainability experts and envois from the treasury department at a national level. The commission is an open to local authorities as well, so Federal Councils can take part in the project management and auditory process (Argentinian Congress, 2006).

The Commission, under this law, is in charge of informing, monitoring, auditing, selecting, directing funds, and providing general planning to bioenergy projects. The commission must safeguard the appropriate allocation of resources and subsidies granted under this regulation, otherwise penalties may apply. Later, in 2007 Law 26.093 was complemented by the Decree 109 of 2007 (Comisión nacional asesora 2007) where the role of both the Commission and the Regulation Authority is detailed, and the proposed blends to be commercialized are specified. Specifically, biodiesel is designed to be mixed at 5% with regular diesel fuel (95%), also known as B5. However, pure biodiesel (B100) can be commercialized as well. Something similar was established for the alcohol fuel market, where the ethanol can be distributed pure (E100) or blended at 5% (E5) (Mathews & Goldsztein, 2008).

It was designated that all biofuel production, mixing and distribution projects must be registered for the approval of the Regulation Authority, even those that are designed to cover self-consumption. The authority also decides which projects are eligible for tax (VAT) deduction in capital investment; or for a differential payment on the tax over income.

The fundamental aspect of that law was the mandatory requirement of the blending levels (B5 and E5), established to be fulfilled by the year 2010. This decree created an estimated demand of 220 million gallons of biodiesel and 70 million gallons of ethanol. It also created a package of incentives for domestic producers in order to cover national demand; however the majority of the production is currently going overseas (D Rutz et al., 2009).

2.4.2.2 Bolivia

The Bolivian position has been cautious in terms of large scale biofuel project implementation, due to the precarious food situation that faces that nation, and the potential impact that bioenergy plans might have on food prices.

The Bolivian bioenergy policy framework is given by three pillars built in 2005:

- Law 3152 "Fuentes de generación de energías alternativas en el departamento de Pando" (Renewable Energy sources in Pando Department) (Bolivian National Congress, 2005),
- Law 3207 "Estimulos a los productores de Biodiesel" (Biodiesel incentives to biofuel producers) (Ajila & Chiliquinga, 2007),
- Law 3279 "Fuentes de generación de energías alternativas en el departamento del Beni" (Congreso Nacional de Bolivia, 2005).

The first and third law pointed out the necessity of implementing alternative sources of energy in Pando and Beni which are two departments located in the northern region of Bolivia, on the border with Brazil. These two regions together cover more than a quarter of Bolivian territory. Within these laws is set the target of achieving a blending level of B10 in a time span no longer than 10 years. Another benefits included in these laws are the total exemption of taxes (specific and direct) on payment that is charged to regular hydrocarbons and a discount of 50% of any other kind of ongoing taxation. Despite these incentives the Bolivian biofuel industry has not yet awoken.

2.4.2.3 Brazil

Sugar-cane became the first large-scale plantation at the beginning of the 16th century, soon after the plant was brought from the island of Madeira by a Portuguese expedition. This crop was as equally important as other colonial crops, such as coffee and rubber. After the colonial period, slaves provided the manual labor required by the industry, then European immigrants.

After 1883 they had secured a cheap labor force for the sugarcane industry and had established it as one of the most prominent industries in the country, up to and including today.

Back in 1933, the Sugar and Alcohol Institute was founded and the first ethanol blend trial in petrol engines took place. Further efforts were made in order to enlarge the scope of the ongoing project, but it was not until 1973, during the oil crisis, when the Brazilian military government decided to fully support exclusive bioethanol development, launched 2 years after the National Alcohol Program, PROÁLCOOL (Coelho, 2005).

Under this program special engines were designed to run purely on hydrous ethanol and some voluntary blends of anhydrous ethanol were proposed. This not only boosted the demand , but also supply was greatly assisted by an economic package that included taxes and investments favoring the industry; allowing new construction and the enlargement of distilleries, at the same time that sugarcane farming underwent an important expansion.

By the early 1990's direct subsidies for bioethanol were eliminated, but an elevated gasoline taxation combined with a wide supply of ethanol-based cars, created a strong incentive to consolidate the market (Coelho, 2005; José Goldemberg, Coelho, & Guardabassi, 2008). However, at the end of the decade two simultaneous events undermined the consumers' confidence:

- ethanol suppliers, due to a drought, struggled to provide enough fuel,
- and cheap oil prices put pressure on the program performance.

Under those circumstances the government decided, in 2001 to set up mandatory blends with petrol, adding between 20% and 24% of anhydrous ethanol to all gasoline. More recently, in 2003, Flex-fuel technology was developed specifically for local conditions, allowing any combination of hydrated ethanol (E100) with a blend of gasoline with 20 to 25% anhydrous ethanol (Edward Smeets, Junginger, Faaij, Walter, & Dolzan, 2006). This has been gaining popularity among Brazilians and only small problems have manifested when pure gasoline is used, but this situation only occurs during trips to other South American countries.

Regarding biodiesel, there is a program that tried to replicate the ethanol experience, called PROBIODIESEL, which started in 2004. One year later a law was issued that mandated the use of B2 from 2007, with increasing targets of B5 and B20 by 2013 and 2020 correspondingly. There are also tax exemption schemes that cater to the small producers of feedstock (Garcez & Vianna, 2009).

There is also an incursion in 2GBf research, in some plants of PETROBRAS, with the intention of producing cellulosic ethanol from sugarcane; however, a commercial scale for this initiative is not yet available. Nowadays, bioenergy projects are mostly managed and regulated by the Agroenergy Policy Guidelines issued by the federal government.

2.4.2.4 Chile

Chile has been characterized by being a net importer of energy, due to the scarce oilfields in its territory. Neither does it count on substantial agricultural production, mostly due to the soil being arid and hard climate conditions. As a matter of fact, Chile is a net importer of food as well, thus their strategy is based on first generation biofuels, although it is still timidly developed, with the majority of the bioenergy plan resting on a future and stronger bioenergy production, based on second generation initiatives.

The Chilean legal framework mandated mixtures up to 5% of biofuels (alcohol fuel and biodiesel) with regular fossil fuels, to be fulfilled by the year 2010. This suggested level can be identified in "Proyecto de ley sobre fomento de las energías renovables y combustibles líquidos" (Bill on support to renewable energies and liquid fuels) (Senado de Chile, 2007), and the official announcement 'Number 30' of the Domestic Taxation Service about Tax application guidelines in the case of biodiesel and bioethanol (CNE, 2007). Within this legislation, biofuels were declared exempt from the charge that is normally applied to any other form of fossil fuel.

The Biofuel National Directory was created by the Chilean National Energy Commission (CNE). This public body is in charge of easing the communication among different domestic and foreign biofuel stakeholders. The Directory coordinates the whole value chain in its different stages. All these stages receive networking support by the Directory, which provides information of several training courses (for the two initial stages mainly), but additionally it encourages research formation centers, and connects the stakeholders with domestic (private and public) and international financial institutions to fund partially or totally bioenergy related initiatives (Ministerio de Energía de Chile, 2012).

The corresponding technical characteristics of bioenergy products distributed and commercialized within Chilean territory are expressed in the Supreme Decree 'Number 11' of 2008. This decree also released a study of the "Infrastructure requirements for the biofuel supply within the ongoing liquid fuel distribution network". The main conclusions drawn out of this study were that for the biodiesel industry, the technical barriers were practically nonexistent; in contrast, the situation for bioethanol distribution was harder, especially because the storage facilities and transport equipment required further adaptation (Arriaza, 2011).

2.4.2.5 Costa Rica

The Costa Rican government decided to set a bioenergy path where, as in the other LAC cases, the main focus is on ethanol (sugarcane-based) and biodiesel (palm-based). Most general guidelines (decrees 31087, 31818, 33357, 34846, and 35091) were issued to frame different strategies to develop the industry. (Contreras & Rodríguez, 2006; Meneses & Valenciano, 2007)

At the beginning of 2008 the main document (Biofuel National program) was published, and it drew an ambitious 4 year plan in terms of goals to be achieved. However, most of them can be classified as voluntary participation, hence it is difficult to assess to what extent they have been fulfilled so far. As an example, the document mentions a complete enhancement of the value chain:

- the agricultural stage can be improved by a voluntary environmental certification process that allows a continuous enhancement of the natural conditions for agricultural production along with the development of other sources of biomass that can be used as feedstock.
- the industrial stage has no real strategy, apart from trying to create adequate and stable economic conditions (i.e. no taxation uncertainty and guaranteeing regular flow of equipment and feedstock).
- for the end use stage, the policy sought to introduce the regular blend levels for biodiesel (between 2% to 5%) and a little more ambitious opening target in the case of alcohol fuels (7.5% ethanol) (MAG-MINAE, 2008).

2.4.2.6 Ecuador

The Ecuadorian policy framework is currently in an early stage of development. Under this initial framework it has established the National Biofuel Council, which is in charge of defining policies, plans, programs, and projects regarding biofuel production, handling, industrialization and commercialization. Furthermore, it must establish standards about quality, prices, and production volume of regular fuels and biofuels (Ortega, Cárdenas, Recalde, & Cazco, 2007).

Probably the most important milestone within the Ecuadorian policy regarding bioenergy is Law 2006-57. This law initiates the Fondo Ecuatoriano de Inversión En Los Sectores Energético E Hidrocarburífero (FEISEH) (Ecuadorian Investment Fund for the Energy and Hydrocarbon sectors). Under FEISEH US$140 million are diverted from domestic oil extraction activities revenues and given to several projects of a strategic nature. One of them is to build an alternative infrastructure for energy distribution in the transport sector, and as part of that plan biomass-based fuels is one option to be considered. The bioenergy sector receives support under this law from several different fronts, including: establishing a trust for funding a microfinance system, and establishing a trust to provide low interest credit to small producers in the agricultural sector. Whatever income that comes from this initiative is free of taxation (Asamblea constituyente de Ecuador, 2007; Congreso de Ecuador, 2006).

The Ecuadorian “Biofuels Program”, created in 2006, sought to reach a mix target of 5% ethanol with regular gasoline. That goal was structured in two stages:

- The first and introductory stage was a pilot plan to be implemented in Guayaquil city (which, despite the fact it is not the capital city, is the biggest and most populated city), and presented an alcohol demand of 40,000 liters/day.
- This plan was to be widened to a national level. By 2005 the domestic ethanol demand, based on the ongoing gasoline consumption (more than 13.5 million barrels/day) would reached nearly 590,000 liters/day in a proposed blend of E10 (M. González, 2006). Similar to the ethanol introduction plan, the biodiesel program was planned to be introduced as a trial run in Quito city, in a blend of B5, which would eventually require210 barrels/day, and an extension of such a plan to national level would increase that amount approximately sevenfold, i.e. 1456 barrels/day (M. González, 2006).

2.4.2.7 El Salvador

The Salvadoran Biofuel initiatives started in 2005 with the National Plan of Bioethanol Production, thus recognizing biofuels as a key factor in future energy security, and was the trigger for a series of further studies, such as:

- the “Financial and Technical Pre-Feasibility Study on Sugarcane-based ethanol production” by the Getulio Vargas Foundation,
- the studies carried out by the Organization of American States (OAS) “Technical and Policy Assistance for Ethanol Blending and Logistics in El Salvador”,
- “Feasibility Study for Distillery Expansions at Existing Sugar Mills in El Salvador” in 2009 (ME-BID, 2008).

In August of the same year the formal biofuel policy (along with a general Energy Policy) for El Salvador, was written, and was guided by the Biofuel Inter-institutional Committee.

In February 2011, the Board of Directors of the National Energy Council decided to run an environmental analysis of bioenergy projects and to design the regulation framework, in order to develop the Salvadoran Biofuel industry. (Cerrato, 2011).

In general the Government of El Salvador seeks to reach a blend of E10; hence, in order to reach such a target, it has established tax exemptions to boost alcohol production and use. On the other hand, the biodiesel introduction is still in an exploratory stage and pre-feasibility studies are being carried out.

2.4.2.8 Guatemala

Most of the skeleton for the Guatemalan biofuel legislation is defined in the Law DL-17-85, and the general rules AG 240-1985. Within the LAC region the Guatemalan legislation regarding the implementation of biofuels is probably the second oldest after Brazil. The legislation sets a mandatory goal of at least 5% ethanol blended with regular gasoline. (Lorenzo de Juárez, 2011). However, to date it has not put it into practice (Mirón, 2010).

In 2010 a brief report entitled "The Ethanol fuel in Guatemala" was presented, where is stated that ethanol production in this Central American country depends mainly on molasses that comes from the sugar processing industry. Despite the existing infrastructure and the processing capacity in Guatemala (nearly 1.4 million liters/day), most of the ethanol is exported as traditional alcohol or alcohol fuel and just a small percentage is employed domestically in spirits manufacture, so there is no ethanol remaining for domestic consumption as fuel. Previous political and economic conditions have not favored the bioenergy industry in Guatemala, but the last 3 governments have tried to reactivate law DL-17-85, to build more dynamism around the sector once again. (Mirón, 2010).

Under current government plans they will try to reach a mix of E10, however, the processing capacity is only able to supply ethanol to cover a mix of just 3% of the domestic gasoline consumption. As methyl tertiary butyl ether (MTBE) is being phased out as a gasoline additive, the opportunity for the sector is becoming more promising (Mirón, 2010).

On the other hand, the Guatemalan biodiesel industry is even less developed that most countries in the LAC region and it cannot count on a legal framework to support or regulate the sector. It is possible to find isolated efforts from the private sector, e.g. Biocombustibles de Guatemala, which is a research firm dedicated to Jatropha Curcas production and manufacturing, or Biopersa S.A., which is a firm that treats waste vegetable oil for biodiesel production. The reported biodiesel processing capacity in Guatemala in the Corpoica report is 4000 gallons/day (ACR, 2011; Lorenzo de Juárez, 2011)

2.4.2.9 Honduras

In 2007 the Honduran government published Law 144 (Ley para la producción y consumo de Biocombustibles, Law for the biofuels consumption and use). Several goals were achieved through this law: A special division (Technical Unit for Biofuels) was created to regulate, and promote biofuels production and distribution, and it was also accompanied by a set of regulations that provide financial support in terms of tax exemptions, particularly income related taxation, and taxes on imported materials and equipment required to produce biofuels. These exemptions last 12 years once the biofuel production project starts.

In Honduras regular fuels are charged with a tax that is used to fund transport infrastructure, however, the law has established that biofuels will be excluded from such payment for the first 15 years of their introduction (Hernandez, 2008).

The law did not establish a mandatory blend, and depending on the discretion of the Technical Unit for Biofuels this target is still to be formulated. Any biofuel endeavor will need to obtain environmental approval in order to work, i.e. it must comply with the General Law of the Environment of Honduras (Hernandez, 2008).

2.4.2.10 Mexico

The bioenergy initiatives in Mexico are quite recent, and therefore, so is its legal framework. In February of 2008 the Law of Promotion and Development of Bioenergy products (or Law DOF 01-02-2008) was released, which announced the interest of the Mexican government in developing a biofuels industry under sustainable production. Under this law the Commission of Bioenergy products was created and as part of its duties this entity had to draw the general guidelines for the industry and create communication mechanisms between public and private parties within the sector. It also had to define a strategy, establishing priorities in terms of public expenditure to strengthen the biofuels industry. (Cámara de Diputados, 2008; SAGARPA, 2008; Secretaría de Energía, 2009).

Within this document is set, in a very broad sense, the need to support bioenergy initiatives, taking into account three different key aspects:

1. Sustainable production: there is specific emphasis in supporting small rural feedstock producers and jobs creation throughout bioenergy cropping, harvesting and general handling. In fact, the bioenergy initiatives must guarantee a participation share of at least 30% (for small landowners or co-operative firms) of the total feedstock production, and preservation of natural resources.
2. Infrastructure boosting: The bioenergy initiatives will need financial tools to be competitive, so modernization of the existing equipment, plus acquisition, fabrication and maintenance of machinery and plant will require economic policies that ease resources to support such activities.
3. Technological and Scientific research: Training and technology transfer are the two main pillars to build the Mexican bioenergy knowledge base. This knowledge must permeate from the top of the scientific and biochemical engineers to the bottom of the rural workers. It must include exploration of new materials (algae and forestry) and

technologies (like new yeast developments and enzymatic treatments)(D Rutz et al., 2009).

Nevertheless, there are no concrete dispositions in this document that determine or suggest any particular feedstock or blending levels. On the contrary, in a previous study organized by the Mexican Secretary of Energy, published in 2006, it is pointed out that sugarcane ethanol might be a good choice to serve national energy needs in the short run (between 2007-2012) if a blend of 5.7% ethanol with regular gasoline is implemented. In the long run, a mix of E10 could be reached by using sugar, molasses and other feedstocks as maize and sweet sorghum. The investment required to back up such a plan would be close to US$160 million in the short term and US$2.25 billion beyond 2012 (Masera, Rodríguez, Lazcano, & Horta, 2006).

For biodiesel, the landscape is bleaker given the low economic competitiveness of current feedstock, in comparison with regular diesel fuel domestic prices. Despite this viewpoint the report dares to suggest that a biodiesel program can be implemented, where, in an initial stage, a mix of B2 can be reached by using waste oils or animal fats, and later on, in a subsequent stage, it can be produced from other feedstock, such as rapeseed, soybean, jatropha, and sunflower among others (Masera et al., 2006).

2.4.2.11 Nicaragua

The main boundaries for the policy structure of biofuels in the case of Nicaragua are given by the National Policy of Agrienergy and Biofuels or PNAB (Política Nacional de Agroenergía y Biocombustibles). The PNAB seeks to widen the Nicaraguan energy matrix with a fuel with financial soundness, but also it embraces a sustainable vision of biofuels production through the implementation of social inclusion. It contains incentives for both sides of the market forces - supply and demand. The feedstock producers and biofuel processors benefit from tax exemptions related to imports, added value and property. The fuel purchasers receive a partial exemption of the selective consumption tax (ISC, Impuesto selectivo al consumo) that is charged to regular fuels and they (purchasers) are not charged any import duty on Flex-fuel vehicles. Most of the financial resources to back up this initiative are pooled in the Biofuel Production Promotion Fund and they come from a percentage of the ISC.

2.4.2.12 Panamá

The Panamanian biofuels regulation was marginally given by Law 8 of 1987 and Law 30 of 2007 that rule any activity related with the production, distribution and use of regular hydrocarbon products. Within these laws was established that the authority in charge of directing and implementing this regulation is the Ministry of Commerce and Industry. This entity initiated a study which stated the imminent need of establishing an alternative to the current fossil fuel consumption (Hoffmann, 2006). However, recently Panama formalized a bioenergy exclusive legal framework and it started with Law 42 of 2011. The law entitled "Law that provides the guidelines for the national biofuels policy and biomass-based power generation within the national territory" set a mandatory mix of E10 to be reached in 2016 in an escalation program, as follows: It will start on April 1st 2013 with a mix of E2, and will be increased annually, reaching E5 in 2014, E7 in 2015 and finally E10 in 2016. The scenario that is shown in the law is quite positive and, in fact, it contemplates the possibility of modifying the suggested mix in order to enlarge it if the technology allows, or possibly where new hydrocarbon products are available for blending with biofuels (Asamblea nacional, 2011; Secretaría de Nacional de Energía, 2012).

In Law 42, biodiesel and biogas production and their use are planned for, however, any guidelines, parameters and requirements are still under consideration (Asamblea nacional, 2011).

2.4.2.13 Paraguay

This South American country counts on one of the biggest infrastructures in the world to supply energy (electricity) to the population, by using hydropower generation (approx. 9000 kWh/capita) (Lovera, 2010). However, according to a study from the Ministry of Agriculture, Paraguay is totally dependent of imports, in order to satisfy its fossil energy needs, hence, the importance of developing an alternative energy source remains at the top on their agenda (Aquino, 2006).

The legal framework in the Paraguayan case is defined by a set of regulations. The most prominent one is Law 2748 of 2005 (Law of Biofuels Promotion). This law highlights the national interest in developing a strong biofuel industry and proposes to use not only fiscal incentives (established in Law 60 of 1990 [Law of investments], and Law 2421 of 2004 [Law of administrative redistribution and fiscal arrangements]), but also any resource that can be raised throughout Clean Development Mechanisms (CDM) (Cámara de Senadores, 2005).

It also states that the Ministry of Industry and Commerce will act as application authority (D Rutz et al., 2009), in co-operation with the Ministry of Agriculture that acts as the auditing and certifying institution for feedstock source and treatment. This law is supported by the decrees 7412 of 2006, 4952 of 2010, and 12240 of 2008, which set out a program that includes all the information that a bioenergy project requires within Paraguayan territory to work legally (Cazal and Cáceres, 2006, such as blending requirements (Cazal & Cáceres, 2006), the promotion of

Flex-fuel technologies, and the commitment to provide internationally-trained specialists to support biofuels development (D Rutz et al., 2009).

This legal framework does not specify directly any mix levels, however, in other documents such as resolution 162 of 2009, it is stated that an ideal target would be E24 mixed for 85 and 95 octane gasoline, while 97 octane gasoline and jet fuel do not have mix requirements (D Rutz et al., 2009).

The Ministry report argues that, by 2006, in some parts of Paraguay there should be blends between E14 and E16, and there are potential conditions to reach up to E25 in some cases (Aquino, 2006).

2.4.2.14 Peru

Peru has started to change its energy mix aggressively: in 2002 nearly 70% of its energy needs were covered only by oil use, while four years later that proportion dropped to 53%, and a substantial growth of natural gas and condensates took a big bite of that share (they climbed from 7% to 20%). But the share of renewables is important as well, and is expected to cover a third of the Peruvian energy needs in the near future, i.e. an expansion of this alternative fuel source by 10% from 2002 (Garrido, 2007).

As part of this expansion is the bioenergy sector. The first legal milestone in the Peruvian biofuels history is Law 28054 of 2003, or 'Law of Biofuel Market Promotion'. Within this law, like other LAC countries, are the drivers behind an active bioenergy policy. However, in the case of Peru there is an additional element on the table: Biofuels are not a mere strategy to bring dynamism to rural areas, but they go beyond such ambitions , given that the implementation of energy crops can be used as an appealing option in the drug crops eradication incentive (Congreso de la República, 2003; D Rutz et al., 2009).

Under law 28054 the Biofuels Promotion Program was created, PROBIOCOM, which is in charge of directing an investment fund to support the bioenergy program and to raise awareness of the economic, social, and environmental benefits and achievements in the sector. There is also the creation of a Technical Commission (with the participation of 3 Ministries, and some other private and public stakeholders) that will define a schedule of implementation stages for suggested mix levels of both ethanol and biodiesel.

Later, the Peruvian biofuel policy was framed under the decrees DS 013-2005-EM, and DS 021-2007-EM (Ministerio de Energía y Minas, 2007). The first established that within national territory the commercialized kinds of gasoline will be blended with 7.8% alcohol fuel and will be considered as ecofriendly fuels. The production of ethanol and its respective mix started in 2006 in the north eastern region of the country and then, two years later was extended to the northern and central Peruvian region. Finally in 2010, in accordance with the schedule, all of Peru was permitted bioethanol production and the subsequent commercialization. Within this decree was set out the biodiesel program as well: The proposed mix levels were 2% and 5% biodiesel with the two commercial sorts of diesel found in Peru (Diesel N.1 and Diesel N.2). The production schedule began in 2008 in the northern and central region, and then full coverage was implemented 2 years afterwards (Ministerio de Minas, 2005).

Decree DS 021-2007-EM, in turn discusses the advisability of biodiesel mixes and it was decided that just Diesel N.2 is appropriate for B2, B5, and B20 manufacturing, and animal fats and used cooking oil can be used as feedstock as well. In terms of ethanol mixes the decree establishes a special nomenclature regarding the octane grade, rather than the ethanol mix (which is the same in every case 7.8%), the mix of ethanol and gasoline is named 'gasohol'. Thus, four kinds of gasohol have been commercialized: Gasohol 97 plus, Gasohol 95 plus, Gasohol 90 plus, and Gasohol 84 plus. Distribution of regular fossil fuels mixed with ethanol and biodiesel is now mandatory in Peruvian territory. It started in 2010 in a few departments and then the mandate covered the entire nation by mid-2011 (Consejo de Ministros, 2007).

The strived for targets established by the Peruvian government have occasionally had feedstock and bio-product shortages. For instance, "In early 2009, 72000 barrels of biodiesel were imported by PETROPERU to meet the blending mandate. The challenge for Peru will be to import the raw material and refine it within the country instead of importing biodiesel directly" (D Rutz et al., 2009).

2.4.2.15 Dominican Republic

The strength of the Dominican biofuel production has been achieved mostly through the participation of private initiative, but it was through initial government participation that gave the Dominican Republic one of the earliest starts in the LAC region. In 1949 the Dominican Republic experienced an extreme shortage of gasoline and the government at the time made it mandatory to blend alcohol fuel and gasoline at levels between 15% and 30% under public law 2071 of the same year (DENC-SEIC, 2009). One year after the "Destilería Universal" was built and it was the official distillery in charge of producing, blending and distributing "the national fuel". This initiative lasted for one year and was subsequently closed.

The Dominican biofuel policy remained untouched until 2000, where the interests for renewable energies returned to the government agenda. Legislation around hydrocarbon product handling and production was proclaimed, along with a new perspective regarding power generation. However, it was not until 2002 with Decrees 557-02 and 732-02 that the biofuel sector entered into the government energy strategies, as electrical power co-generator agent and as fuel alternative(DENC-SEIC, 2009).

Law 57 of 2007 establishes that all biofuel initiatives will have exemption of any kind of taxation during a time period of 10 years, if and only if, biofuels do not exceed a volume beyond 20% in the domestic transport fuel consumption (Cepeda, 2007; Gomez, 2010).

Under the last legislation, biofuels will receive financial aid if the project is destined to satisfy self-consumption or if they are designed to favor communal use and are organized by social institutions (communal organizations, producers associations and co-ops). The aid will consist for financial support for the initial investment of up to 75% of the total amount. Depending on the approval of the National Energy Commission, the project could either have full support from the government or it could have access to the lowest interest rates and payment conditions (Congreso Nacional de la República Dominicana, 2007).

2.4.2.16 Uruguay

In Uruguay, the most important policy related to biofuels was first introduced in 2002 and it was entitled Law 17567 or 'Law of Production of Alternative Fuels, Renewables and Substitutes of Derivatives of Petrol Extracted from Domestic Raw Material from Vegetable or Animal Origin'. The use of "domestic raw material" denotes a very protective national policy around the agricultural sector, by guaranteeing that most of the benefits will be received by domestic suppliers, rather than processors that work with imported feedstock (Senado de Uruguay, 2002).

This regulation was bolstered with the law of biofuels or Law 18195 of 2007, which defines the rules on biofuel promotion, production, commercialization and use. This will be controlled and monitored by ANCAP (Adminsitración Nacional de Combustibles, Alcohol y Pórtland [Fuel, Alcohol and Cement National Bureau]), (Senado de Uruguay, 2007).

At first, in the case of diesel, an introductory stage was established where diesel fuel could be mixed with biodiesel in order to reach B2 level before the end of 2008, but from the beginning of 2009 it became the minimum mandatory standard and gradually increased up to B5, which in turn was established as the minimum blending level from 2012 (Bittencourt & Reig, 2009).

On the other hand, ethanol fuel has received less attention regarding specifications of mix. The ongoing regulation establishes that any regular gasoline can be blended with alcohol; using a maximum of 5% of alcohol in the mix, and such norms will remain in force until the end of 2014.

The Uruguayan policy framework stresses the importance of keeping separate small productive initiatives from large in the biodiesel sector and it adapts the regulation in that regard. Small initiatives are considered those that produce less than 4000 liters of biodiesel on a daily basis, and use that product for self-consumption or for supplying a small fleet of vehicles (once Government permission is obtained to that end). In that case, there is no need for product registration with ANCAP. A large initiative is any enterprise that does not comply with the aforementioned conditions. While they can use up to 4000 liters/day for self-consumption, any level beyond that must be reported and managed by ANCAP. The destination of the product can be for domestic use or for eventual export.

In the law there are some incentives regarding the taxation system. Firstly, it is established that any biofuel product must follow the regulation in force for any other regular fossil fuel; nevertheless the national executive power authorities are entitled to promote this industry using any means necessary, including total or partial tax exemptions; although, any suggested exoneration must be built on sound grounds approved by the Congress. This empowerment means that further modifications can be done to current proposals:

a. for a period of ten years national biodiesel will not be charged with the Domestic Specific Tax (IMESI or *Impuesto Específico interno*),
b. for a period of ten years any biodiesel or ethanol producer will be fully exonerated from commerce and industry tax payment,
c. any biodiesel or ethanol producer will be exonerated from patrimony tax (Bittencourt & Reig, 2009).

2.4.2.17 Venezuela

Given the abundance of crude resources in this South American country there is no legislation regarding an active support to biomass-based energy initiatives. However, it does not mean that Venezuela remains isolated in bioenergy efforts. Albeit, there is not current production, there is an interest for blending and eventually producing biofuel domestically. Venezuela has set the goal of phasing out the use of MTBE to oxygenate gasoline and the alternative at hand is alcohol fuel. As a result of an alliance with Cube some ethanol has been brought to Vanezuela to run some trials (Ryan, 2006).

2.4.3 International trade protocols

There are several proposals of trade protocols that have been put on the table in order to establish some guidance in terms of production, distribution and use of bioenergy, having in mind sustainability standards. In Christodoulidis' work it has been identified at least three major proposals: (1) Bioenergy Labelling Organization (BLO) and United Nations Agreement on Bioenergy (UNAB), (2) The Biopact, and (3) Bioenergy Policy Options (Christodoulidis, 2011).

The BLO, according to Christodoulidis offers a system based on certification and progressive price premium related to the final quality of the bioenergy product. Such system establishes different levels of compliance on several criteria, a preliminary bioenergy governance system. As the certification process is broken down in different levels, this allows the entry on different producers under a variety of circumstances. The implementation of such system would require Governments' stimuli by a) applications of covenants between governments and the industry on boosting certified bioenergy use and b) use certification schemes as a mechanism to restrict imports of non-certified bioenergy products c) implementing regulation to include costs and benefits in the final prices of energy. The latter would help to level-up the differences between no-certified and certified energy (Verdonk, Dieperink, & Faaij, 2007).

The authors of the BLO initiative anticipate that such proposal rest on an overreliance on conscious consumer, therefore it is also proposed a an United Nations Agreement on Bio-energy (UNAB), which would help to harmonize the implementation of the system and would guide the process of establishment of national covenants and regulation regarding import and production.

The second proposal is released by Mathews and it comprises a sort of regime where the OECD can act as third party between the North and the South in a bioenergy trade, in such manner that the former can secure continuous supply of bioenergy products and the latter can benefit from a stable and open market for their biofuels. The OECD would guarantee that such production has been undertaken in a sustainable way (Mathews, 2007b, 2009). Mathew's proposal is based in the latecomer advantages that can be developed by those countries in the South (low costs and implementation of technologies developed by those incumbent countries) and the future reliance of advanced countries on alternative transportation fuel (Mathews, 2007a). This pact should be negotiated between the involved parties (those countries within the OECD and some other invitees, which voluntarily take part in the deal), instead of being imposed by the strongest party (i.e. EU or US).

The proposal has some limitations as it is pointed out by Christodoulidis and Mathews himself, regarding the scope that can have the OECD to control its members and some other countries, nevertheless; it is also argued that in accordance to Mathews proposal "OECD countries would agree to generate investments in biofuel facilitation in the South and unlock the financing needed" (Mathews, 2009).

The final option mentioned by Christodoulidis is the one regarding the High-Level conference on world food security and the challenges of climate change and bioenergy held by the FAO in June 2008. Such conference puts on the table a set of 3 concrete policies for an international management of biofuels:

- The first one leads to continue in a current model where each country is responsible for designing and implementing their policies, and to adapt international regulations when they are compatible with domestic regulations. The implications to the public eye might be not as positive as expected given that is not sensed a high level of commitment regarding sustainable development.
- The second one asks for moratoria of some feedstock for biofuels production. The intention behind such proposal is to accelerate the shift to second-generation biofuels. Nevertheless, a prohibition of this sort can create negative incentives to a nascent industry in terms of investment, research and business interest and it would be difficult to enforce a governance of this nature.
- Finally, the third option is the generation of an intergovernmental consensus building which provides an ideal institution around biofuel production within a sustainable framework. Such institution could be shaped into a forum, an annex or a code of conduct and could combine the two options that have been presented formerly.

In this proposal presented by the FAO is given recognition to multi-stakeholders institutions (such as GBEP Global Bioenergy Partnership and Round Table for sustainable Biofuel) that have provided guidance to structure bioenergy policy-design, however it is questioned the scope of these organisms, given their limited numbers regarding memberships, in order to achieve a global authority to regulate international standards.

A parallel suggestion provided by Christodoulidis proposes to use the UNCTAD (United Nations Conference for Trade and Development) as a multilateral organism to propel bioenergy development. It is understood that one of the general principles of UNCTAD is to guide developed countries in helping developing countries to accelerate their economic and social progress, and to make changes in their own economies to reach such purpose. UNCTAD plays an important role in aligning goals regarding world economic state and development and designing of practical solutions to overcome disparities.

The UNCTAD Secretariat eases decision taking processes through research and data collection which is employed in project design and technical assistance, particularly to boost the development of least developed countries. This is carried out within an environment of intergovernmental consensus and autonomy of the institution itself, expecting the avoidance of biased decisions of those parties (or countries) which might exert pressure to their favor by economic.

Particularly in the area of energy it is posed by Christodoulidis that UNCTAD should participate in trade and development issues as well as trade and environment synergies. The consideration on CC is also important but it is well stressed that such efforts have to be done without duplicate ongoing actions undertaken by some other organizations in such regard.

UNCTAD should provide support to those countries (particularly developing countries) in pursuing biofuels expansion in order to encourage social, technological, agricultural, trade development and the associated gains that can come with these initiatives. At the same time UNCTAD must minimize adverse effects that might emerge in the social and environmental fronts.

The main strength of UNCTAD as regulatory organism, in comparison to other institutions, is its research work and objective position. As UNCTAD has exhibited its leadership in trade and development topics, based on analytic grounds, it is a sound candidate to lead, guide and regulate international biofuels trade, in words of Christodoulidis.

Despite the fact that UNCTAD has not conducted a direct effort on producing any publication regarding sustainable energy production, commercialization and use; it is a fact that such institution can provide its vast experience and knowledge in trade and development (among a broad spectrum of topics). Based on the above, and the conjunction of the intergovernmental character, the large number of members and the by-consensus decision making framework, become this organization in a perfect candidate to guide a process where biofuels trade can be encouraged within a path of sustainable standards, but having respect for other organisms' sovereignty.

2.4.4 Conclusions

There is a clear intention within the LAC countries to actively develop a bioenergy legal framework that can be used to support the biofuel industry and in doing that achieving several strategic goals. In most cases, and following the global trend, what is sought through these policies is to enhance energy security and local development (as a consequence of rural job creation and investment in the sector). There is also an environmental purpose in some cases, where a reduction in pollution can be achieved with protection of nature. Countries like Brazil and Colombia have advantages in terms of commodities exports, and that situation can be encouraged with a mature biofuel sector. Finally, in some particular cases like the Colombian, Peruvian and Bolivian biofuels can be used as a viable alternative to illegal crops.

All these legal initiatives are quite recent within the region and they are under a development and fine-tuning stage. Just a few cases (Brazil, Colombia and Argentina) among the LAC countries have the capability of cover their domestic needs and eventually export, by using domestic production only. In cases like the Argentinian biodiesel, this situation emerges as a consequence of the evident advantage in soybean production that already exists in this country, rather than from a deliberate effort that materialized through legislative means[38].

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[38] An important table similar to the one presente here, but with a different geographical coverage can be seen in (A. Faaij, 2007)

Table 5 Biofuels domestic policies for USA, EU and LAC region

Country	Fuel (Produced, used or to be used)	Subsidies	Tax Exemptions	Identified planned targets or mandates Timeframe given when possible
USA	EtOH and Biodiesel	X		Blending 36 billion gallons by 2022 in transport fuels
EU	EtOH and Biodiesel	X	X	Blends of at least 5.75% to be reached by 2010.
Argentina	EtOH Biogas and Biodiesel		X	E5 and B5 by 2010
Bolivia	EtOH and Biodiesel		X	Legal framework but no fuels
Brazil	EtOH and Biodiesel	X	X	E20 up to E100. B20 by 2020
Chile	EtOH and Biodiesel		X	E5 and B5 by 2010
Colombia	EtOH and Biodiesel	X	X	E10 and B5 by 2010
Costa Rica	EtOH and Biodiesel			Voluntary blends B2 - B5
Ecuador	EtOH and Biodiesel	X		E10 by 2010. B5 in Quito
El salvador	EtOH		X	Exploratory stage
Guatemala	EtOH and Biodiesel			E10 (Actual E3)
Honduras	EtOH		X	Under construction
Mexico	EtOH and Biodiesel			E10 and B2 (not implemented)
Nicaragua	EtOH and Biodiesel	X	X	NA
Panamá	EtOH Biogas and Biodiesel			E10 in 2016
Paraguay	EtOH and Biodiesel			Ideal target E24 mixed for 85 and 95 octane gasoline
Peru	EtOH and Biodiesel			E7.8 declared ecofriendly. B2 and B5
Dominican Republic	EtOH and Biodiesel	X	X	Biofuels a electrical co-generators
Uruguay	EtOH and Biodiesel		X	At least B5 by 2012. Maximum E5 by 2014.
Venezuela	EtOH			NA

If a comparison is made across the policies it is possible to identify key elements within these legal frameworks:

- there are mandates with a fixed or increasing penetration target,
- there are financial aids from the governments (tax exemptions and tributary incentives) and private sector (low interests credits and incentives to buy FFV’s).

However some timid behavior can be found as well: The Chilean proposal maintained a voluntary introductory mix level, and it was not until 2010 that it became mandatory. Nonetheless, the main policy is aiming to promote second generation biofuels, given its agricultural restrictions. Bolivia has been cautious as well, given some concerns around food security and food prices. Venezuela is probably the country in the LAC region that has acted with the least enthusiasm towards bioenergy production (understandable given its vast oil reserves). Biofuels are considered just as an eco-friendly alternative and can be used to reduce the environmental impact of traditional energy carriers.

Government policies towards a bioenergy sector as a whole, but to biofuels in particular, have had a great impact in the industry's development. The global dynamics of the sector are not explained by market forces, but by the political leverage that has been received so far. The experience of the major producer countries indicates how significant those policies are, and based on that, it is possible to foresee the key role they still have to play in this industrial progress. Currently, with exception of the Brazil, where the bioethanol production is competitive (without subsidies) in comparison with gasoline, the feasibility of the industry as a whole is inextricably linked to the existence of a legal framework. In general sense, these regulations share the same structure:

- an expression of interest in bioenergy as one of the appealing alternative energies, with all the drivers behind the initiative,
- a decision about the blending level and the nature of the mandate associated with it,
- and finally, the explanation about the tools to be used by the government and the explanation on how to have access to those benefits.

The quick pace that has faced the biofuel industry is reflected in the spread of the legal tools designed to promote it. In some cases, this rush resulted from undesirable outcomes: as a matter of illustration, for the USA and EU alike the proposed targets mentioned in the ongoing legislation have turned out to be far too ambitious, and overwhelm current domestic industrial capacities. In some other cases, initial mandates can be modified when the proposed target represent a threat to food security, or when the law does not have enough credibility among the population. An example of the first case is the Peruvian one, which despite having active and open support to the biofuel industry they experienced shortages of feedstock, hence, the need of importing biodiesel in order to fulfill the B2 mandate. In some cases, like in Argentina, it is possible to have a contradiction between the policy target and the goal achieved: the law promotes local production through small farmers' participation in order to satisfy the domestic demand, however, by 2010 all of the production was exported, because the remuneration was better in foreign markets and the policies were not put into practice with enough thoroughness (D Rutz et al., 2009).

It is fundamental to align targets and policies in order to have a buoyant industry. Pakistani and Indian cases are the counter-examples of this, due to taxes that have been applied to alcohol sales, resulted in creating a huge disincentive to the ethanol sector (Gonsalves, 2006; Khan, Khan, & Yusuf, 2007). Another mismatch that has been referenced is when the authority that rules any bioenergy program has clashing targets and the implementation of the regulation becomes weak or poorly handled. For example, when the Ministry of Hydrocarbon products is trying to raise oil sales but at the same time is required to show good progress on the biofuel front.

Fiscal policies are under constant scrutiny because they are considered expensive by some authors (Jatzke, 1994; Saikkonen, Lankoski, & Ollikainen, 2012; Singh, 2006). Thus, the decision on whether or not to support a bioenergy project through public funds, or by applying tax exemptions, heats up the debates around cost-efficiency. During most of the PROALCOOL program Brazil maintained a tax discount on bioethanol production. Between 1975 and 1987, the Brazilian alcohol program cost US$9000 million; however, it paid off in import savings of approx. US$14000 million (Worldwatch Institute, 2006). But the financial feasibility of biofuel projects hinges on the international prices of crude oil. In fact, for the Brazilian case, the low price experienced during the late 1980's, in addition to an expensive sugar price, led the industry to a critical point where the program was practically cancelled.

There are several components to assess cost associated with biofuel policies. One of them is the opportunity cost of implementing such regulations. Although, countries can avoid the cost of importing fossil fuel, it is also true that the taxes behind oil import quotas are not noticed. In Brazil, the cost of this was calculated and included for the State of Sao Paulo, and the amount went up to US$600 million during 2005. In the UK, according to Dufey, the income that the government did not receive would be around £90 million (nearly 160 USD) if a penetration scheme were to be implemented with a blending mix of 1% (Dufey, 2006).

Moreover, in those countries where agricultural commodities are exported, like in most LAC countries, a diversion of feedstock to supply the biofuels domestic market could represent a substantial diminishment in the income from exports.

3. ENVIRONMENTAL PROBLEMS IN COLOMBIA AND THEIR RELATIONSHIP WITH BIOENERGY PRODUCTION

Colombia accounts for a series of complex ecosystems with tremendous wealth in environmental terms. The introduction and use of traditional fuels for transportation, in an agricultural country such as Colombia, has direct or indirect effects on nature, the people and the economy. It is vital to understand the interaction between Colombian natural stock, social and institutional dynamics that emerge from it and the bond that biofuels production can represent.

Biomass has been traditionally used to cover several human needs: food, fodder, energy source, fibre production, forest products and ecosystemic services. Its consumption creates responsibilities regarding use of the resource (and linked resources), and off course downstream it implies waste and residues management. Bioenergy therefore entails competition for resources, and alternatives for various sectors.

The work presented by Perez's team unveiled a set of 8 problems of major scope in terms of environmental development (Perez, Rojas, & Ordoñez, 2010). While all of them have their own importance; a sub-selection of 6 will be the focus, based on the likely impact they might represent as a potential barrier that bioenergy projects have to face in their implementation stage. Furthermore, it will be explained how bioenergy or biofuel countries can improve or worsen the status quo of such problems.

The group of problems identified by these researchers from Universidad del Valle is presented as follows:

1. Loss of biodiversity and ecosystem base
2. Land degradation, pollution and inappropriate use
3. Water pollution and inappropriate use
4. Air pollution
5. Climate change
6. Deterioration of the environmental quality of the human habitat

Those problems that have direct linkage with biofuels production and use will be described in detail, however, those that are related to a minor extent will only be approached marginally.

3.1 Loss of biodiversity and ecosystem base

Biodiversity is defined as the variation of forms of life that is exhibited in different organization levels within nature, from individual, small cells to large communities, ecosystems and landscapes. During recent years the study of biodiversity has obeyed a system of hierarchic levels, as follows:

- biogeographic diversity,
- diversity of ecosystems,
- diversity of species,
- diversity of populations,
- cultural diversity

For some time, conservation and sustainable use of biodiversity is a top priority at a global level due to the appalling consequences should we suffer its loss, in term of productivity and recovery capacity that are embedded within the ecosystems, in the same way that it represents a serious threat to the survival for the billions of people that depend on them.

It is common to include nature preservation by excluding protected areas in assessments of biomass expansion potential use (just as it is implemented in this study). This implies that forest and already threatened areas are left out of calculations of potential expansion areas, but some other ecosystems also require protection and the current state of it may be insufficient (Chum et al., 2011). Some marginal lands, in spite of having low yields, count on high natural biodiversity; therefore the use of those areas may jeopardize current natural balance.

Losses of biodiversity can be consequence of either a) large monoculture settings or b) by establishing croplands for new bioenergy projects or for diverting food crops to low-yield marginal lands. Nonetheless; biodiversity can be enhanced by the introduction of new species in poor or degraded areas, or by the implementation of new agricultural techniques such as agro-forestry systems, that combines food and biomass production for other purposes.

The high rate of destruction and change in natural vegetation, associated with overexploitation of natural habitat, the illegal profiting from them, the destruction of the ozone layer, climate change as a consequence of environmental pollution, the introduction of exotic species, and the raising of illegal crops have led to a big percentage of fauna and flora facing some degree of risk of extinction or a severe reduction of their populations.

3.1.1 Geographic biodiversity

Colombia is a megadiverse country[39] considered as one of the Top 5 countries in the world in terms of biogeographic and ecological biodiversity. Such biodiversity is represented in a great variety of ecosystems and species (of flora and fauna), both terrestrial and marine kind, that as a whole create an impressive genetic richness. Colombia is considered as the second mega-diverse country having within it 10% of the biodiversity of the planet (Romero, Cabrera, & Ortiz, 2008). Colombia contains two hotspots of biodiversity: Choco/Darien and tropical Andes (Brooks, De silva, Foster, Hoffmann, & Knox, 2008).

Within the main policy of biofuels production and use in Colombia (Conpes 3150), there is recognition that bioenergy projects, in particular the establishment, management and processing of energy crops could represent a threat to biodiversity (Castiblanco & Hortúa, 2012). Nevertheless some studies, applied to palm oil sector, refer that effects on biodiversity are linked with particularities of every location regarding climate conditions, production system, chosen feedstock (León, Valbuena, & Borrero, 2006). These impacts could be positive (by widening the knowledge base of related species, habitats recover, and preservation) or negative (like interruption in the biological organization levels, disruption of trophic chains, diminshment of alterations of biota).

In the Colombian Case it is important to bear in mind that most sugarcane plantations have been stablished since colonization times and nowadays they occupy less than 200 thousand ha for sugar and ethanol production and they have not undergone through vast expansions. A similar case is presented for palm oil plantations. The growth rate of production in higher than the plantation area growth during the period 1962-2012, indicating a non-expansive behavior of these two energy crops[40].

Current plantations of sugarcane in the geographic Valley of Cauca River and palm oil in the Northern coast, Nariño and Meta departments do not compromise any biodiversity hotspots and further expansions have been forecasted, taking into account protected areas in such regards.

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[39] A mega diverse countries are those that shelter most of the living species on Earth, and are therefore considered as extremely biodiverse

[40] Based on FAOSTAT database it can be seen that in 1961 sugarcane plantation area was nearly 300 thousand ha, while for palm this area was 800 ha in Colombia. The highest point of expansion in sugarcane was reached in year 2000 with slightly more than 406 thousand ha, but it droped dramatically in 2009 to nearly 170 thousand ha and it has maintained similar levels ever since. Palm plantations have experienced a fairly continuous but slow growth during the whole period with an average growth rate per annum close to 9.39% and it has been reached an area of 165 thousand ha since 2006 and it has been maintained until today.

3.1.2 Issues related with ecosystem diversity

One of the main threats to ecosystemic diversity is the loss and fragmentation of ecosystems that affect their composition, structure and functionality (Fahrig, 2003). This phenomenon is mainly due to anthropic activities in the way of expanding agricultural frontiers, or by enhancing or augmenting infrastructure projects and mining exploitation, among others. Such problems bring as a consequence:

- reduced functionality of ecosystems, by a reduction of forest areas and their diverse products,
- decline of quality in the remaining areas,
- loss of connectivity between them,
- creation of borders or boundaries over the habitat,
- and geographic isolation due to the fragmentation of these zones.

In terms of species, there is also a notorious reduction in their population size, geographic isolation, reduction in the genetic variability, and increased difficulty for procreation (Fahrig, 2003). The main consequence of fragmentation of the ecologic equilibrium is a continuous change in the landscape, which puts at risk its feasibility and potential use in the long-run (Etter, 1993).

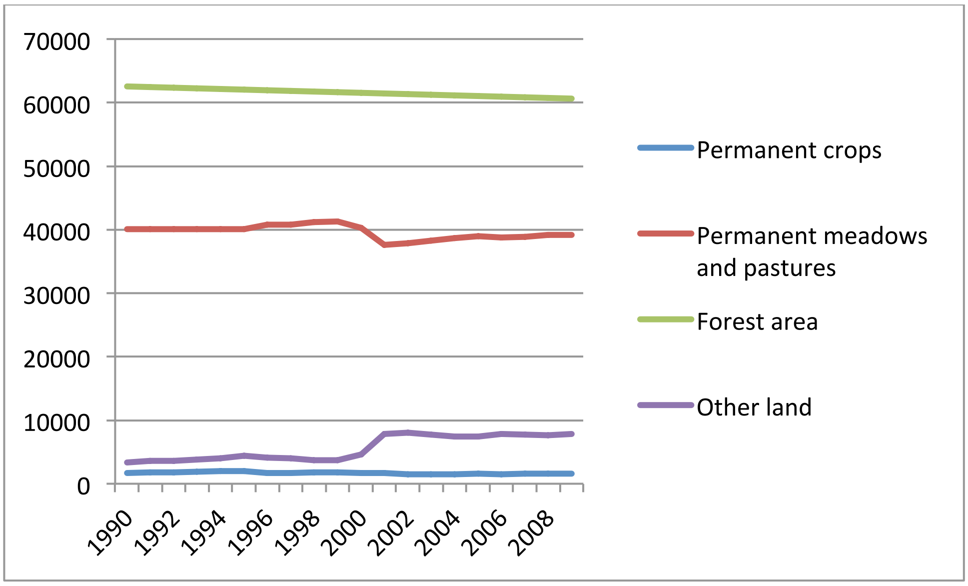
There is one ecosystem in particular that has suffered more than the rest of the Colombian biomes - forests. There is a great loss of forest and woodlands. While it is true that Colombian territory was covered by approximately 49 million hectares of natural forest in 2009, which represents near to 53% of the whole of Colombia, in a little more than 4 decades (1961-2005) there has been a loss of almost 5.3 million hectares. That would imply an average deforestation rate of 120 thousand hectares per annum, which draws a deforestation rate of 0.25%, which is slightly higher than the world average (0.2%). This deforestation has been more concentrated and severe in the Andean and Caribbean zones of Colombia, which are precisely the regions that exhibit higher population densities and more economic development, but with less access to water resources (FAOSTAT, 2009).

The most preoccupying consequence of the loss in the vegetation is that tropical and subtropical moist broadleaf forests are highly affected, and it clashes directly with the hotspots of biodiversity and the ecological importance that they represent. For instance, 50 of the species of birds of the world are located in the Choco and Amazonia region, and most of them can only survive in the delicate environment that these ecosystems provide. It is a similar situation for some tropical mammals and rare primates. However, probably the most threatened ecosystems are the mountain and sub-mountain Andean forest, and the tropical dry forests, given these locations are in vastly populated areas.

Also a big concern is the intensive use of agrochemicals, that have had an average increase in usage from 205.36 kg/ha (182.87 for fertilizers and 22.49 for pesticides) in 2002. to 305 kg/ha in 2011 (291.8 for fertilizers and 13.45 for pesticides), which is above the average Latin American levels in the same period, also experiencing a leap from 77 to 109kg/ha (FAOSTAT, 2014)[41]. Excessive use of these kinds of substances weakens the soil's response capacity in natural ecosystems, resulting in eutrophication processes that inhibit normal development in aquatic fauna.

The loss of forest cover has also been a consequence of wood extraction, firewood consumption (given that just 2.4% of rural families use any other kind of cooking or heating fuel) and forest fires. While at the same time, reforestation efforts are limited to an area of 16,475 replanted hectares per year has to compete against 120,000hectares that are deforested on an annual basis. Finally the construction of road infrastructure and the expansion of urban settlements have contributed to the detrimental transformation of the natural habitat.

Figure 10 Evolution of land use in Colombia



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[41] For Colombian and Latin American case the calculations were made by adding the total Nitrogen, Phosphate and Potash consumption of fertilizers assessed in tonnes. Pesticides include the use of insecticides, herbicides and fungicides, also assessed in tonnes. It was taken into the account just the area corresponding to arable land and permanent crops.

Part of the huge difference that is presented between the Colombian and the Latin American case can be due to the fact that in FAOSTAT database is missing information for fertilizers in the case of Brazil, Paraguay and Venezuela for the whole period 2002-2011. Some other countries also present blanks in the information collected in such regards.

3.1.3 Diversity of species and their problems

The introduction of exotic species is also a big concern in terms of biodiversity preservation, particularly in the Andean region of Colombia. It has been calculated that nearly 107 out of 117 invasive species (or with invasive potential), are found within the region. Some of these species were incorporated into productive activities, and subsequently they occupied vast monoculture arrays. In the case of bioenergy, initially there was a direct impact by the introduction of African Palm for vegetable oil extraction, and biodiesel production more recently. There have been some introductions of alien species as part of feed and plague control experiments, as is the cases of the bullfrog and the crazy ant (*paratrechina fulvia*). These two species turned into invasive organisms that nowadays have reached high occupation levels in the different biomes in the Andean region.

Thus, the introduction of alien species threatens directly the biological diversity and the landscape composition in the region. For that reason, with the adoption of new species it is possible to displace native incumbent species, creating severe problems for further development. Thus, it is vital to have a clear inventory of those species introduced within a nation, as well as clear identification of those species of invasive flora and fauna (or with invasive potential) in order to establish the proportion of species that embody a threat to native species or ecosystems.

3.2 Land: degradation, pollution and inappropriate use

Soil degradation is clearly and mainly related to human activities, but it can be generated through natural processes, such as geologic erosion, earthquakes, landslides and changes in the climate. Nevertheless, the anthropic factors can be controlled by the action of conscientious authorities, among others, by establishing policies, legislation and other tools.

Land and soil usage change is one of the human activities which most influence the ecosystems' capacity to provide environmental functions. The simplification of ecosystems caused by human activities makes it impossible for modified ecosystems to provide all the regular services that otherwise would be offered in their natural state (Assessment, 2005; Carpenter et al., 2009).

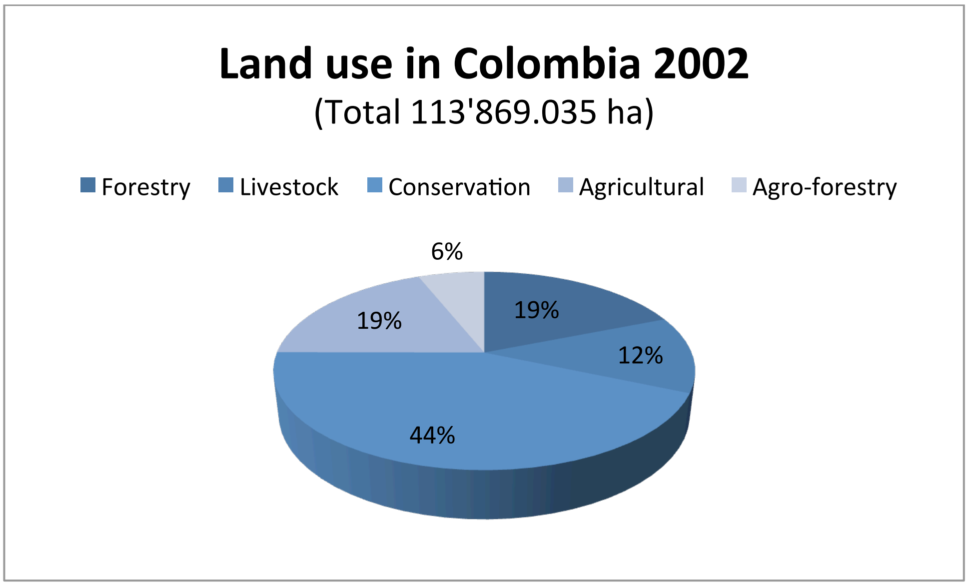
In the biophysics field, land use change (LUC) and change in the soil cover affect those nutrient cycles in the terrestrial and aquatic ecosystems, local and regional climate, water cycle and it might cause decline in biodiversity levels, and erosion and soil loss among other consequences (Metzger, Rounsevell, Acosta-Michlik, Leemans, & Schröter, 2006; Ojima, Galvin, & Turner, 1994).

The main human activities that trigger soil degradation are:

- agriculture,
- livestock farming,
- urban expansion,
- mining,
- road construction
- and wood extraction (WB, 2007).

Regularly these activities take place where potential soil use differs from the one that it is actually used for. In Colombia land use vocation is changing. It was estimated, a decade ago, that approximately 43.5% of the total area is destined for conservationist purposes, followed by agricultural activities, forestry projects, livestock farming practices and agroforestry endeavors.

Figure 11 Land use in Colombia 2002



(Pérez, Rojas, & Ordoñez, 2010)

3.2.2 Conflict over land use

Biomass plantations are usually established in surplus agricultural land; thus intensification in agricultural systems is required given that influences land availability for biomass plantations (by defining land requirements for the food sector) and it may enhance biomass yield levels. (Chum et al., 2011) Therefore within the calculations for the technical potentials of biomass production presented in recent studies, is highlighted the need of taking into the account a combination of high-yielding agricultural systems (in new and existing agricultural land) and international energy trade agreements (Ausubel, 2000; Cassman, Dobermann, Walters, & Yang, 2003; Fischer, Shah, van Velthuizen, & Nachtergaele, 2001; Tilman, Cassman, Matson, Naylor, & Polasky, 2002), as well as the dietary customs of different geographical regions (Gerbens-Leenes & Nonhebel, 2002; Smil, 2002; Stehfest et al., 2009; Wirsenius, 2003).

In Colombia, the conflict over land use is highly correlated to livestock farming practices. An intensive ranching practice induces to forest loss, ecosystemic degradation and changes in the human territory composition (Andrade, 2004). In Colombia, according to assessments and studies, it has been calculated that the suitable area for such purposes approaches 14 million hectares, whereas the area actually being used is more than 38.9 million hectares (FAOSTAT, 2009). In addition, the use of these lands is highly inefficient. Despite the fact that heads of cattle have increased continuously between 1961 and 2005, the increment of the number of heads per hectare has remained practically at the same level (from 0.6 to 0.9), so the level of efficiency has practically not evolved in more than 4 decades. According to statistics from the (Food and Agriculture Organization) FAO, the number of heads of cattle in 1980, including bovine, sheep, goats, and horse cattle (but excluding pigs), reached levels of nearly 30 million, and in 2009 this number grew to over 35 million.

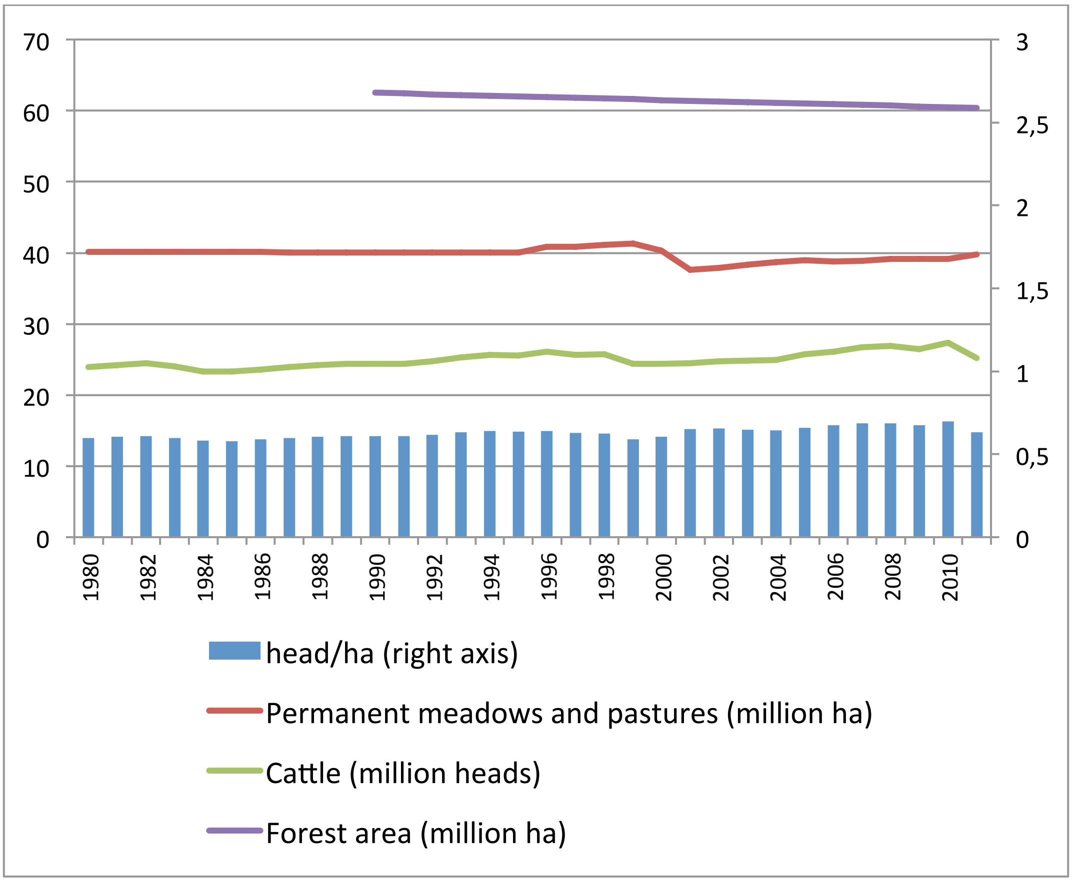
The impact that ranching activities has on employment is not as substantial as the one that can be produced by agriculture (Vergara, 2010), and the impact on the environment is higher with the former (Northoff, 2005; Vergara, 2010). Besides, the influence that cattle farming has on the social structure in terms of violence and land concentration is more accentuated than in some other agricultural activities (Andrade, 2004; Vergara, 2010).

The productivity indicators that reveal ranching sector's performance are not at the cutting-edge compared with some other countries within the LAC region (i.e. Argentina and Uruguay). For instance every ranch on average counts on 25 heads, where nearly 55% are destined for meat production, 4% for milk production and 45% for double pourpose. The level of sacrifice of female animals is 22%, while in US is 77%, Argentina is 54% and Uruguay 44%. The extraction or total sacrifice rate has been stuck in 14% for the last decade, indicading low progress in the productivity in the sector. the production of meat in some countries in the region is over 214 kg per head, but in Colombia such indicator has been reported in 197 kg per head. (Vergara, 2010).

Data from FAO indicate a quite stable and low-productivity behavior for the sector, where there is not even one head of cattle per ha (see graph below).

All these arguments confirm the idea that the use of land for livestock and other cattle farming exhibits a widespread and parasitic pattern, which has a great negative impact on the environment.

Figure 12 Land use in Colombia for Livestock growing purposes



Another part of the problem is that not all the territories that have the potential to grow forests and similar ecosystems are doing so. The environmental regulation has “secured” an area of only 11.5 million hectares through the program of national parks. Apart from the problem generated by the fact that some areas are not being used for their natural vocation, there is overexploitation in nearly 17% of the total area in the country. This phenomenon is related to intensive use of the ground, through a model of industrial agriculture, based on a vast use of machinery, modern irrigation methods, and agrichemical boosters. In any case, based on the data exhibited in the previous figure, is not posible to argue that cattle ranching expansion is given at expense of forest area.

Another factor that contributes to a major extent to the deterioration of land and soil is the existence of illegal crops. Agricultural practices that are undertaken to maintain, as well as to eradicate, these sort of crops are extremely aggressive on the environment and they contribute to the change in acidity levels, leading to salinization, resulting in desertification progression. Within the last 20 years, these types of crops have quadrupled, and it is important to bear in mind that they are usually located high up in the mountains, and in forests and jungles where their eradication becomes rather complex. Nevertheless, it is fundamental to remember that these illegal crops have undergone a substantial reduction within recent years, particularly since 1999. For instance, *papaver* or poppy crops have been reduced by almost 50%, and so have coca plantations (UNODC, 2007).

The Colombian government has tried to re-engage the communities that are involved in cultivating illegal crops, by offering them some alternatives. Perhaps the most influential scheme that has been employed as policy of State, in coalition with foreign (United States of America) help, was the so-called plan “Plante”. During the period 2000-2004, soft credits were offered (total amount of more than 160 billion COP i.e. more than 55 million USD) to peasants mostly in Putumayo region, as an incentive to abandon coca crops (Vargas, 2010). In this case the product that was employed as an alternative, was the heart of some edible palms. However, a more recent initiative is to employ energy feedstock(DNP Departamento Nacional de Planeación [National Economic Planning Bureau], 2008).

3.2.3 Land degradation

Apart from conflict over the land, given by inadequate vocation allocation or by illegal use, one additional problem is land degradation, which shows symptoms of erosion, salinization and desertification.

Erosion covers a considerable area of Colombian territory, it is predicted that near to 50% of it suffers some degree of land degradation, while 23% displays erosion problems that can be classified between moderate and severe. Those lands in severe condition, which occupy near to 7.8% of the total territory, are considered impossible or very expensive to restore. Erosion, as expected, has more presence in those areas densely populated: high and very high levels of erosion are shown in Orinoquia region (20.9% of its area), Caribbean region (14.5%) and the Andean zone (9.9%). Meanwhile, the Amazonia and Pacific regions are the ones that have a minor impact from this variable, which is fortune given their importance in terms of biodiversity (IDEAM, 2004).

The other problem is salinization, which is usually associated with irrigation methods. However, the first difficulty faced by the scholars and technicians that try to study and characterize such problems is the lack of information. The use of extensive monoculture methods and extensive livestock farming practices unleash salinization problems that are evident mainly in the Caribbean zone, affecting 60% of its territory, with levels between high and moderate salinization. Other regions affected by this problem are the Andean region with particular concern in the departments of Cundinamarca, Huila, Tolima and Cauca Valley. These salinization levels are directly linked to an over proportioned growth of irrigated land - it started with 400 thousand hectares in 1981 and ended up with nearly 900 thousand in 2001 (WB, 2007).

The cost of land degradation, due to erosion and salinization processes, assessed through loss in crop productivity, was estimated at US$ 670 million in 2004 (Larsen, 2004). One of the complications that prevent the land degradation problem from being solved is the lack of regulation and laws oriented to keep control of them. Neither law 99 of 1993, nor any other dispositions, establish clear mechanisms or responsibilities to mitigate land degradation. In the best scenario, both erosion and salinization are mentioned as problems that require proper attention by the environmental authorities; nevertheless, they do not indicate how these actions must be implemented and controlled.

This fact becomes a difficult barrier to overcome. While there is a desire to assess the relevance of applied policies oriented to preserve land quality, there is a great lack of available data because the authorities that implement them do not use performance indexes and there are no specific targets in terms of erosion and salinization control.

3.2.4 Soil contamination

Land and water are the two abiotic elements of the biosphere that have great interaction thanks to the bio-geochemical cycles of the elements and the hydrologic cycle. In addition, these two elements constitute a fundamental foundation for the development and proper working of several terrestrial and aquatic ecosystems. Having said that, it is clear that those vectors of anthropic contamination that affect water will also compromise land quality, and the difference is marked by the corresponding effects and magnitudes. Land pollution by way of biodegradable organic matter does not constitute a serious problem in most cases, given that the superficial layer on the soil is a very rich bio-reactor. The superficial layer of the ground is also high in biodiversity due to its elevated content of active microbial flora with an extraordinary biodegradation potential. The real problem arises when there is an excessive and uncontrolled use of pesticides, herbicides and in some cases fertilizers, which results in severe contamination of land.

Zúñiga et.al. point out that between the 1950´s and 1980´s fertilizer applied in cultivated areas was much less (in comparison with product yield) to current methods. Nowadays, it is necessary to apply big quantities of agricultural input to obtain current production, creating a high dependence on fertilizers. Excessive application of nitrogen has contributed to an accelerated deterioration of land quality, therefore, there is an urgent need to promote an agro-sustainable model as the only solution to recover and maintain soil fertility and productive capacity of the Colombian agricultural systems (Zúñiga, Osorio, & Cuero, 2009).

It is clear that these contamination factors are tightly linked to inadequate agricultural practices, both on an industrial scale and on small scale. Among those practices responsible for hastened soil fertility loss (Zúñiga et al., 2009)is monoculture is, which is the main setback, but also:

- the extensive use of fertilizers with synthetic chemical,
- the use of agro-toxins,
- over working the land,
- irregular clearing practices such as burnings,
- soil compaction by excessive mechanization processes
- and irrigation with inadequate waters can be count as.

A perfect illustration of such a situation is given by the case of a variation in the level of organic matter within the soils of the Cauca valley region (Besosa, 2005). In the 1960's this region contained 7% of organic matter within its soil, but every decade it has lost one percent. So by the year 2010 it was assumed to have level of 2% of organic matter. The reader must remember that this particular region in Colombia has been characterized by the cultivation of some fruits, but predominantly it uses sugarcane to support most of the agricultural income in this zone.

Thus, the loss of organic matter in soil leads to a disastrous impoverishment in terms of nutrients, caused by monoculture practices, the lack of crop rotation, and burning methods for clearing purposes. It is also known that continuous and permanent crops of the same species entail a constant extraction of the same nutrients and minerals over and over again.

Alternatives

Intensification and aggressive agricultural management have to be treated carefully because they may imply large input of nutrients, water and pesticides bringing negative consequences to the surrounding environment (like change in species composition, water pollution and eutrophication). However, intensification does not suggest necessarily industrialization of the agriculture, given that yield can also be improved in some regions, via organic farming methods, but with better practices than the ongoing ones (Badgley et al., 2007). Additional techniques of soil and water preservation can also contribute to increase yield in rain-fed regions employed for agriculture having into the account that best agricultural practices are not applied to many world agricultural areas (Godfray et al., 2010), as consequence of poor information, capacity building, access to markets, among others (Neumann, Verburg, Stehfest, & Müller, 2010).

There are some other opportunities to widen expansion areas in sustainable ways if conservation agriculture and mixed production systems are deployed, and water use efficiency and carbon sequestration techniques are developed, and some particular agricultural inputs such as nitrogen are limited in usage. Some other possibilities can emerge in the change of traditional resource-intensive fodder (soy and corn) (Dale, Allen, Laser, & Lynd, 2009), reducing grazing requirements (Chum et al., 2011).

Marginal lands are also an alternative; however there is much uncertainty on how much potential can be used for expansion of bioenergy plantations. Several obstacles need to be tackled in order to take advantage of such lands, among them long periods of time and financial efforts for maintenance and land reclamation task, low yields and involving established populations and their ongoing needs.

3.3 Water pollution and inappropriate use

Colombia has a history of generous rain fall over the years, resulting in it recently being catalogued as the fourth country in the world in terms of water availability. However, nowadays it is facing a conflict between socio-economic development and water sources preservation. Current national growth has led to a critical situation where some regions experience regular water shortages, and where population growth also exerts an additional pressure on the resource. Understanding this, it is important to have a general review of this key input to agricultural production, therefore market forces and other implications in terms of pollution are briefly presented below.

3.3.2 Water supply: related issues

Colombia is a country that counts on an immense water supply, which can be broken down into superficial and underground sources. Adding up the national water availability Colombia has a store of 2100 km^3 of fresh water, i.e. 50,000 m^3/y/capita, which by far surpasses the supply found in countries like Brazil, Argentina and Mexico. The allocation of underground streams and aquifers are important, given that 30% of fresh water comes from this type of sources, and nearly 40% of municipalities' water supply depend on aquifers for drinkable or potable water provision (IDEAM, 2004).

Notwithstanding, one of the most important features of the water supply in Colombia is its heterogeneity in terms of territorial distribution. It has been established that most of the water resources are concentrated in those unpopulated regions. Thus, the 66,344 m^3/sec that belong to Colombian territory are distributed in 5 different hydric basins that conform to the national continental territory, as defined below:

- Amazonia (22185 m^3/sec)
- Orinoquia (21339 m^3/sec)
- Caribe (15430 m^3/sec)
- Pacific (6903 m^3/sec)
- and Catatumbo (427 m^3/sec).

As it is evident, more than two thirds (76.1%) of the whole water supply is located in the least populated areas (Amazonia, Orinoquia and Pacific). Therefore, only 23.9% of the water is located in those basins that supply high population areas (Caribe and Catatumbo), and subsequently have a greater concentration of economic activity. The Caribe basin itself has Cauca and Magdalena rivers and account for approximately 70% of the Colombian population.

In terms of the hydrographical basins, it is estimated that 40% of the big basins have a degree of vulnerability between moderate and intermediate. This is reflected by the fact that during a dry season 25% of the municipalities face problems with water availability (and that covers 60% of the population). Such shortages fluctuate between medium, medium-high, and high. If such trends continue, as expected in 2015, the affected population could reach 65%. The most vulnerable region is the Andean one, followed by the Caribbean zone (DNP, 2007).

It is vital to have these water availability constraints in mind for further biofuel project implementations, given that the availability of this liquid resource impacts directly not only in its yield, but also in further expansion of such bioenergy feedstock.

In the same way it is expected that global warming exacerbates the impact of such phenomenon. This could result in a total lack, or at least periodical shortages, of water resources in some strategic zones, above all in the high-Andean ecosystems, which are fundamental providers of the liquid.

3.3.3 Water demand: related issues

Water demand for different sectors starts to unveil the roots of conflicts regarding this resource, especially if the uneven geographic distribution is taken into account, as it was just mentioned. The *Instituto de Hidrología, Meteorología y Estudios Ambientales –IDEAM-*, (Institute of Hydrology Meteorology and Environmental Studies), presented a study in 2004 where it was indicated that the water demand in 2003 reached 7,435,000 m^3, where agriculture was the most intensive water user (54.5%)

However, in the cases of agriculture and human consumption, there is a presence of high levels of inequality given that those small-scale and poor users are excluded from having proper access (IDEAM, 2004).

Regarding agricultural sector, the World Bank states that small-scale farmers do not have access to the water rights that they have been allocated, because these usually go to those more powerful and bigger sized users (WB, 2007). Studies on the water footprint of the Colombian agricultural sector establish a clear increment in the water use for this activity. The agricultural water footprint for Colombia includes the total volume for producing food and other raw material from the agricultural sector, however, without including illicit crops and flowers. Pérez calculated this indicator in 2003 to be 42.7 Gm^3, without including losses by inefficiency in irrigation systems. The volume of water use has undergone a continuous increase since 1961, where it had a level of nearly 13 Gm^3, and it had an outstanding peak in 1992 exceeding 45 Gm^3, followed by a gradual decrease that stopped in 1999 (at 32 Gm^3) when it reverted to a growing trend that end up at virtually 43 Gm^3 in 2003. The net effect of the whole period was 29 Gm^3, which can be translated in an annual growth of nearly 5%. This is slightly above the growth of the GDP of the agricultural sector, which has been reported as 4.5%. The issue that emerges here is that such demand is focused in just these few hydrographical basins with the lowest water availability, adding extra pressure on current water supplies (Perez, 2007).

In the case of human consumption, aqueducts are better equipped in urban areas; where coverage is wider than in rural areas. Nevertheless, even in cities, in those poor neighborhoods and those settlements in urban perimeters water distribution systems are not as good as the ones provided in inner cities.

3.3.4 Water pollution in Colombia

In the case of water pollution, it must be taken into account that this resource is available from three possible sources: superficial water, underground water and sea water.

Water quality in Colombia is affected for the most part by organic pollution and sediments (DNP, 2007). The latter are related to soil erosion by agricultural activities and mining. The main culprit for organic matter disposal, which is assessed in BOD (Biochemical Oxygen Demand), is the agricultural sector, which accounts for 84%, followed by residual households' waters (10%), and residual industrial waters (6%).

Nevertheless, at the present time there is no sure diagnosis for contamination caused by household water management at a national level. Neither is there enough nor reliable information on the current state of water resources, that includes in the analysis elements such as assimilation capacities of the receptor body, impacts of spills on quality of health of exposed populations to water contamination by chemical or microbiological causes. It is important to keep in mind that anthropic contamination that is produced all along the Andean mountains is disposed of in the Caribe basin, and ends up on the North-Western coast of Colombia.

Water scarcity may be a limit for intensification possibilities and possible expansions projects applied to energy crops, or energy plantations in general (Berndes, 2008a, 2008b; de Fraiture & Berndes, 2009; Rost et al., 2009).Nonetheless, this obstacle can be overcome partially by using water management treatments (Rost et al., 2009).

3.4 Air pollution

3.4.2 Air pollution in the World and in Colombia

Presence of substances in the air, in certain quantities and during long periods of time might alter health and human wellbeing, as well as possibly causing disruption in the normal behavior of ecosystems. Such a situation in known as air pollution, and it manifests through the interaction of different sources and the contaminants or pollutants that they release, as well as the influence of external factors such as the atmospheric conditions in those places where the phenomenon takes place.

Air pollution in produced by those uncontrolled emissions of gases that are freed in to the low atmosphere. Such emissions might be categorized by their incidence or scope on the environment, generally considered as local or global. Some of these substances introduced to given environments by the actions of nature, but there are others that come from man's actions. The origin of these anthropic emissions can be broken down into stationary sources and mobile sources. The former mostly consists of industries and households mostly, while the latter refers to any form of transportation that causes considerable emissions - basically any engine-based terrestrial, aerial, fluvial, or marine means of transport.

The most common pollutants present and which cause more severe reactions for humans and environmental health are:

- Sulphur oxides (SO_X),
- Nitrogen oxides (NO_X),
- Carbon monoxide (CO),
- Tropospheric ozone (O_3),
- Lead (Pb),
- Particulate matter (soot, ashes and dust),
- Volatile organic compounds (VOC's), among others.

Regarding the sources of emission for those pollutants mentioned above, there are several different systems of classifications. The first way of classifying these sources, involves separating natural from man-made sources. Among the natural sources are volcanic eruptions, sand storms, and organic matter decomposition in natural environments such as swamps or wetlands. While the ones that come from man's actions include, fossil fuels use, industrial processes, waste management and treatment, just to mention a few.

A different approach to sorting, is the use of the spatial reference of the source. As mentioned previously, this is the source of emissions from a stationary or mobile source.

In general, most of the problems that are associated with air pollution have a strong link with anthropic activities, like the use of fossil fuels, either for transportation purposes, or for other common kinds of energy requirements from households and industries. Pollutants have a close connection to the industrial activity that is being performed, so, for instance, transportation contributes vastly to levels of sulphur and nitrogen oxides, and to a minor extent with lead. Energy production (e.g. electricity), on the other hand, accounts for a great deal of nitrogen and lead oxides, and to a lesser extent, sulphur oxides. Carbon dioxide and carbon monoxide, are associated with the use of fossil fuels, but these are also generated by agricultural activities, livestock and cattle farming, and waste disposal (IDEAM, 2001b).

With regard to those gases that create a local effect, the emission core, are more closely associated with the great urban areas, due mainly to a more concentrated and comparably bigger energy demand than in rural spots. This is obviously explained by a higher population density, and those industrial processes of materials transformation that are condensed within cities. Thus, Colombian metropolises like Bogota, Cali, Medellin, Barranquilla, Cartagena, Barrancabermeja and Sogamoso create most of the emissions of potentially local impact, therefore, making more vulnerable the people that inhabit these urban settlements. Bogota, Cali, and Medellin, are some of the more polluted cities on the American continent (DAMA, 2004; Gurjar, Butler, Lawrence, & Lelieveld, 2008; IDEAM, 2004; REDAIRE, 2003).

Particulate matter represents a serious threat to human health and its level of danger is inversely related to its size. Those particles with 2.5 µm or less are markedly more hazardous to human kind (Franklin, Zeka, & Schwartz, 2006). Indeed, the local pollutant that attracts more attention is particulate matter, because it is responsible for most human health issues (Azizi, Zulkifli, & Kasim, 1995; Calixto & Díaz, 1995; N Lozano, 2003). In the biggest cities, the level of total suspended particles (TSP) and particulate matter with less than 10 µm (PM_{10}), frequently exceeds the guide values established in the standards of the regulation in Colombia (DNP, 2007).

3.4.3 Sources of air pollution and affected sectors in Colombia

According with IDEAM calculations, 41% of total atmospheric emissions, and close to 75% of the national burden of industrial pollutants are focused in the 8 biggest cities and industrial centers in Colombia (IDEAM & MAVDT, 2007). Crossing data with DANE, near to 45% of the urban population in Colombia is located precisely in these places (DANE, 2005). Furthermore, it has been established that mobile sources of pollution, within these 8 cities, are liable for most of the gases emissions in to the atmosphere. A vast proportion of them occur in Bogota, where mobile sources account for nearly 169 thousand tons out of 200 thousand tons. However, the situation is similar in other cities:

- In Medellin mobile sources load the environment with 110 out of 128 thousand tons
- and Cali 99 out of 127 thousand tons

In the remaining 5 cities, Barranquilla, Sogamoso, Bucaramanga, Cartagena and Pereira, pollution levels do not surpass 50 thousand tons of total emissions each (Brugman, 2004).

In contrast, stationary sources of air pollution are much lower in comparison to mobile ones, in a national perspective. By 2002, the transportation sector was accountable for 85% of the total volume of contaminants (including TSP, PM_{10}, SO_X, NO_X and CO). In addition, there is a substantial difference between the sulphur content between the fuel that is domestically produced and that which is imported. And consider that gasolinegenerates1000/300 ppm, while diesel is 4500/500 ppm. The industrial sector was culpable for only 9% of the total volume of pollutants, while the thermal energy generation sector (firewood combustion, coal, liquefied petroleum gas, kerosene and natural gas)was accountable for a slight 3.1% (Brugman, 2004).

Therefore, massive transportation systems (like articulated buses) must be encouraged to work efficiently from an environmental perspective and also in terms of energy consumption. An added benefit with massive transport - it reduces the number of cars on the road, thus improving overall travel time for commuters, but it is also a good alternative to protect urban environments. In the same way, a review of less polluting alternatives must be considered as well. Bioenergy for instance can capture carbon dioxide when the chosen feedstock is grown, via the photosynthetic process, although it does have inconveniences associated with the process, as will be explained later. Electric engines could also diminish most gases emissions; however, such technology needs to be proven safe in terms of battery disposal management. Like those examples, there could be other devices and technological advances that help to curve the increase in air pollution, however, at this time most of them are too expensive to be implemented in the short run, or simply too complex to be introduced into the Colombian context.

Picking up the thread on pollutant sources; agricultural practices, such as burning of biological wastes after harvest, have a big role in producing CO and NO_X. In Colombia, by 1996, the participation of the agricultural sector in the production of these gases was 47% CO and 19% NO_X. Unfortunately, such practice is still widely spread in sugarcane cultivation, greatly affecting those populations close to the plantations. Nevertheless, it is important to acknowledge that there are no epidemiological conclusive local studies that infer a direct association between such practices and the potential hazards on human health by those populations directly exposed to those pollutants that emerge as by-products of burning routines (combustion gases and particulate matter) (Perez et al., 2010).

In regards to greenhouse gas (GHG's) emissions, those activities that implied the use of fossil fuels, industrial processes, inadequate agricultural land management and forest exploitation, jointly released near to 150 thousand Gg of $CO_{2\text{-}Eq}$ in 1994 (IDEAM, 2001a).

Air pollution is definitely a great problem in big urban and industrialized settlements in Colombia. Monitoring plans are still quite precarious and are neither continuous in time nor provide accurate and up-to-date information, that can help to build up a National System of Air quality. There are 19 air quality networks that operate within the national territory, but management issues, like constant changes in the operating staff, avoid proper delivery on the information (Perez et al., 2010).

3.4.4 C

3.4.5 onsequences of air pollution in Colombia

Air pollution in urban cores has become in an important problem, in terms of public health, due to the fact that it raises the likelihood of morbidity, and mortality in infants and elderly people, particularly by causing respiratory conditions and cardiovascular diseases (Franklin et al., 2006; Norman, Cairncross, Witi, Bradshaw, & Collaboration, 2007; Slaughter et al., 2004). The CONPES document 3343 shows the annual cost of public health on account of air pollution in urban zones in COP$1.5 trillion (USD 535 million approx.). Such cost have been assessed based on the treatment of premature mortality as a result of cardiopulmonary problems and lung cancer, and several deaths respiratory type (DNP, 2005). It has been estimated that there are close to 6000 deaths by these causes per annum. The incidence of particulate matter on the health of rural population is also a big concern, due to the use of traditional biomass, i.e. firewood, as fuel for heating and cooking purposes (WB, 2007).

Despite the abovementioned points, there are difficulties to evaluate properly the impacts of air pollution on human health, because analysis has identified deficiencies in data collection and compilation, in conjunction with poor reports of respiratory syndromes associated with air pollutants. If the aforesaid is added to a deficient monitory protocol in the assessment of atmospheric emissions, the whole situation is clouded in uncertainty. This lack of definite correlation between health issues and air quality prevents establishing actual benefits from government interventions in terms of prevention and air quality control. Therefore, large investments in emissions estimations and forecast, monitory programs, and development of control strategies might be lost if it is not clear to what extent these initiatives help to enhance health levels of affected communities (Perez, 2007).

3.4.6 Air management in Colombia and their problems

Air quality management is the process whereby strategies are designed to implement plans and use tools in order to control and monitor sources of pollutant emissions. This management set guidelines and put in motion policies in order to restore air quality and reduce harmful impacts on health and environment.

There are 18 air control networks installed in Colombia, but the IDEAM ratifies just 6 of them, who have a record of registers for some pollutants. Consequently there are constraints in the quality of information and the possibility to aggregate data at a national level (IDEAM, 2004). In summary, with the little information available it has been possible to identify that particulate matter (PM_{10}) is one of the pollutants that supersedes the regulated standard value.

However, there is an urgent need for studies that can precisely determine the magnitude of the effects on human health that is caused by concentration of particles into the air and the incidence of other contaminants, such as that of particulate matter less than 2.5 µm, and tropospheric ozone (DNP, 2007).

Recently, projects around the *Sistema Integrado de Transporte Masivo –SITM–* (Massive Integrated Transportation Systems) have been introduced as a response to mobility issues in several cities, however, the environmental aspects have not been considered as a relevant factor in any of the current SITM projects. So far, there is no a single SITM project that reports any positive correlation with the SITM implementation.

Biofuels, on the other hand, have received support from the government and have been presented as air cleaning agents (or less polluting agents in comparison with regular fuels), because precisely one of the promotional drivers is their ability to act as catalyzers, improving the combustion effect.

3.5 Climate change and climate variability

3.5.2 Climate change and climate variability

Climate change (CC) is the biggest environmental threat in recent times, and despite its vast discussion on the public stage and political arenas, this concept is subjected to different interpretations. Therefore, this concept tends to be mistaken for climate variability, the greenhouse effect and global warming. Climate variability (CV) makes reference to variations in the average climate conditions and other climate statistics (such as standard deviation, extreme phenomena, etc.) in all spatial and temporal scales that go beyond a meteorological event.

On the contrary, CC is defined as the modification of climate over large periods of time, usually decades, and related with comparable historic periods, due to natural causes, internal or external to the Earth, or anthropic but occurring in the geological past.

The net effect of CC on agriculture and bioenergy production is highly uncertain, given on one hand new trends in temperature that have not been recorded before, and on the other the adaptive response of farmers to such phenomenon (Chum et al., 2011).

Climate warming moves along with CO2 concentrations and corresponding changes in stages in the water cycle (like precipitation patterns and transpiration effects). None of the potential effects from these natural modifications can be currently forecasted with certainty.

3.5.3 Causes and forces of the Climate Change in Colombia and in the World

Climate change (CC) can be unleashed by natural causes but also by the action of man. The most important trigger that has been reported and studied is the Greenhouse effect, which has both natural and human origin.

Most of GHG's emissions are explained by CO_2, in fact they account for 75% of the gross emissions. However, this does not take into account the CO_2 lost from the atmosphere by effect of forest recuperation, or oceanic absorption. Following that line, the remaining elements of methane, carbon oxide, N_XO_X, O_3 and Chlorofluorocarbon gases (or CFC's), are equally responsible for global warming. The GHG's are predominantly produced by fossil fuel combustion, related with various production sectors around the world.,

World levels of CO_2 have reached an atmospheric concentration of 379 ppm in 2005, compared with an approximate concentration of 280 in 1850 (Solomon et al., 2007). Methane concentrations have risen as well over the same period of time (from 0.7 ppm in the industrial era to 1.7ppm in 2005), due, among other factors, to an enormous release of gases by extensive livestock and cattle farming, solid wastes and burning practices. There has been reported an increase in the levels of nitrous oxide (going from levels of 0.27ppm to 0.32 ppm just in 2005) which correlates with the change in agricultural practices and intense use of fertilizers. It is important to point out that the global warming potential of these gases far more powerful than CO_2, (Methane 21 times more than CO2, and Nitrous Oxide 3100 times!) (Solomon et al., 2007).

The contribution of Colombia to this particular problem is quite low, reaching only 0.4% of the global total in comparison with other nations around the world, and even in the LAC region, being surpassed by countries like Mexico, Brazil, Argentina and Venezuela. In 2001 the IDEAM presented a study which calculated the GHG's emissions (particularly $CO_{2\text{-Eq}}$). It that study Colombia was calculated to produce emissions of more than 54 million Gg, and nearly 34.1% of that was the responsibility of the transportation sector.

Therefore, an energy source such as ethanol or biodiesel, which reduces emission levels, might help to alleviate, temporarily, the pressure on the environment, only if the net effect is not affected greatly by LUC and iLUC effects. These effects will be the subject of further discussion later.

3.5.4 Effects and consequences of climate change in the World and Colombia

All these factors in union, or even individually build up climate phenomena (changes in the atmospheric pressure, in the air circulation systems, rain distribution and frequencies), which in turn might result in climate change.

Nevertheless, there is uncertainty as to what extent and how fast the consequences of it take place. This uncertainty is inherent to the weather system, due to its non-linearity and complexity.

Bioenergy takes part in the terrestrial carbon cycle given that resulting emissions from burning processes will be absorbed later during the growing period of the plantations42. In accordance with a particular land use terrestrial carbon stocks are released to the atmosphere, therefore the inclusion of LUC effects is crucial for recent LCA studies[43].

Production and use of bioenergy influences climate change through emissions from the bioenergy chain, changes in the biopheric carbon stocks, alteration of markets (such as the fossil fuel one) by the implementation of bioenergy and changes in established environments (modifications in existing albedo) (Chum et al., 2011).

It is important to point that bioenergy does not necessarily unleash LUC effects. For instance combination of feedstock and some other crops can avoid land displacement. Use of cellulosic material, as well as some wastes and residual oil also provide an alterntive in this case. The case of Colombia presents a particularity where it is traded part of the land that was formerly used for exporting sugar and nowadays is utilized to feed the ethanol production process, therefore, there is no need for additional land under the current circumstances, but it could be reconsidered in the near future if ethanol and sugar exports are taken into account.

The use of firewood in a traditional way for heating and cooking task is not efficient, and produce large amount of incomplete combustion products, that impact negatively on CC and the local air quality (K. R. Smith et al., 2000). Consequently its reduction by the implementation of modern biomass products can alleviate those aspects recently mentioned, and the AGB stocks, and forest preservation (with its results on biodiversity) can be done easily (Ravindranath, Balachandra, Dasappa, & Usha Rao, 2006).

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[42] Net carbon balance is not necessarily equal to zero, given that the sequestration process can take longer than the emission one in some cases (Chum et. al., 2011).

[43] These effects can be broken down in direct and indirect LUC. The former have been included in LCAs since the year 2000, while the inclusion of the latter is practically absent in studies of this nature. In this document both effects have been taken into consideration.

3.5.5 Policy actions to tackle CC in the World and Colombia and their main obstacles

According to the latest report of UNFCCC, Colombia was responsible for the emission almost 180 Tg CO2 Equivalent in GHG during 2004[44]. In fact, in comparison with the previous assessment in 2000, the growth of GHG has raised up to 1.33% over the whole period. The contribution of LUC effect and associated emissions for 2004 was nearly 14.5%. (UNFCCC, 2013) Even though Colombia does not contribute heavily to GHG's (just 0.5% to the world's total emissions, i.e. 30689.5 Tg CO2 Eq in 2004) (Anderson, Fergusson, & Valsecchi, 2008), it has been active within different agreements and treaties on climate change, like:

- the World Meteorological Organization (WMO) and its World Weather Watch (WWW) program,
- the program of the Inter-American Institute for Global Change Research
- the UNFCCC and its Kyoto protocol,
- through laws 164 of 1994, and 629 of 2000.

Within these agreements Colombia has committed to develop political answers and strategies through mitigation and adaptation, which have been recognized as valid solutions to CC problem.

Since the first official national communication to the UNFCCC (IDEAM, 2001a), Colombian has adopted an active role in implementing mitigation actions, by mean of Clean Development Mechanisms or CDM's as introduced in the Kyoto protocol. These projects cover energy production, urban mobility, waste and residual management, among others. So far, these projects represent 0.86% of projects at global level (DNP, 2007).

The quota of responsibility in GHG's emission for Colombia at world level is quite low, for that reason it is difficult to think of a public policy directed at climate control that gives national priority to mitigation of CC. Despite the benefits that are included in the CDM's that have been implemented so far in Colombia, it is important and imperative to highlight the urgent need of setting in motion an adaptation approach, given an enormous vulnerability of strategic sectors such as water resources, agriculture, health and life-supporting ecosystems. It is also crucial to focus political efforts, institutional capacity and knowledge development in this field.

Climate change can be faced with an adaptation strategy, but CC requires a long term strategy as well. So, work must be directed to diminish GHG's emissions and move forward on mitigation actions. This implies the need of restructure the energy matrix towards sustainable

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[44] Including LULUCF/LUCF

alternatives, such as solar, photovoltaic, wind, tide, etc. First generation biofuels in particular can be a transitional option. However, they still represent serious threats to environmental and social equilibriums, if they are not managed properly. Nevertheless, they can provide a low-cost alternative, giving some time to mature other options like cellulosic bioethanol, or algae-based biodiesel, or even some other future options for transportation.

In order to achieve integral management capable of facing the challenge that threatens, it requires an holistic vision or to assume CC as a common factor in the environmental problems that Colombia is confronting, and as an issue that should be managed with a trans-focal and trans-disciplinary approach that covers more areas of expertise that just environmental management, it also needs political, economic and social intervention at a national level, incorporating an adaptation perspective. Alongside this, Colombia must develop an institutional framework that coordinates such management tasks, taking into account those different sectors (DNP, 2007). By doing so it is possible to build a more effective set of policies, create regional coalitions for the inclusion of people, and extend the scope of the local effects to a global level (Bergkamp et al, 2003).

With regard to vulnerability reduction in Colombia, and thinking of the possibility of increasing its adaptive capacity, it must be considered that, albeit adaptive capacity of ecosystems hinges on several biological factors, among them the extension of ecological niches, genetic reserves, etc., human capacity of adaptation goes beyond and does not only depend on knowledge (technology), but also on the institutions, social, legal and political powers, that rest upon public workers and society in general (Bergkamp, Orlando, & Burton, 2003).

Among the weaknesses for prevention and control regarding CC, at a national level, there is an evident lack of a general action plan, as well as local and regional strategies for mitigation and adaptation to CC. There is no adequate institutional framework either, that coordinates such management: it presents failures in responsibilities allocations and coordination capabilities (DNP, 2007).

Therefore, the next 10 years will be fundamental for Colombia to define its position towards a threat of climatic variability and climate change, given that the adaptation costs from now until 2030 at a global level could increase between 5% and 20% for global GDP (Stern et al., 2007).

3.6 Deterioration of the environmental quality of the human habitat

The problems with the human habitat can be described by a lack of environmental rationality expressed in either rural or urban living standards. This can be sensed, described, and assessed by the severe flaws in quality of life for different sectors of the communities. Such problems frequently manifest by the habitation of degraded environments, which are commonly associated with poverty conditions.

A clear manifestation of the aforementioned in urban environments is the accumulation of people in overcrowded cities, which in fact are unable to provide adequate sustenance locally, and are incapable of processing or disposing of waste adequately. The result of the great number of needs, and a shortfall in infrastructure, is that support for an enormous population turns into excessive energy consumption and big environmental impacts.

Urban settlements in developing nations are growing without control in most cases. It is common to find megacities without green zones or basic health infrastructure, along with severe shortages in water and shelter. In such cities, just under 50% of their population have running water, and 25% go to public fountains, or wells, or use manually operated pumps, while the remaining 25% have to use non-drinkable water (Habitat, 2008).

In a general sense, cities have been growing in a segregated way, surrounded by slums and precarious public spaces, in strongly degraded social and physical environments. Colombia has not been the exception to such trends.

Urban demographic growth and rural population diminishment.

Colombia has experienced a similar urbanization process to the one experienced by several countries in Latin America. In just 40 years the organization of Colombian territory has changed drastically, turning into a more urbanized country. The last census that was carried out in Colombia, took place in 2005. This statistical exercise revealed a population of 41.5 million, of which 76% were living in urban areas as a result of the expected migration from the countryside to cities, but also augmented by the forced displacement phenomenon from internal conflicts. It has been suggested that by the year 2020 populations could reach 43 million people in urban settlements.

The growth of Colombian cities has not followed any sort of formal planning whatsoever, and as a consequence some of the environmental problems mentioned earlier emerge.

The possibility that bioenergy brings to this problem is one of the main drivers associated with an active biofuel implementation policy - to provide different alternatives for rural development. Therefore, if energy crops are established as part of an extensive policy, the migration from rural areas to cities can be reduced. This situation would lead to less crowded spaces and eventually better life conditions.

3.7 Conclusions

Biomass use is definitely a source of conflict, therefore its employment for energy provision require a balance of advantages and disadvantages. A disruption in the natural equilibrium entails a thread of environmental crisis, which can be summarized in 5 problems. Those problems are closely linked with the implementation of biofuels plans, such as the one that is presented by the Colombian government.

Biofuels production, commercialization and use can help to mitigate some of those issues, but also can trigger or stregnhten others.

In particular for Colombia is concluded that current location do not pose threat on biodiversity, and future expansions have only been considered within authorized (non protected) areas. However some other obstacles might emerge as the disruption or fragmentation in natural habitats, and the intensive use of agrochemicals.

LUC and iLUC effects are also foreseen in the implementation of bioenergy projects. Soil can be seriously deteriorated by agricultutal practices, therefore R&D and training to farmers are required to use a soil-friendly techniques, without compromising yields. Bionergy projects in Colombia can be expended in detriment of livestock farming, which is neithr intensive nor technified enough.

Water availability is one of the biggest difficulties to overcome for biofuel expansion projects, due to the heterogenic distribution of the resource. Eventually water management treatments can mitigate this issue.

Biofuels can contribute positively and negatively to air pollution and CC. On the good side, photosynthetic activity removes vast amounts of CO^2, produced by manufacturing and burning processes, but at the same time biofuels itself required to be burned and in the agricultural stage offer a great contribution of NO^2 among other GHG's.

On the social aspect, biofuels might turn into an attractive alternative to bring bact confidence in the rural areas. As consequence of this, inverse migration from urban to rural areas could be unleashed with a better distribution of a very uneven demography.

4 BIOFUEL COSTS AND PRICE FORMATION

As part of the economic analysis of the biofuel chain in Colombia, there are those factors that determine both costs and prices within the industry. This section reviews contractual agreements and formulas that explain the role of the feedstock producer, transformation agent, and commercial trader.

4.1 Biofuel production costs

Costs in any agricultural-based chain or product development will depend on several factors:

- price of land,
- labor wages,
- technological level,
- domestic capabilities to provide proper equipment, and others.

At a global level, those biofuel processing nations that are at the forefront of development and production have proven to be quite efficient in their processes and the cost of production, and have exhibited remarkable results. For example, biodiesel in the case of Malaysia and Indonesia, and sugarcane-based ethanol in the case of Brazil, noted as follows: "The US, the 2nd leading ethanol producer in the world, has variable costs of production of corn-based ethanol of US$0.96 per gallon. Fixed costs range from US$1.05 to US$3.00 per gallon. While in Brazil the total cost of production was approximately US$1.10 per gallon during the 2005 crop year, with variable costs of US$.89 per gallon and fixed costs of US$.21 per gallon."(Martines-Filho, Burnquist, & Vian, 2006).

Such very competitive costs are not the outcome of a sudden set of conditions, but on the contrary, come from the implementation of long-run strategy. In fact, it is reported that by 1980, at the beginning of the PROALCOOL program the production cost in Brazil was near to US$100/barrel, i.e. between US$2.7 and US$3.2 per gallon (José Goldemberg, Coelho, Nastari, & Lucon, 2004).

4.1.2 Palm oil biodiesel cost

In the case of biodiesel there is a wide range of results regarding the chosen feedstock as is shown in Hass and his team's study: "Calculated production costs (which included the cost of the feedstock and of its conversion to biodiesel) ranged from US$0.30/l ($1.14/gal) for fuel produced from soybeans to US$0.69/l ($2.62/gal) when rapeseed was the feedstock." (Haas, McAloon, Yee, & Foglia, 2006).

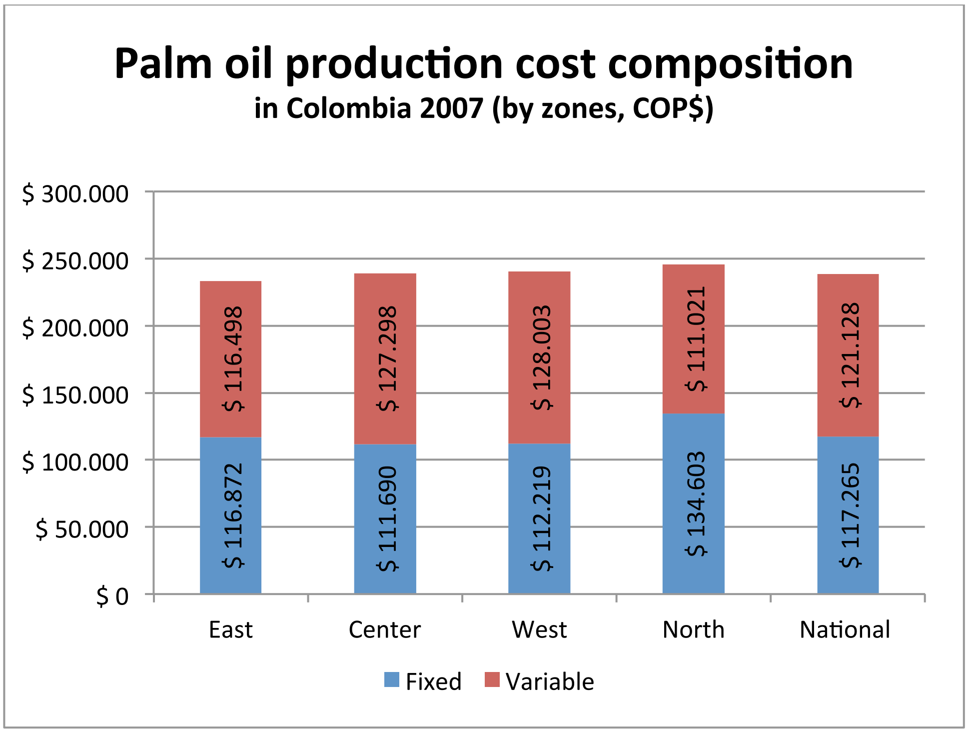
Compared with these experiences, Colombia must overcome several barriers in order to mature its ongoing biofuel industry in this competitive market. Among them, is the excessive labor cost. In fact, by 2010 the regular wage for an agricultural worker went up to US$13 (for a normal shift), whereas in other tropical regions around the globe (like Indonesia), it is possible to find shift payment under US$5/day. These incredibly low costs are due to workers from other poorer nations being introduced to gain cheap productivity.

There are several studies and estimations that provide an insight to the costs of production of palm oil in Colombia. Some of these studies include comparisons with the international references mentioned above. Despite the closest reference in regional terms would be to the Argentinian figures, it is not as profitable when compared to the South East Asian countries, given that Argentina has its strength in soybean production, while the SE Asian countries and Colombia have a palm-based biodiesel industry, and also share similar climate conditions.

The main component of the cost of Biodiesel is the cost of feedstock itself and in this case, it would be used the vegetable oil, as price floor. According to some calculations, the cost of producing palm oil in 2006 was US$ 482 per ton (in the Eastern region of Colombia). The exchange rate was close to COP$2500 per dollar and if it had dropped by 20% (COP$2000/US$) the cost would have grown by 25% (Infante & Tobón, 2010). When checking other sources of information, such costs have been underestimated: FEDEPALMA has published data for the same year, and by using the actual exchange rate of COP$2387.58, showed a cost of US$536.16/ton (at a constant prices for 2007), which gives a more accurate calculation. In fact, during 2007 the national average cost was COP$1,285,014, but with an exchange rate of COP$20078.35 per dollar, it resulted in a production cost US$618.29.

The most important thing in an analysis of this sort is following the relative evolution of the cost rather than establishing such costs in absolute value. This means that a break down on the data into fixed and variable costs might boost the performance of the industry, as it is presented in the graph below.

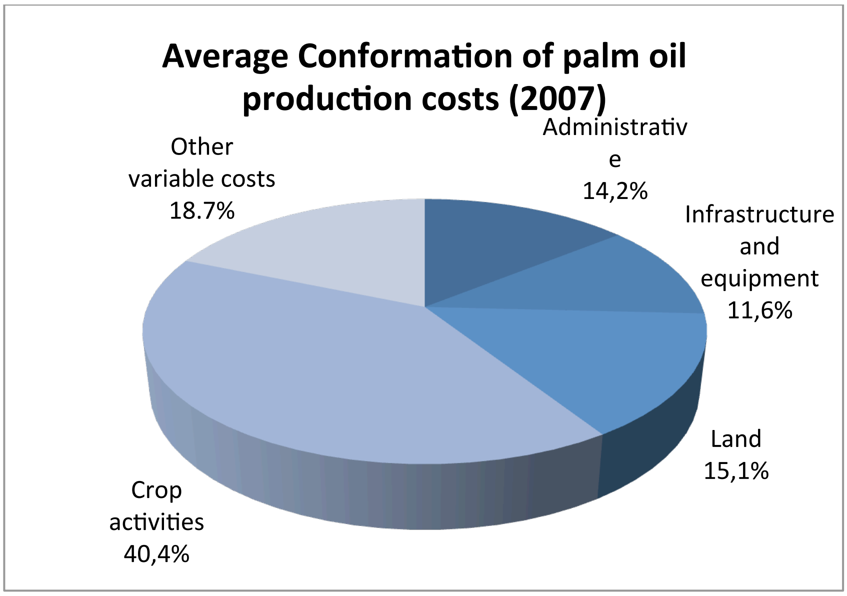
Figure 13 Palm oil production cost composition



Compiled by the author. Data source: Fedepalma website

In particular, the zone with the lowest cost is the Eastern region of Colombia, and here variable and fixed costs are evenly distributed. On the contrary, the Northern region exhibits the highest cost of all, but here, just as in the Eastern region, costs are uniform (nearly 50/50 in both cases). The difference among regions is not substantial at all. By 2007 the gap in cost was close to US$6 per ton.

Figure 14 Average Conformation of palm oil production costs



Compiled by the author. Data source: Fedepalma website

Another deconstruction of cost is given by the data provided by Fedepalma in its website, where it is established that the main part (more than 55%) of these costs can be explained by agricultural activity if both land acquisition or leasing, and tasks related with the crop management itself, are included.

4.1.2.1 Palm oil fruit price

Price structuring in the case of Colombia, for the palm industry was presented and accepted several years ago, so the benefits of the agricultural process must be shared between farmers and processing plant owners. The scheme is based on the foundation of shared risk, thus the payment on the palm fruit would be in accordance to the amount of oil obtained from each ton of fruit.

The extraction rate can fluctuate significantly from one processing plan to the other, or changes can be noticed among different plantations, depending on the palm variety and harvesting conditions. Nonetheless, in most cases rural farmers receive between 60% and 78% on the extraction rate, and the remaining fraction goes to the processing plant owners.

There are various factors that determine to what extent the percentage can be increased that goes to the farmer, as is explained below:

- Crop age, because yield varies according to the stage of the life cycle.
- Quality of the product, understood as the percentage of the oil contained in the palm fruit

- Degree of competition within a limited zone
- logistic expenditures

The existence of contracts in the palm fruit industry is infrequent, thus in some cases negotiations take place under informal arrangements. However, when contracts do exist, they must specify parameters for:

- the conditions of fruit reception and delivery,
- terms of price settings and distribution,
- regular payment timing conditions,
- and supply exclusivity commitments with some of the available extraction plants (López, 2000).

Within these contracts it also must also be clear that some of valuable agricultural wastes, such as the empty fruit husks belong to the farmer and must be returned by the plant processing owner. If the owner states otherwise, compensation must be offered to the farmer to offset this loss (Hurtado & Hernández-Salazar, 2010). This sort of waste has turned into a quite interesting by-product with a high content of moisture and nutrients. With a simple procedure it can be easily transformed into natural fertilizer. Besides, it seems that this by-product has the potential to be used as feedstock for cellulosic bio-ethanol.

taking into account that the job of the farmer is to produce as many palm fruits as possible, with the highest oil content as possible, while the plant owners should extract as much oil as conditions allow, it seems that the described payment method for palm oil is a good foundation to transfer proper incentives to the different links in the chain. However, there is a factor that needs to be solved to seek standard fares - each processing plant must report the accurate measurement of the oil content of processed fruits, so they do not have to follow regional average productivity indexes that are employed nowadays.

In order to move forward into better and stronger relationships, it is important to formalize links between the stakeholders, or at least between direct parties within the processing palm chain, by adopting models of contract that specify commercial, technical, economic and legal aspects, eliminating uncertainty and gaining trust and stability for each party (López, 2000).

The palm sector relies a Price Stabilization Fund (PSF), which determines the price of crude palm oil, therefore, this price is the most common used as a reference for those sales between farmers and extraction plants (García, 2008).

This fund acts as an income stabilization agent for palm oil and kernel oil producers, throughout compensations and transfers in function of international prices of these products and their substitutes.

The reference domestic price for palm oil is built upon the base of the international price of this product, or its substitutes, plus tariffs and logistic expenditures (such as freight and port charges). The reference price then turns into an import parity price.

The reference international price (when the product is exported overseas) is calculated based on the regular international price, minus freight charges (from Colombia to abroad) and export expenditures. In this way the external reference price is an indicator of the FOB price for national production.

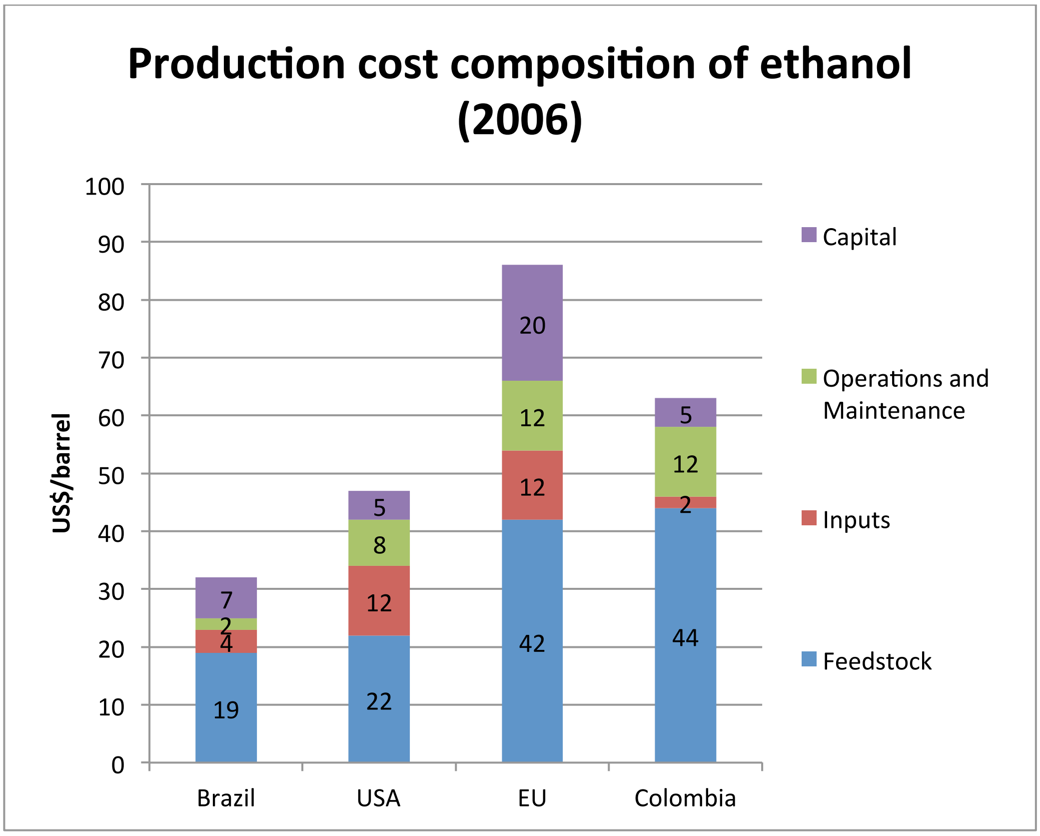
The PSF mandates transfers when the international price is above the reference price, and uses compensations when the international price is below the reference price. Under this procedure the PSF looks to stabilize the average income for agricultural producers, based on their sales to markets that have different prices and profitability.

Given that reference prices are established by the PSF for a 30-days period and the information is provided in advance, it is possible for crude oil producers to inform their providers almost immediately of such adjustments. In this way, Fund's operations have a direct effect over the income that is perceived by the producers, i.e. the payment of the palm fruit.

4.1.3 Sugarcane-based ethanol

The competitiveness of Colombian biofuel prices has not reached international standards, as seen by the ethanol prices - by 2006 a barrel of bio-ethanol using sugarcane produced in Brazil cost US$32. The same amount, using corn in the USA reached US$47 and in the EU using beet US$86 (Tokgoz & Elobeid, 2006; Von Braun & Pachauri, 2006). In Colombia a barrel of ethanol costs US$63. The cost of feedstock only, in the Colombian case (US$44), exceeds the total cost of Brazilian ethanol and nearly matches the American one (Infante & Tobón, 2010). Feedstock takes nearly 70% of the total cost in the Colombian example, and while it is the largest component of the final cost for every country, it is only against the Brazilian case where the gap is not that wide (in percentage terms, although in fact it is the wider in absolute terms) See graph below.

Figure 15 Production cost composition for a barrel of ethanol in different countries



Source: (Infante & Tobón, 2010)

Note: In Brazil and Colombia ethanol production is sugarcane-based, whereas in USA and EU main feedstocks are corn and beet respectively.

The Americans have experienced a more volatile path than the other producers involved in the graph. In 2008 the price of corn soared drastically, and so did the price of ethanol, touching nearly US$85 per barrel.

Situations like that, of course, favor Colombian competitiveness, but at the same time also benefit direct competitors like Brazil, or any other sugarcane-based ethanol producer[45]. A way to improve attractiveness to international markets is to drop prices via capital investment, i.e. machinery acquisition and technological conversion. However, a choice of that nature is highly sensitive and, in point of fact, possesses a negative effect in terms of job creation.

In the Cauca river valley region of Colombia, sugarcane yield is close to 120 tons/ha/year (FAOSTAT, 2011). This amount is cut manually at a rate of 3 tons per daily shift. That would imply that by introducing heavy machinery for cutting purposes they can replace approximately 40

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[45] The data provided in Figure 15 can only be supplied for the year 2006; more recent data do not appear to be available. The tendency for costs of production to come down is widely recognized and discussed for example in van den Wall-Bake et al (2009)

shifts per hectare every year. Furthermore, each cutting machine is able to process nearly 250 tons of cane per day (C.A. Ramírez Triana, 2011).

Using simple math on the case of Cauca valley, we know it has approximately 200 thousand hectares for sugarcane plantation; hence it is possible to produce 24 million tons per annum. If cane were to be entirely cut by modern equipment, in a year it could produce 91,250 tons by one single machine working every day. Under this assumption it would be necessary to employ 264 machines per year to fully harvest these crops. On the other hand, if it is assumed that such machinery is able to replace labor completely, then around 8 million shifts will be lost.

In summary, despite the fact technological conversion could provide a good financial solution for the issue of competitiveness, it represents a high social threat, therefore, it is vital to explore other alternatives in order to reduce cost per unit.

One possible alternative is the introduction of precision agriculture, given that it could enhance productivity and reduce economic losses and environmental impacts through technology (Bongiovanni & Lowenberg-DeBoer, 2004; McBratney, Whelan, Ancev, & Bouma, 2005). Another possibility rests on the fact that transport and storage infrastructure requires update and improvement. There are some regions where the use of pipelines is a better choice than the regular road transport method; however, such decisions require mutual agreement between the government and sugar industry representatives.

4.1.3.1 Price for sugarcane

In the sugar industry, just like in the palm industry, the major players in the chain are the agricultural producers and the manufacturers (or processing plant owners). In order to set a price, what happens in the sugar industry is that farmers deliver or provide sugarcane to the mill or sugar processing plant (also called *ingenio*), and according to the volume and quality of sucrose, the amount of equivalent sugar kilos is calculated. This is used as floor, and over it distribution starts. The farmer receives 50% of revenue from sales by this material. Price is built as a result of a weighted average, which is calculated taking into account all sales by the ingenio in every one of its markets. In this way, indirectly, all suppliers (including the small farmers) participate in each of the markets where the ingenio trade (Infante & Tobón, 2010).

Within contracts, it is defined that all kilograms of sugar that have already been paid for by the suppliers are considered delivered, packed in sacks of 50 kilo each, and ready for being shipped to a traditional market. Any additional expenditure that needs to be paid in order to commercialize the product (different to the ones considered for the traditional market), must be assumed by the sugarcane provider and it is deducted from the total payment. Such expenditures take into account those costs to transform crude sugar to white sugar, or refined sugar, or any other form. In fact, bioethanol is judged to be one of these varieties. Some additional charges include:

- logistics and commercialization costs,
- terrestrial and maritime freights,
- warehousing,
- insurances,
- packaging,
- fixed and variable fees from the international trader,
- and the remaining administrative and financial expenditures.

In addition, the price of the contract can be modified by intervention of the *Fondo de estabilización del precio del Azúcar* -FEPA- (Sugar Price Stabilization Fund), that adjust the processing plants income based on a scheme of retentions and compensations to stabilize incomes to all participants along the sugar processing chain (Prada, 2004).

According to the ongoing legal framework this fund acts as a “Chamber of Compensation”. So, first they set a reference or equilibrium price, then, when the product is sold at a price over the reference one, then the difference is retained by the fund. In a similar way, when sales take place with a price under the reference one, the producer is recompensed with the exact difference between equilibrium and actual price.

In the particular case of the sugar market, FEPA applies its tools to balance the income obtained by each plant individually, based on the average income perceived by the industry as a whole by the sale of sugar and by-products.

By stabilizing prices a constant income is guaranteed for each plant, reducing uncertainty and creating favorable conditions and incentives to supply the domestic market and also to create surplus for exports. This practice is not unfair in any way - - a market like the sugar one, which is highly controlled and subsidized, does not reflect competitive prices in most cases.

The implementation of this scheme is quite similar to the one employed in the sugarcane provision payment contracts explained above. The representative price of each market, which is the adjusting factor for the ingenio’s income, comes from a weighted average of the sales from the entire industry in every one of the markets where their products are traded. This formulation can be expressed as follows:

$PPP = (Y \cdot PRMT) + (Z \cdot PROM)$

Where:-

PPP = *weighted average price*

$PRMT$ = *Representative Price of traditional market*

$PROM$ = *weighted average of representative prices of all other markets*

Z = *share in those markets different to the traditional*

$Y = 100\%-Z$[46]

There are some aspects in the calculation method that need some further explanation.

For export purposes the prices used by the fund are those corresponding to the weighted average of the lowest quality in a given market. The reason why this is the chosen control, is to create an incentive for competition and to foster value creation among the plants owners. The difference between the fund price and the actual sale price affects everyone individually, offering better prices obtained by selling better qualities and by applying processes of added value.

When sales take place within domestic markets, but different to the traditional one, the reference price are the New York price for crude sugar and the London price for white one.

This price intervention mechanism is calculated ex-post, meaning the income for the plant and the industry are assessed once all trade operations have taken place in the sugar markets. Thus FEPA do not intervene inside the markets and do not interfere in the relationships between plants owners and agricultural producers.

The majority of ingenios transfer the effect of the adjustment implemented by the fund to feedstock suppliers; therefore, income for agricultural producer is also affected by FEPA's intervention, and thus proves how important the fund is for all the links along the chain.

4.1.3.2 Sugarcane payment for bioethanol processing

The mechanism described previously received strong criticism from sugarcane producers, when the ethanol processing plants starting to operate during the last quarter of 2005.

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[46] All the Acronyms are intentionally left in Spanish and are translated in the List of Acronyms. PRMT is understood as the price in the domestic market (fixed by the Fund's board and approved by the Ministry of agriculture), thus Y is the share of sales diverted to domestic market, while Z corresponds to the share of sales destined to supply foreing markets. International prices are taken from trading processes. Both domestic and foreing prices are presented in Colombian Pesos (COP) per quintal (and hundredweight, which is slighty close to 50kg). A good example of how the information is managed can be found in Prada Owen. (Prada Owen, 2004)

The cause of this clash when plant owners considered that existing contracts already cover the way to handle sugarcane for bioethanol processing, given that this new product belongs to a surplus market and it substitutes exports within crude sugar market. For this reason, there is neither the need to adopt a new way, nor any additional special formula to calculate the price of sugarcane destined exclusively for ethanol production.

Based on this premise, the final price for sugarcane is determined by the technical fact that from one ton it is possible to obtain up to 75 liters of alcohol (67.7 directly from sugar and 7.3 from molasses). According to the contract, molasses belongs to plant owners, so a farmers share is 50% of that biofuel obtained from sugar directly, i.e. 34 liters per each delivered ton of sugarcane. Thus, the payment takes effect using that calculation as a base, but discounting all the commercialization expenditures that were mentioned before. These costs have been measured and they are equivalent to 8 liters of ethanol, therefore after alcohol fuel is sold ingenios offer only 26 liters/ton to the agricultural producer.

Notwithstanding, the sugarcane producers organization PROCAÑA (Asociación de productores y proveedores de caña de azúcar), consider that this product is destined to cover a national supply of energy, hence it cannot be treated as a mere substitute of the crude sugar exports, despite the fact that it's a derivative of this item. Procañana argues that most of the value content is embedded in the feedstock itself, and they as providers are receiving as payment only 26 liters/ton out of 75, which is barely a third of the whole value. Under this scheme, the entire cost burden is on the feedstock producers' shoulders.

Based on that, their suggestion is to guarantee distribution process in equal parts, i.e. maintaining a 50% rule, but without applying discounts for processing and commercialization activities. By doing this, farmers would increase their income to 44.2%, given that instead of receiving 26 liters/ton they would receive 37.5 liters per ton of sugarcane delivered to the plant under the new scheme.

The lack of agreement on these grounds leads to instability in the relationships between feedstock producers and the processing plant owners, resulting in arguments that in some cases have ended with renegotiation of contracts, or worse, their cancellation. These differences in the criteria of contractual agreement between parties are crucial, especially to review how effective the conflict solution mechanisms are, given that both interpretations share the point that sugarcane productivity must be split into two branches of the productive chain.

Leaving aside the contractual disputes, there are other reasons why this conflict emerges in the particular case of bioethanol production. Alcohol fuel manufacture started in a period where the international price of sugar was particularly high; hence it was clearly unfavorable to compare revenues from sugarcane-based biofuel sales versus the ones that come from pure sugar transactions.

During 2006, payment per ton of sugarcane to those suppliers of bioethanol plants was inferior to those who offer their feedstock for sugar processing, due to a change in relative prices of both products. So, some farmers had the perception that according to the ongoing scheme it was more profitable to use feedstock to produce sugar rather than be manufactured into alcohol fuel. However, the principle problem is not how proportions are determined, but rather, that prices of sugar and ethanol do not always follow the same path, leading to different revenues.

An additional element of divergence is the way discounts are assessed by manufacturers, and similarly, how costs are distributed in the ethanol production process. In order to account for expenditures, ingenios do not apply a standard methodology; instead they come up with formulas and practices of a diverse nature. In some cases, not only are mere operation included, but some financial and reinvestment cost (such as depreciation) are added to the deductions against agricultural producers. These sorts of practices distort the initial idea that is to help the main capital investor (i.e. plant processing owner) to deal with the financial burden of the business.

Both feedstock suppliers and manufacturers agree that the bioethanol market as a clear opportunity to heighten their income sources, and to consolidate a developing industry, with a more diversify market. They also agree that preserving good relationships with each other and strengthening links along the productive chain is crucial to provide a good future for the sugar industry, thus offering improved profits for all stakeholders.

4.2 Conclusions

The Biofuel industry in Colombia has not yet achieved international leadership in terms of cost[47]. Based on the information provided by Infante and Tobon, production cost are around 18.2 - 21.5 USD/GJ[48], while countries like Brazil, Australia and Thailand have reached 14, 21 and 16 (either with sugarcane pressed or molasses) but the initial target is the domestic market, so it can afford the short term poor price management performance, and by the time the industry gains maturity it will be ready for a competitive international market. Feedstock for both alcohol fuel and biodiesel is the most important component in terms of cost structure.

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[47] The SRREN IPCC report shows in its table 2.7 an estimation of production costs that are available for comparison with the Colombian case (Chum et al., 2011).

[48] For calculations it was taken in cosideration equivalence of 1 litre of ethanol has between 18.4 and 21.2 MJ/l, i.e. between 2.92 and 3.37 GJ/b.

Benefits distribution relies on regulated schemes for ethanol, and unregulated schemes for palm oil. In both cases, Price Stabilization funds act as a reference and somehow show the trend for progress in the near future. As the transformation chain is long, conflicts between feedstock producers and processors are emerging and they need to be addressed in future policy guidelines.

5 BIOFUEL VALUE CHAINS AND CONTRACTUAL RELATIONSHIPS

The following section will present a complete description of how value chains work within the biofuel industry and how legal and informal arrangements are establish to ease these chains' functioning. This description is particularly useful to understand how benefits and responsibilities are distributed from a socioeconomic perspective.

The concept of a chain makes reference to a holistic vision of a productive process, which allows proper observation of different links, thus it is possible to see the representation of new forms of new scenarios and bonds which are developed in an economic system, that imply the coexistence of a set of parties and activities that are inextricably interconnected to obtain a product in a given space (Kaplinsky & Morris, 2001). This concept and analytical approach is a fine tool to explain the economic reality of a particular industry. In Colombia the 'Chain Approach' has been adopted as a tool to design and implement public policies for the agricultural and agribusiness sectors (Gilbert, 2008).

Agribusiness biofuel chains, which have their final link in energy provision in the form of a liquid carrier, are highly privileged because of the interactions that they represent. On the one hand, they utilize feedstock and primary crude materials from the agricultural sector, but they also offer and demand products, services, and money flow up and downstream. Government, as a dynamic agent, must intervene in sundry aspects along the chains, with the purpose of regulating, stimulating, monitoring and controlling some of these parties and their corresponding actions.

5.1 Feedstock production and commercialization

5.1.2 Land Use in Colombia and its relationship with bioenergy

The unit of agricultural studies of the DNP (Departamento Nacional de Planeación – National planning department) has made projections on the utilized land area for agriculture and livestock farming for 2010 to 2019, including in these projections the latest progresses in efficiency in both fields. The table below is a more complete version than the one presented in Chapter 3 shows these results, contrasted with some internal data provided by FEDEPALMA, and with forecasted results on sugarcane crop performance. It also uses some information from the Ministry of Agriculture on the plantations for commercial forestry purposes, forestry for preservation, and some data on jungles and natural reserves. Finally, the *Instituto Geográfico*

Agustin Codazzi -IGAC- (Agustin Codazzi Geographic Institute) specified some indiscriminate data on rivers, mountains and cities from the survey that took place in 2004.

Table 6 Current and forecasted land use in Colombia

Current and forecasted land use in Colombia (Million ha)				
Concept	**2007**	**2010***	**2019***	**2019 * (including biofuels)**
Agricultural land without energy feedstocks	4.58	4.58	4.54	4.54
Palm oil for biodiesel	0.00	0.16	0.80	**2.12**
Sugarcane for ethanol	0.04	0.08	0.15	**1.00**
Agricultural land (subtotal)	**4.62**	**4.82**	**5.49**	**7.66**
Livestock and fallow land	38.87	33.90	27.50	24.65
Agricultural land (Total including livestock)	**43.49**	**38.71**	**33.00**	**32.32**
Commercial forestry	0.26	0.35	1.36	1.36
Protected forestry land	7.21	7.21	7.21	7.21
Forest	38.90	38.90	40.60	40.60
National parks and reserves	9.00	9.00	9.00	9.00
Forest and reserves (total)	**55.38**	**55.47**	**58.17**	**58.17**
Cities, rivers and mountains	15.31	19.99	23.00	23.68
Total	**114.17**	**114.17**	**114.17**	**114.17**

*** These calculations are based on the projections of the PNBs**

Source: (Infante & Tobón, 2010{Fernández Acosta, 2009 #499)}

Evolution of the agricultural sector is shown in the previous table. In particular, it can be seen that the last 2 columns represent future scenarios. In the very last columns it is shown an aggressive plan put forward by the Ministry of Agriculture, where by in 2020 the land for ethanol production will increase by up to 1 million hectares and the area destined for biodiesel feedstock crops will reach 2 million hectares. That will be noted as scenario 1. The other projections (plain 2019) correspond to a scenario where it is assumed to follow the ongoing production trend. That will be noted as scenario 2.

Following the initial scenario, i.e. under an active biofuels production scenario it is thought that the destined territory for biofuel plantations would grow from 0.24 hectares to 3.12 in a time span of 9 years. Such a projection would imply agricultural arrays 13 times bigger than present, to cope with biofuels demand, in less than a decade. In other words, this change would require an annual growth rate of approximately 33.25%. In the second scenario the growth of this area is more discrete, starting at 0.24 hectares in 2010 and ending up with 0.95, which corresponds to slightly less than 4 times the production of the beginning of the decade. That is an average annual growth rate of 16.51%.

In the 2 scenarios the projections are more favorable to biodiesel production rather than ethanol production. In the first situation, by 2019, the planned area destined for palm plantation is 13.25 times the one presented in 2010. This can be seen as an annual growth of nearly 33%. In the case of ethanol production, the plantations destined for sugarcane need to develop at a similar pace (only slightly less). In the second scenario this dissimilarity is more obvious: while palm area develops a speed of 19.58% per annum, sugarcane would require a growth rate of 7.23%.

There is no substantial negative effect on the agricultural frontier in terms of direct food and feed provision in either scenario. Despite this great progress for biofuel feedstock plantation areas, the subtotal agricultural area does not seem seriously affected. The agricultural land destined for other purposes different to bioenergy crops will decrease 0.04 million hectares in 9 years, under either situation. However, the agricultural land destined for bioenergy and agricultural crops together will grow at an average pace of 5.28% in the pressure scenario, whereas just at 1.45% in the "no-rush" plan.

Of course land destined for bioenergy projects must be taken at the expense of other alternatives. According to these forecasts, the burden of cost will be on the fallow and livestock farming land, which falls by 6.4 million hectares between 2010 and 2019 in the less active scenario, and 9.25 in the other one. It is important to highlight that these reductions are not that significant if it is assumed that it was caused entirely by biofuels production. Based on those numbers presented on the table, only 11.09% and 31.13% of such reductions could be explained by bioenergy projects implementation, for the non-active and active scenario correspondingly. It is important to note that as in most cases, projections of expansion can be overestimated, as was illustrated with the American, Peruvian, and European cases in chapter 2.

Despite the allegedly minor effect of these lands conversion, it must be taken into account that cattle displacement could be costly financially and environmentally. The other option is using fallow land, which also has some implications. If those lands are deteriorated marginal lands, then bioenergy projects could be a very attractive choice in terms of profit, in the sense that they could invigorate depressed rural areas. If other feedstock varieties are contemplated (even those such as Jatropha) and the implementation needed to create the new agricultural array involves land clearance, particularly using burning methods, it could result in appalling consequences, by releasing all the carbon embedded underground and new carbon by the combustion effect (Achten et al., 2007; Romijn, 2011).

Additionally, it must be advised that bioenergy crops should be added to food crops, instead of substituting them, given that so far the feedstock used to produce biomass-based energy do not clash with food provision, but it is taken from that destined for export. Under any circumstance it is extremely important to keep monitoring land use, because the best agricultural lands should not be used for harvesting palm or sugar, for energy purposes.

There are some constrains in term of land quality in Colombia. Despite the recognition that there is enough land available for bioenergy projects, some areas are barely usable within government projections. For instance, in the eastern region of Colombia, there is a zone called the "wavy reef" in Orinoquia, a Colombian department, which has an land area greater than 6.4 million hectares that is hardly productive whether in agricultural projects or in cattle farming initiatives (Sánchez & Cochrane, 1985).

So, a real barrier to be tackled by Colombian bioenergy initiatives, under the *Plan Nacional para el desarrollo sostenible de los biocombustibles* –PNBs- (National plan for sustainable Biofuels Development) is to obtain enough land to cope with the ambitious demand. There are lands available in the eastern region (with some limitations as referred previously) and others in the Caribbean zone with good prospects to plant palm in particular. However, it is unwise to forecast large agricultural arrays, because:

- current land owners are hesitant to participate in biofuels initiatives ,
- diversity in soil qualities,
- varieties of climates and heterogeneity in quality.

Despite these possible setbacks, there are documented successful experiences within these areas with biodiesel based enterprises. There are some cases where natural conditions do not permit to classify the used lands as suitable for cropping either.

The experience with the sugarcane programs, leaving out those implemented in the Cauca Valley region, is quite limited in terms of documentation.

5.1.3 Production of palm oil

In Colombia the production of palm oil is relatively new. The first attempts to introduce palm oil took place during the early 1930's, but the plant was used for decorative purposes. It was not until 1945 when commercial plantations were setup in Buenaventura (on the Pacific coast) and Aracataca, close to the Caribbean coast. Central government asked the Cotton Promotion Fund to encourage these palm arrays for economic purposes, in the first half the century, and since then palm crops have grown significantly.

Given that palm trees were well suited to Colombian climate conditions; their expansion has been rapid and wide throughout national territory, with a presence in at least 11 out of 32 departments (geographically equivalent to states in other countries). About 34% of the planted area is located in the eastern region of Colombia (Casanare, Cundinamarca, Meta and Caqueta), 31% is within the Northern region on the Atlantic coast (Atlantico, Magdalena, North Cesar), 24% in the central region (Santander, North Santander and South Cesar) and the remaining fraction in the south western region (Nariño) (Infante & Tobón, 2010).

The palm industry has brought noticeable economic and social impact within the mentioned regions, and it has been one of the most dynamic agricultural sectors since the 1980's. Nowadays, it creates more than 16 thousand direct jobs and over 32 thousand indirect jobs (FEDEBIOCOMBUSTIBLES, 2010b).

Crop expansion of palm trees has been remarkable during the last 3 decades. In 1980 the planted area accounted for 31 thousand hectares, while in 2008 plantations covered around 335 thousand hectares. This would imply that the area planted has increased by practically eleven-folded in a period of 18 years, which is an average growth rate of 8.87%. It is important to keep in mind that these areas provide oil for both cooking and biodiesel use.

During the 1980's, planted areas grew on average 7690 ha/year, whereas during the 1990's this number dropped to 4790 ha/year. However, since 2001, due to vigorous promotion on the benefits of palm agriculture the statistics shown production reached an average of 24,518 ha/year. This represents an introduction of nearly 180 thousand additional hectares, so 54% of the current area was planted during this period.

Two zones with the highest participation in this outstanding advance have been the ones located in the eastern region (38%) and northern region (30.4%) of Colombia. The contribution of the central zone has been important as well (23.6%), while the south-western region has shown some progress but not as significant as the other regions (9%). Thus, trend suggests a concentration of diesel bioenergy projects in the northern and eastern regions, followed by the central region.

Despite the fact that most land for new plantations has been taken from cattle farming, it is also true that to a minor extent, some land previously dedicated to rice crops have turned to bioenergy production, particularly in those northern and eastern regions in Colombia. Yet, the total area utilized for rice growth has not decrease. On the contrary, it has increased, between 2002 and 2011 it went from 408 to 430 thousand hectares (FAOSTAT, 2011).

The accelerated growth of palm plantations is a result of several factors:

- Rampant international prices for vegetable oil, in particular palm oil, which started in 2001 and maintained its level until 2008. This fact had a positive impact on the profitability of the biodiesel industry.

- Upbeat policies, news, and expectations around the sector created an attractive environment for investing.
- Being part of the eligible crops within the ICR[49] destinations, boosted initiatives to start new plantations. In addition, flexible credit systems for the sector eased the access to required lands, resources and equipment.
- The decision taken through law 818 of 2003 to create exemptions to those slow-maturing crops covers palm oil, and with the benefits lasting 10 years from the beginning of production, the farmer (or investor) has enough time to recover financially. However, it is important to bear in mind that this incentive can be applied only to those plantations that have not benefited from any other public resources.
- The improvement of safety perception in rural areas has raised interest in new investors. In addition, several firms have allowed access to this market to third parties to act as feedstock suppliers, contributing to an improved social and economic environment for the surrounding population.
- The implementation of incentives to create productive alliances between small-scale, medium-scale, and large-scale feedstock producers, and processing plant owners, predominantly those flexible and long-run credits with publicly subsidized interest rates.
- The possibility to have new markets for palm oil, apart from the already exploited (vegetable oil). So biodiesel and its by-products are an attractive option for agricultural developments.

Because palm oil trees are considered a variety of slow-maturing plant, planted area can be classified into two different categories: the one that is in a developing stage, and the one that is production already. There is an initial period of about 3 years where the palm is unproductive. Afterwards, productivity will gradually increase until its potential is fully developed for approximately 30 years.

Despite the fact that palm plantations have extended rapidly throughout Colombia, there is no corresponding effect in terms of productivity, particularly during the last 15 years. If truth be told, it was observed that between 1994 and 1999 the average yield of crude palm oil was 3.6 tons/ha. Right after 2000, productivity rates grew to 4 tons/ha, and was maintained until a period between 2006 and 2008 where the rate dropped to 3.56 tons/ha, which is quite similar to the level experienced during the last part of the 1990's.

This productivity level is comparable to that achieved in other countries such as Costa Rica and Indonesia, that produce nearly 3.7 tons/ha. But, competitiveness in terms of yield per area

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[49] Incentivo de capitalización rural – Rural funding incentives

in the palm sector are led by Malaysia (4.2 tons/ha) and Papua New Guinea (4 tons/ha) (Mielke, 2008). According to FEDEPALMA projections, Colombia is ready to reach 5.5 tons/ha by the year 2020 (Fedepalma, 2000).

There is a very wide range of outputs per hectare in Colombia. The predominant factors are:

- to what extent farmers are capable of introducing appropriate technologies
- and to what extent they are willing to put into practice advanced agricultural methods on the field.

So, there are reports of some plantations with 2.5 tons/ha of crude palm oil, while at the same time, there are others with 6.3 tons/ha. Such divergence in the outputs has been explained by the fact that some low-yield varieties were introduced at the beginning of the program as an experiment. Additionally, the majority of the farmers could not use good quality seeds , due to a low availability, taking into consideration the necessity to adapt to the particular conditions of different productive zones (Mosquera Montoya, Bernal Hernández, & Silva Carreño, 2009).

Furthermore, those programs directed to enhance seeds genetically are under the control of CENIPALMA, who have only recently been active, and have been facing several barriers. Among them, is the low availability of material with the required agro-industrial features, but also underuse of available genetically modified material already developed. These progresses in the genetic front would help not only to widen those varieties that are commercially accessible in Colombia, but also to gain resistance to diseases such as *pudrición de cogollo* (bulb decay) and *marchites letal* (lethal withering) (Cenipalma, 2000; Fedepalma & MAVDT, 2011).

The only zone that has been capable of continuously improving its productivity is the one located in the central region. By 2010, this region had achieved its highest average yield (4.6 tons/ha), and unlike other regions, it has not been affected by the decreasing trend of the recent years found in other regions. Meanwhile, in those plantations located in Nariño the productivity has reported the lowest average yield, near to 2.9 ton/ha, whereas in Eastern and Northern regions registered yields have exhibit 3.3 and 3.5 tons/ha respectively (Infante & Tobón, 2010). These reductions have been caused mostly by the diseases mentioned early, which has had substantial impact on the south-eastern region. Another factor that contributes to such yield diminishment has been the notorious change in climate behavior, in particular the presence of lengthy rainy season leads to biomass decomposition.

These observations are not isolated whatsoever: the low yield phenomenon in the processing stage has accompanied the low yields in the agricultural stage, i.e. fruit output per harvested hectare. The average as reported between 2000 and 2005, was 19.3 tons/ha, but between 2006 and 2008 this yield dropped to 18 tons/ha.

Thus, the current state of affairs indicates that the introduction of high oil content fruit has not had the expected effect on commercial output. As a matter of fact, the ratio of the amount of vegetable oil per ton of fruit has remained steady for the studied period. This indicator is vital to analyze the performance of the industry as a whole, because it includes both the agricultural and the processing performance.

Based on the aforementioned, it can be concluded that in the last 17 years, there have been no substantial advances in the processing stage, in charge of oil extraction (Infante & Tobón, 2010). By incrementing efficiency in extraction plants it is possible to maintain oil yields, despite low fruit outputs. This data represents a huge opportunity for the Colombian biodiesel industry, given that most of the extraction plants are not concentrated in a kind of cluster, but instead they are spread out, and they usually work under a small-scale scheme and in some cases their production capacity has been underused.

5.1.3.1 Agricultural structure of palm oil production

According to data published by the RNP *Registro Nacional Palmero* (National Records for the Palm oil industry) in 2008 it was reported that 3245 palm oil productive units existed (i.e. agricultural land arrays for palm trees plantations, regardless of the ownership of a processing plant). The majority of these units have a relatively small area, meaning that more than 80% of them have less than 20 hectares of land.

One possible interpretation of such a phenomenon is that the participation of small farmers within the palm industry is significant, however, data proved otherwise. By 2008 land distribution among the units was extremely uneven, up to 76.7% of land concentration was in less than 10% of the productive units, which have more than 200 hectares. As a matter of fact, those large-scale plantations that use more than 1.000 hectares represent barely more than 1% of the units and yet, they have slightly less than 40% of the whole area (225,474 hectares).

In general terms, it has been established that the average plot size for palm plantations in Colombia is 70 hectares, which is quite small if it is compared with the world top producer, Malaysia, which has an average plot size of 1800 hectares (Sumathi, Chai, & Mohamed, 2008). Recent plantations show a trend of increasing in size for biodiesel purposes, reaching levels of 5000 hectares.

High concentration arrays are resulting as a consequence of the oil extraction industry, which has established an optimal standard of efficiency that is reached when the surrounding plantations covers between 7,000 and 10,000 hectares. Such technical assessment leads to two potential strategies:

- the first one would imply building a policy framework that eases the purchase of enough land for these large agricultural arrays,
- the second would operate by encouraging and engaging small landowners around processing plant to work together to create large parcels and act as a common production unit.

5.1.3.2 Contractual arrangements in palm oil production

The relationships established between oil extraction plants and feedstock agricultural suppliers are quite informal. In general, they are characterized by the lack of formal tools and documents that regulate and provide stability to both parties. Such situations, in principle, make it difficult to record and analyze these verbal and goodwill arrangements.

There are three possible ways to organize the fruit supply system to oil extraction plants:

1. by acquiring crops to be processed by the plant owner under a single proprietorship of the whole chain,
2. by creating an association of feedstock supplier-manufacturer (either way resulting in productive units with extraction plant),
3. an arrangement where independent farmers can have access to extraction plant facilities to process palm fruit. Under this procedure the agricultural producer owns the extracted oil, and there is no obligation to sell it to the plant owner. However, plant owners can act as vegetable oil intermediaries and they can eventually purchase the oil produced by the farmers.

In 2008, only 44 out of 3245 production units were associated to extraction plants. The land occupied by these units accounted for 85,183 hectares. The remaining units hire the plant services to process their fruits, obtained in a surface area of 140,291 hectares.

5.1.4 Sugarcane production

The Cauca Valley has optimal conditions for growing sugarcane. It is located at an altitude of nearly 1000 meters, is has an average temperature of 25°C, relative humidity of 76% and an annual precipitation of 1000 mm. Cauca Valley boasts great fertility in its soil and good physical conditions. This region is one of the 4 zones in the world where it is possible to grow sugarcane all year round.

Currently there are 495,000 hectares covered with sugarcane crops. These plots can be categorized in 2 different types. The first one is used for *panela* production and it has a dedicated area of nearly 253,000 hectares. Panela is an unrefined crude sugar with a high content of sucrose and fructose, which is sold in a brick shape, and is obtained from the evaporation of sugarcane juice. The second category planted with sugarcane (approximately 41%) is utilized for refined sugar production (H Martinez, Espinal, & Ortiz, 2005).

These two varieties of sugarcane are different in their purpose but also in location, yield and sugar content. In fact, the Cauca Valley region has been traditionally used for sugar production since the 16th century (Asocaña, 2009), whereas the predominant region for panela production has been in the central region of Colombia, in the departments of Santander and Boyacá (along the basin of *Río Suárez*) (H Martinez et al., 2005).

Sugarcane for panela production is one of the main segments in Colombian agriculture, and it is mostly developed by small-scale farmers. Because establishment of these initiatives is quite informal, it is difficult to collect reliable statistics for the sector, however, it has been estimated that this form of agriculture has nearly 70 thousand productive units. The way to process biomass (obtain its juice) in this case is by using old-technology, i.e. animal powered mills in most cases, and afterwards juices are boiled, clarified, beaten, and left until cooled. The whole processing station from juice extraction to panela packing is called *trapiche.* According to an FAO report, it is believed that by 2008 there were roughly speaking 15 thousand trapiches. Therefore, the impact of this activity on rural jobs is very significant, based on rural statistics collected by the Ministry of Agriculture: by 2005 the panela sector employed more than 350 thousand farmers, putting the sector as the second largest employment generator in the countryside, right after the coffee industry (H Martinez et al., 2005).

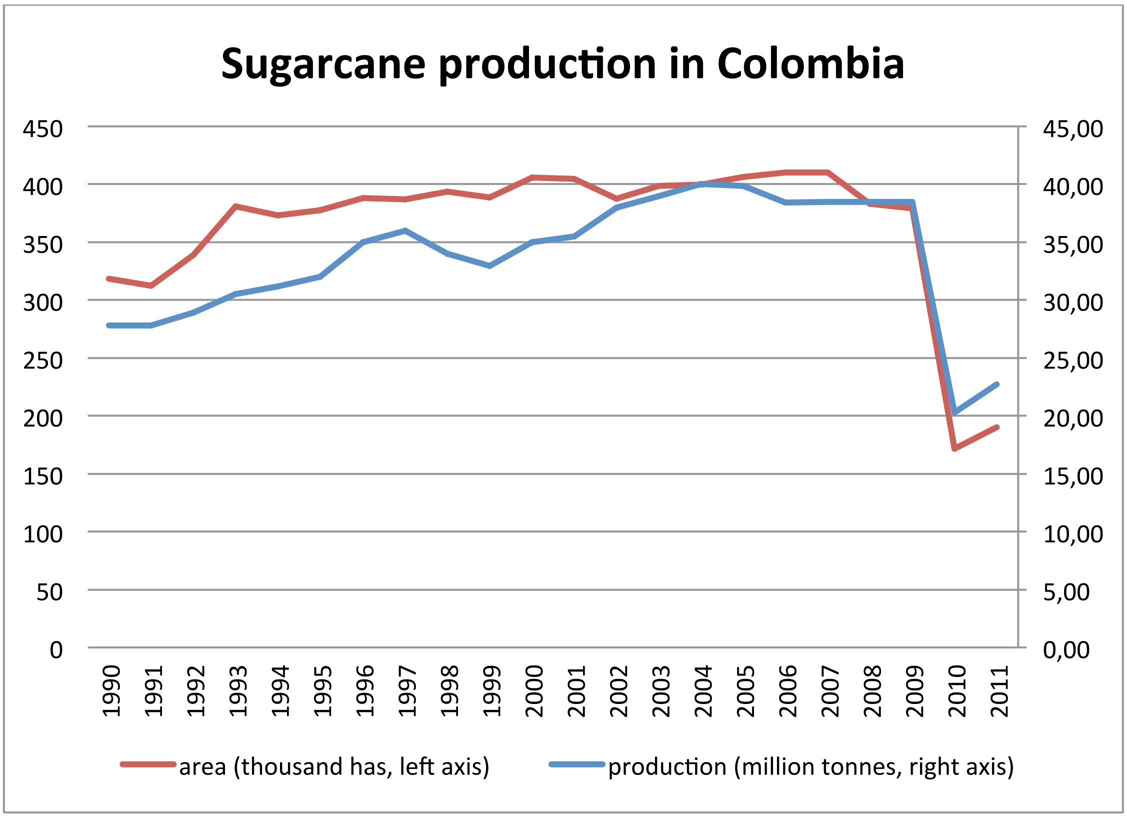
Sugarcane crop for panela purposes has been widespread in Colombia because it has high adaptability to different ecosystems and environments. For example, it is able to be planted on steep mountains, unlike other products. So, this crop is harvested all year round in nearly every department within Colombia, however, at least 70% of is production is concentrated in Antioquia, Cundinamarca, Nariño, Santander and Boyacá.

One of the policies of the central government has been to engage the panela production sector into bioethanol manufacture. Several efforts have been implemented to boost this possible alliance. Research programs and technology transfer dynamics have been put into motion to enhance productivity and to provide farmers with managerial and entrepreneurship training. In fact, some of the actions have been addressed to apply a bioethanol production model specifically with panela-sugarcane, to the extent of building pilot plants based on such feedstock. The results achieved so far have not been as expected. In Barbosa, Santander, a pilot plant was established after an investment of US$3million and with an installed capacity of 5000 liters/day, and with the purpose of using 200 hectares of land. Nevertheless, this experimental plant had to be closed because vinasses (waste product) could not be treated properly and caused land and water pollution. It is being discussed what to do with the plant, and one of the contemplated alternatives is to allow the Industrial University of Santander to carry out some experiments ("Plantas de etanol...", 2010). If some of the main setbacks can be explored and overcome, the plant can be used for demonstration and then start a dissemination process of these technologies around Santander region. There is a similar plant under construction in Frontino, Antioquia, however, in this case it was planned from the beginning to be managed by the University of Antioquia ("Plantas de etanol...", 2010).

According to the Asocaña database, sugarcane production has grown steadily. Since 1980 sugarcane production has increased from 11.5 million metric tons to nearly 22.2 million. Sugarcane growth has accelerated particularly in the period between 1986 and 2004, with a small exception during 2001, which exhibited a production slump (ASOCAÑA, 2012).

During 2006, the level remained stable but the subsequent two years experienced a serious downturn as a consequence of an increase in rain levels. This situation also coincides with a conflict with the plantation workers, in mid-2008.

Figure 16 Sugarcane production in Colombia



Compiled by the author. Data source FAO 2013

In 2010, due to “La Niña”, plantations were severely affected by unfavorable climatic conditions, affecting expected yields, not only in Colombia but in the rest of South America as well (Asocaña, 2011).

Growth of sugarcane production comes as a result of a continuous increase in the planted area, along with more efficient land management methods. On one hand, the cultivated surface maintained a steady increase between 1980 and 2008, undergoing a change from 133 thousand cultivated hectares to 206 thousand.

There is of course a gap between the area that has actually been planted and the one that is actually harvested. This difference is due to different factors, such as plagues, diseased crop, climate alterations, among others.

Based on the trend of cultivated area, it is possible to separate the agricultural behavior of sugarcane in 3 sections or stages:

1. During the first stage, from 1980 to 1989, there is no a substantial increase of the sown surface, maintaining an average of 136 thousand hectares. At the beginning of this stage, the harvested area was nearly 43 thousand hectares below the cultivated level,

which implies that two thirds of the cultivated area was productive. At the end of the stage, this gap closed and the difference between cultivated and harvested areas was only of 24 thousand hectares, reaching a profit on cultivated area of 83.2%.

2. Between 1989 and 2002 the second stage was developed, which registered the highest growth rate within the three studied decades. In fact, cultivated area was enlarged by 41% during this period. The main reason for this is that sugarcane progressively occupied more of those terrains that were initially used for other purposes, such as soybean, sorghum and cotton, due to the low profitability of these crops, exacerbated by the political decision called “apertura económica” in 1991, retracting the mechanism to protect these lower value crops which was accentuated for the political decision of the economic opening promoted by the Constitution of 1991. Along with the reduction of possibilities for some of these commodities, some opportunities appeared for other products; and in this case, the sugar industry was favored by the liberalization policy, because it expended in to new markets, different to those already established (CAN and American quota). This stage was characterized by high fluctuation in harvested output, and it was possible to achieve productivity close to 100% of the planted area on two occasions: in 1996 and 2000, near to 180 thousand hectares in both cases.
3. Before the end of the second section stage, there was a subtle reduction in the cultivated area (in 1999) and the effect of this setback was felt during a part of the last stage, which goes from 2003 onwards. This situation was evident until 2006, and afterwards it recovered its pace only slightly. This stagnation might have been due to a shortage of available land in the Cauca Valley. Nowadays, most of the growing trend is explained by using marginal lands.

It is worth mentioning that the introduction of bioethanol plants in 2005 has not had a substantial impact on the planted and harvested areas. Basically, alcohol fuel has been produced based on the already cultivated surface and, as has been mentioned previously, the required feedstock comes from sugarcane that would otherwise be used for export.

The productivity of this crop has fluctuated around 120 tons of sugarcane per hectare. There have been some moments, like in 1995 and 2001, where this productivity fell, reducing the average to 105 tons/ha. It is presumed that such low performance can be explained by poor agricultural management. Notwithstanding this, since 2002 the yield has remained relatively stable.

With this in mind, productivity (in terms of the yield of sugarcane per hectare) has not exhibited substantial progresses. Crop productivity performance (in terms of the yield of sugar per hectare) leapt from 8 tons/ha to 12.4 tons/ha from 1980 to 1992. Since 2002 this level has kept above 13 tons/ha, that means an increase in sugar productivity near to 60%.

Another indicator of crop performance is the amount of sugar that is obtained by every ton of sugarcane used. This value would give an insight of the commercial yield and the industrial efficiency of the crop. In 1980 this ratio was 9.4% and it rose to 11.9% in 2006.

An analysis of this situation leads to the conclusion that farmers have achieved a better output of sugar per hectare, which indicates an improvement in soil productivity. This has been a direct result of implementing better agricultural practices, which includes the introduction of varieties with higher sucrose content and short-maturing kinds.

The addition of new techniques and technologies to the sugar processing industry from its agricultural stage to its manufacturing comes as a result of a very solid system of technology transfer, led by CENICAÑA, and by ingenios themselves, in order to disseminate and put into practice those agricultural advancements that increase the amount of cane per area and shorten the maturing cycle of the crop. Some other factors than have positively affected industry performance as a whole, are:

- the rise in the educational level of the nearby population,
- agro-entrepreneurial training,
- innovative capacity and economic solvency of the farmers, which is predominant in the Cauca Valley region.

5.1.4.1 Agricultural structure of the sugarcane production

In the sugarcane crop industry there are at least 2200 productive units, which are mostly represented by medium-scale farmers, with an average size of 92 hectares per unit. It has been calculated that 40% of them have a size between 50 and 200 hectares, and occupy 44% of the entire area used for this purpose in the region.

Thus, close to 50% of these units have an area less than 50 hectares, and they employ 14% of the whole surface used for sugarcane cropping. This suggests two phenomena about the sugar industry: the first one is that land concentration still remains high, and the second one that small-scale agricultural entrepreneurs have an important participation in the market. The latter corroborates that there has been a continuous division of properties and large agricultural arrays that were predominant in the times of the colonial Spanish influence. Today those parcels that exceed 500 hectares for sugarcane cultivation represent only 12.5% of the agricultural units.

Those lands used for sugarcane crops in the Cauca Valley region benefit from a great irrigation infrastructure, given that 48% of the sown surface has access to superficial water sources, and 16% use underground water springs. Only a small fraction of land does not receive irrigation (1.2%). The remaining fraction uses a combination of both shallow and underground water. In the Cauca Valley region road infrastructure and supply utilities are appropriate to cover the industry needs.

5.1.4.2 Contractual procedures in sugarcane production

Unlike the case of the palm oil industry, the supply system of the sugarcane provision to processing plants, either for sugar manufacturing or alcohol fuel production, is well organized and its structure has foundations in several agreements between farmers and processing plant owners. These agreements have been designed and evolved during a number of years and they take into account technical, economic, legal, commercial and cultural elements, providing a flexible framework adaptable to the conditions described or required for each agreement mode.

It is crucial to understand land proprietorship and distribution around those grounds linked with the productive process. Ingenios (or sugarcane processing plants) own 24% of the total cultivated area. So, the remaining land is owned by third parties under different management agreements. In fact, slightly less than 103 thousand hectares out of 152 thousand hectares are directly managed by independent owners, representing 51% of the whole area for cultivation. Ingenios handle the rest of it through diverse kinds of associations (described below).

In terms of Colombian agriculture, the sugarcane industry presents a truly peculiar characteristic - there are just a few cases where there is no formal contract between farmers and manufacturers (these examples account for less than 4% of the total cultivated area).

Sugarcane price is inextricably linked to sugar price; hence, the price of feedstock does not follow supply and demand dynamics. Usually payment to farmers is through a contract where there is a shared risk, which is a common system utilized around the world (Buchanan, 1975; Keerthipala & Thomson, 1999; Moor & Wynne, 2001).

The type of contracts mentioned above, have been categorized in some official documents (IDB, MME, MADR, MAVDT, & DNP, 2012; Infante & Tobón, 2010; Londoño, 2012) and are described as follows:

Contract of sale:

This sort of contract is applied to those farmers that undertake all these tasks related with production: land preparation, required infrastructure provision, payment related with the agricultural process, application of agricultural practices recommended by CENICAÑA, etc. In this case these farmers, acting as independent suppliers, have an entirely commercial relationship with the processing plants.

In such contracts, sugarcane payment is done under a fixed predetermined amount of 58kg per ton of sugar. This number has been calculated based on assessments of sucrose content (which is 11.6% in Cauca Valley conditions). Thus, 50% of sugar yield value belongs to the farmer, and the other half is paid to the ingenio as reimbursement for its processing services.

If it is taken into account that farmers and manufacturers income hinge on the sugar market, then sucrose content and not sugarcane weight indicates the real remuneration factor. Nowadays, near to 48% of cultivated area operate under this “contract of sale” mode and include clauses that make it explicit that the payment would be based on the content of sucrose rather than the sugarcane weight. Thus, any parameter that directly affects this indicator, such as sugarcane handling, storage, and transport, should be considered in the contractual conditions.

The duration of these sorts of contracts are directly related to the productive cycle. They are generally negotiated to finish simultaneously with the life span of the sugarcane stock, which is close to 8 years. In most cases some sale exclusivity clauses around the feedstock are established.

Contracts in participation accounts

Under this mode farmers give their land to processing plant owners and the latter assumes full responsibility of the sugarcane life cycle from the planting stage until the harvest. Unlike what happens in regular sale contracts, landowners do not take part in the production process whatsoever. In this mode ingenios carry out all duties required for sugarcane production, likewise they bear the burden of all associated costs. Land proprietors receive a remuneration based on the content of sucrose, i.e. the number of kilograms of sugar that can be extracted from a ton of feedstock. A reference parameter that is commonly used is 25kg of sugar per one ton of sugarcane.

Just like the contract of sale, in contracts of participation accounts, sugarcane payment will change according to each area’s production capacity and cost of cutting, handling, transporting and storage, so the range of payments can start from 20kg up to 35.3 kilograms, after the corresponding adjustments and discounts.

For this kind of contract there is an additional factor that defines terms of negotiation - the required investment for land preparation. Thus, if the processing plant incurs a large financial outlay, there will be a proportional discount in the payment that the landowner will receive. The lengths of these sorts of agreements are generally for a fixed period of 10 years. At the end of the period the ongoing stocks will be property of the land owner.

Contract of land leasing

Under this type of contract landowners will receive a fixed value or lease rental per planted hectare, based on the amount of kilos of sugar per ton to be paid by the lessee to the land owner. The reference parameter that is normally used is 120 kilograms of sugar per rented hectare monthly. Nevertheless, this number is used only as reference because there are several contracts that agree to pay a different sum with a wider variation than the former 2 modes.

Contract of land administration

This sort of agreement is applied to a very specific and small number of suppliers, which in most cases have a direct connection with the ingenios. Under this mode the processing plant owner takes over the crop administration, so all the responsibility of the sowing, maintenance, and harvesting falls on the ingenio. In return the ingenio receives a commission, based on a percentage that is negotiated at the beginning of the season. The calculation of the percentage is associated with the cost that the ingenio assumes for running the crop. Frequently this number varies between 5% and 8% of the total production.

In all contract modes sugarcane payment is based on the amount of sugar that can be drawn from a ton of sugarcane. For each there is a reference parameter which provides a guide for individual negotiations, which are in fact, adjusted by various technical and economic factors that are inherent to the sugarcane productive process. Regardless of the contractual type, sugarcane bagasse and molasses are by-products that come from the industrial stage, therefore, they are considered property of the processing plants.

The relationships between agricultural producers and ingenios have been founded on competition, convenience, and mutual trust. Such pillars, along with cultural and familiar aspects, have built a solid economic structure with a great social scope.

5.2.2 Transformation of palm fruit into crude vegetable oil

In Colombia there are 53 palm fruit extraction plants, and most of them have a processing capacity below 25 tons per hectare, in fact only 24% of these plants are able to exceed this limit. This more than anything shows that the Colombian palm processing industry is far behind the world’s top producers, such as the Malaysian and Indonesian industries, which achieve average levels of 30 ton/ha and 40 ton/ha.

At present time, each plant is capable of processing an average of 4250 ha, which does not correspond to an optimal size. Based on these facts, it is possible to conclude that there is a mismatch between the processing capacity and the processed feedstock, being that the latter is inferior to the former. It has also been reported that the average size of these plants is not big enough to reach minimum standards of efficiency. According with the Ministry of Agriculture’s calculations the ratio between the actual use and the installed capacity yields a usage index of 52%, which indicates that the palm processing industry is inefficient due to unnecessary and higher processing costs (MADR, 2005).

In order to achieve greater efficiency and use all inputs, products and by-products in a proper way, it is considered that the optimum size should be near to 30 ton/ha of palm fruit. The reason for this is that such a size justifies the incorporation of heavy machinery for processing tasks, in particular, the use of turbines. Through the use of turbines it is possible to transform the steam that comes from a boiler in electricity, reducing costs, making use of different processes to create new by-products, and possibly eventually commercializing electricity surplus to the nearby population, or even become a power supplier to a local energy grid. However, should the plant not achieve the minimum level of production, it cannot justify the installation of a turbine, which is very expensive.

A plant of 30 ton/ha can operate with a medium level of efficiency if it is able to process the fruit that comes from a plantation of 7 thousand hectares of palm and with high efficiency if it is supplied with the fruits of plantations between 7 and 10.5 thousand hectares.

Plantations must be located around extraction plants, forming a core that simplifies and hastens the coordination between agricultural processes and the first stage of the industrial transformation. This fact is crucial, due to the continuous ripening of the fruit, which results in deterioration caused by increasing acidity levels 10-12 hours after harvest.

Based on the aforementioned, plantation size, distance between palm trees, availability of communication methods and road infrastructure that connects different plantations and plant facilities that ease fruit delivery after collection, are fundamental factors for industry performance, and of course, they guarantee that extraction plants are located on zones where there is enough fruit provision to use plants at full capacity (Fedepalma, 2006b).

It has been suggested the establishment of alliances as strategic interaction between actors along the chain, so plant owners can come to an agreement with small landowners, with available lands. By doing this, new farmers engage in the process and increase palm fruit volumes aiming to achieve the needs of the processing plants. No all of the extracting plants are able to cover plantations costs, given that investment required for a palm oil agricultural array could be substantial (US$3600 without including the cost of land).

So far, some alliances have been established with all sorts of entrepreneurs that include large-scale, medium-scale and small-scale farmers. They have been created with an orientation towards different goals. For instance, some alliances moves toward efficiency and productivity, whereas others that try to look for economic and social stability for the population located where crops are expanding (Ministerio de Agricultura, 2007, 2011).

These alliances work on the basis of mutual convenience between the parties, being in most cases a palm processing firm that is linked to the extraction stage, representatives of a set of small-scale agricultural producers that act together to engage in the productive process, sharing both risks and benefits of such endeavors (MIDAS, 2010; Ministerio de Agricultura, 2011).

Both, managing party and agricultural organization, obtain obvious benefits out of this type of alliances:

- Better stability and security: the improved possibilities of income increase for both parties. Agricultural producers engage with a highly recognized for-profit organization. These firms work under clear and established rules accepted by everyone. Under this sort of alliance access to market is basically secured and additional complementary economic and social services are gained.
- Access to the ICR, which helps to subsidize up to 40% of the plantation planting. A farmer that does not belong to an arrangement of this kind will face extreme difficulties gaining access to those benefits to fund a private project.
- Those funds that are used to finance the alliances have access to the FAG (Fondo Agropecuario de Garantías) – Agricultural and Guarantee Fund - that covers up to 80% of the total value of the credit granted for crop sowing and maintenance purposes. Furthermore, in some cases the managing party finances the remaining 20%.
- The agricultural party has access to technology and technical assistance in order to enhance crop productivity. The alliances often receive this automatically, either directly

or through offers that come from big-scale plantation owners or extraction plants that are linked to the initiative.

- They promote and encourage small-scale farmers to take part in the crop related assets, thus in some cases the managing party transfers land ownership to these peasants, or in other cases they provide support and assistance in the entitlement and legalization processes of properties in favor of the most vulnerable population. In the same way, those alliances that have exhibited an advanced level of development encourage the participation of small-scale farmers to become shareholders of the extraction plant, which in some cases have been up to 49% of total ownership.
- Through initiatives of this nature, members have access to additional complementary social and economic services that improve living standards. One of the most important is perhaps the right to use or eventually acquire housing facilities

On the other hand, managing parties can get some timely benefits, the most important one being the possibility to secure and to stabilize feedstock supply, and reduce the amount of time the plant is idle. In addition, the managing party, under specific circumstances, may have access to more government financial help. For instance, coverage given by the ICR can be increased 20% to 40% over the investment amount, just like the small-scale farmers, using the full extent of governmental support for palm crops.

One additional advantage of being a managing party is to reduce those costs that otherwise they would have to assume if the participation of ownership was greater. Under these alliances the entrepreneurial structure is lighter, but with reduced risk given that, to some extent, there is certainty in terms of quantity and quality of the feedstock that is available for their plants. This fact is mostly a consequence of an active engagement in crop planting, in the technical assistance for their allies, and technical coaching and training to arrange more productive processes that are convenient for the 2 parties.

Alliances have been demonstrated to be a tool with a tremendous potential to improve the socio-political environment where they take place. Furthermore, they are a target for corporate social responsibility activities, boosting stability and sustainability in the industries that decide to put them in to motion.

Productive alliances can be a tool that does not reduce competitiveness in the productive chain. There is some evidence that shows a reduction in costs in established agricultural units, in both plantation settings and also in production cost per unit (Fadul, N.D.; Ministerio de Agricultura, 2007).

These findings strengthen the idea that small-scale farmers can take part actively and efficiently in developing economies of scale that emerge from palm plantation initiatives, contributing to agricultural competitiveness.

Still, these alliances have been useful in moving forward the formalization of contractual relationships in a sector that is characterized for being highly informal; which is even more valuable, when what is at stake is the establishment of clear guidelines and rules between large-scale entrepreneurs and small-scale agricultural producers. It is also fundamental to move ahead in the setting, standardization and formalization of commercial links in the long run.

Those agricultural units that have been managed under this mode, are neither completely independent nor subject to maintenance standards, which are very common for small-scale farmers in Malaysia and Indonesia (Basiron, 2007; FPP, 2007; Sumathi et al., 2008). On the contrary, in the Colombian case by will of the small-scale agricultural producer, palm plantations can receive technical supervision from the managing party, which have more trained staff and more expertise. This aspect turns out to be one of the most important for land preparation, fertilization, and crop maintenance tasks.

Undoubtedly, the Colombian experience in this matter has been interesting and constructive. Alliances must be adopted and need to become into a core element in policy designs, oriented to guarantee an equitable distribution of all the benefits obtained by the development of biofuels initiatives, or any other agricultural product that should be supported.

In those frontiers where it is not possible to implement this sort of alliance with small-scale agricultural producers, other alternatives should be considered, such as the Financial Social Model (FSM) explained previously.

In recent years, alliances with small-scale agricultural producers have seen remarkable growth, given that at least 62 thousand hectares have been managed under this method. This number includes approximately a third of the planted area within the national territory between 2000 and 2008 (180 thousand hectares) (Ministerio de Agricultura, 2011).

As a result of the frantic palm oil production growth, palm oil production and palm kernel cakes has increased. In particular, crude vegetable oil has shown a steep rise during the last 20 years, starting with 232 thousand tons in 1989, and reaching more than 778 thousand tons (2008), which represents a growth rate close to 6.5% per annum.

This rapid production evolution has been able to keep pace with the increasing demand in domestic consumption, given that the average personal intake has experienced a noticeable increase from 9 kg in the early 1990’s to 10.3 in recent years. Additionally, the abundant supply of vegetable oil has created a substantial volume of surplus for exports. The quantity of vegetable oil that is not consumed domestically has reached levels of 341 and 318 thousand tons in 2007 and 2008 respectively. In fact during the last 7 years exports represented up to 40% of total production of the crude palm oil.

5.2.3 Transformation of crude palm oil into biodiesel

In Colombia biodiesel production started during the second half of 2008, firstly at an experimental level, and at the end of the same year it began the blending program with fossil diesel on a commercial scale. Although, there were some efforts to use other feedstock, nowadays, biodiesel production in Colombia is based completely on palm oil. Some other alternatives have been explored such as castor oil, algae, and jatropha curcas (Campuzano, 2011; Corpoica, 2011; Patiño, 2010), but they have not been expanded to commercial scale.

At present times there are 7 plants for biodiesel production, which are located in the northern and eastern region of the country. This will be explored in a later section..

5.2.4 Transformation of sugarcane and its apparent consumption

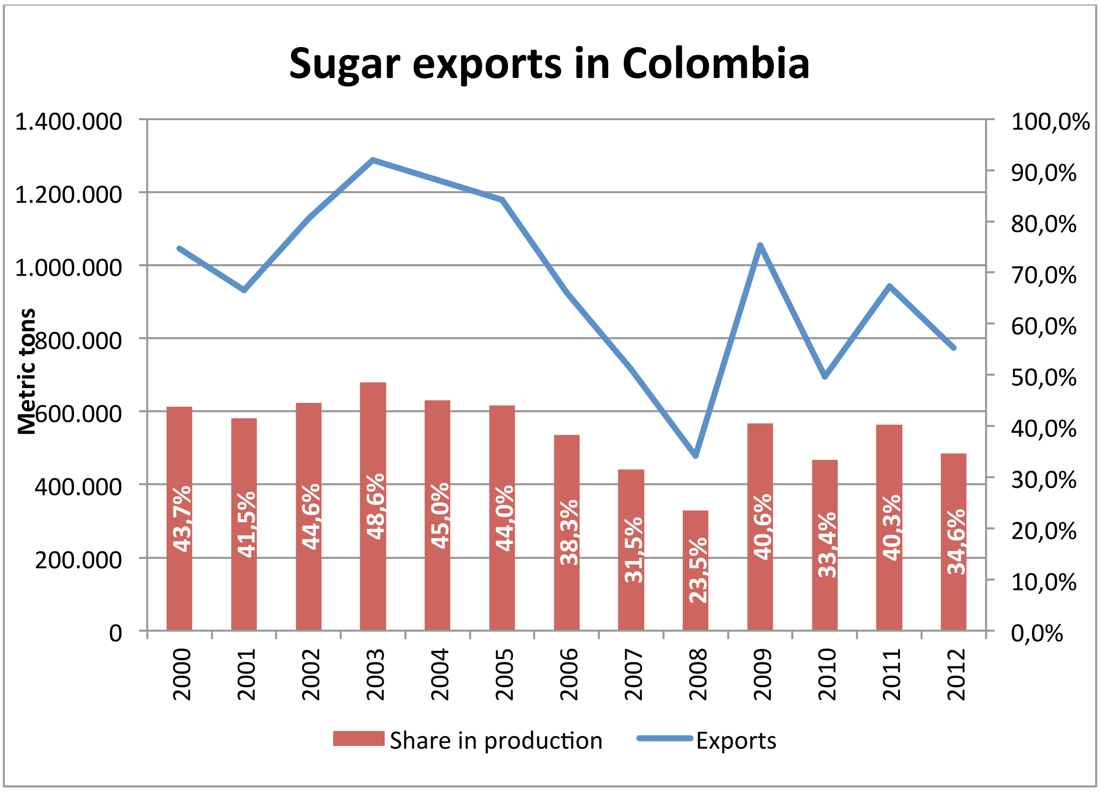
Sugar production in Colombia has had an important growth in the last decades, given that it has increased from 1.2 million tons in 1980 to 2.7 million in 2004 (expressed in equivalent tons of crude sugar). Nevertheless, from 2005 it has suffered a considerable reduction in sugar production, reaching levels of 2 million tons in 2008. This implies a reduction of 25% on the levels exhibited in 2004 and it represents a difference of nearly 700 thousand tons.

This setback in sugar production is directly associated with the disruption to the rain season frequency, and a decrease in the harvest due to a labor strike by the sugarcane cutters in 2008. Nevertheless, they were not the only factors that influenced this situation. During the third quarter of 2005, the new bioethanol plants were put into motion, and the cane juices originally destined for sugar production were used for biofuels.

Thus, it is possible to see that since 1987 the Colombian sugar industry has sufficiently supplied the domestic market, so has been exporting surplus ever since. The volume that is put on the international market has increase by a 4 factor, starting with 300 thousand tons (Infante & Tobón, 2010) and reaching a maximum of 1.29 million tons in 2003. In 2012 the commercial year ended with exports of 710 thousand tons (ASOCAÑA, 2012).

Such surplus production has been the principal boosting factor for sugar production in Colombia and, therefore, its rapid expansion to foreign markets. Yet, as presented in the graph, sugar exports have dwindled vastly since 2004, going to levels near to those experienced in 1992.

Figure 17 Sugar exports in Colombia



Compiled by the author. Data source: (ASOCAÑA, 2013)[50]

It is obvious, that there is a clear correlation between the commencement of operation of bioethanol plants and the drop in export volumes. This is not unexpected, since this was precisely the purpose of the original biofuel policy plan - to use surplus production for ethanol production and use the latter for blending with gasoline. It was calculated that in pursuing this path, the potential impact, if any, on the Colombian domestic sugar market would be minimal in terms of imperiled supply or price explosion.

In this sense, sugar sales within the domestic market have risen 200 thousand tons between 2003 and 2008, whereas the ethanol production market has required at least 300 thousand tons of equivalent crude sugar per year. These two facts, along with the previous explanation of the

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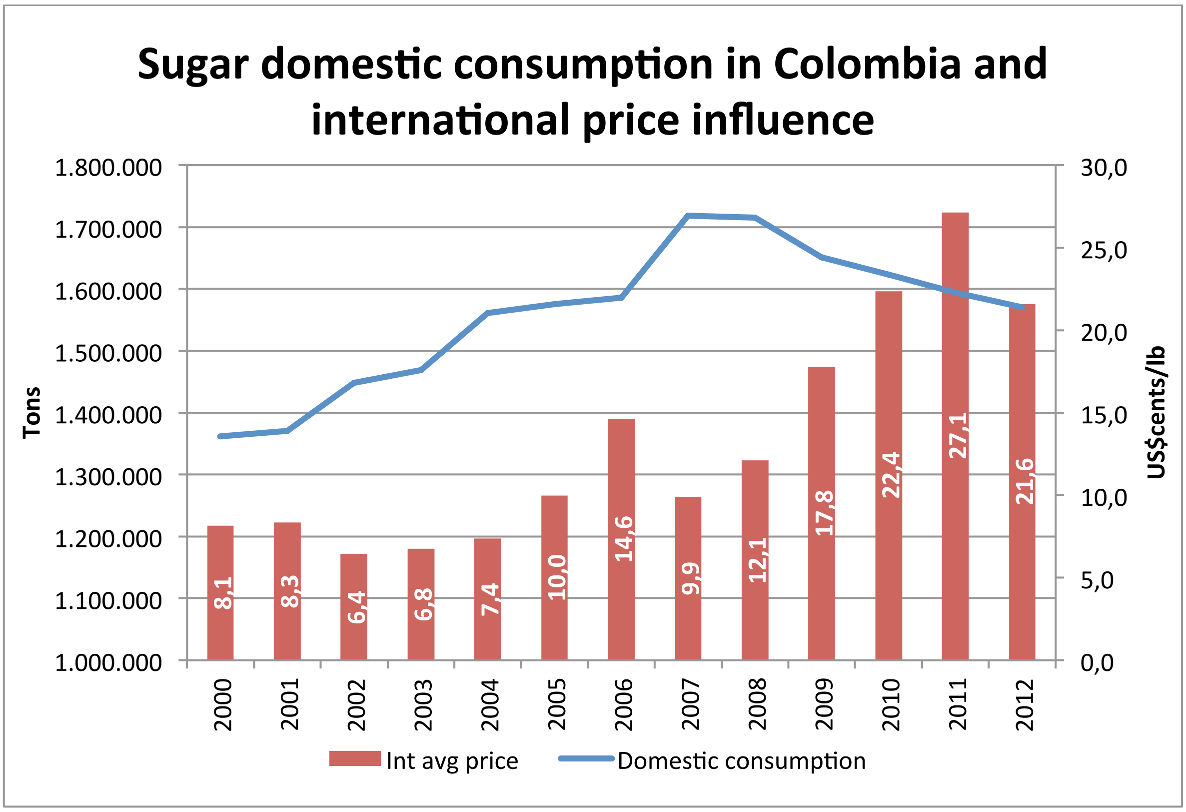
[50] Asocaña is the association of sugarcane farmers, and this institution gathers and organizes, on monthly-basis, all the information that is reported by its members. Further details about the origin of the data can be seen directly in the website (http://www.asocana.org/modules/documentos/5528.aspx).

reduction in sugar production during 2007 and 2008, clarify the exports declining behavior throughout the studied period.

Figure 18 Sugar domestic consumption in Colombia and international price influence



Compiled by the author. Data source: (ASOCAÑA, 2013)

So, one of the interesting findings is that neither the use of juices and molasses from sugarcane, nor the reduction in sugar production and exports since 2005, created any perverse effect on the sugar availability for the domestic market. On the contrary, the apparent consumption has risen steadily during the 3 years following the introduction of ethanol production(followed by a reduction due to the fall in production), not only because the sales trends of the processing plants have remained unchanged, but also because the imports of sugar have contributed to keep sugar availability.

Although, in relative terms the involvement of imports have been marginal, it is noteworthy to point out that from 2001 sugar imports have exhibited a perceptible increase, hence, nowadays (2012) they represent slightly more than 16% of the total domestic consumption.

Table 7 Sugarcane trade statistics for Colombia

year	Production (metric tons)	Sales to domestic market	Imports	Total domestic apparent consumption	Exports
	metric tons				
2000	2,391,324	1,348,822	12,889	1,361,711	1,045,349
2001	2,244,756	1,312,222	58,075	1,370,297	931,497
2002	2,528,756	1,361,914	86,372	1,448,286	1,127,229
2003	2,649,966	1,351,739	116,628	1,468,367	1,287,256
2004	2,741,363	1,523,427	37,853	1,561,281	1,232,782
2005	2,683,215	1,515,380	59,648	1,575,028	1,179,642
2006	2,415,145	1,459,872	126,010	1,585,881	925,565
2007	2,277,120	1,558,170	160,439	1,718,609	716,380
2008	2,036,134	1,549,845	165,384	1,715,229	478,442
2009	2,598,496	1,512,739	138,295	1,651,034	1,053,939
2010	2,077,613	1,438,973	184,311	1,623,284	694,396
2011	2,339,988	1,405,725	188,147	1,593,871	942,035
2012	2,236,605	1,318,870	251,276	1,570,146	774,779

Source: Elaborated by the author, Data source (ASOCAÑA, 2012)

Sugar imports in Colombia have registered 3 different periods of rampant expansion. The first one, between 2002 and 2003, international prices of sugar skyrocketed, and so did exports of this commodity. Under such acceleration of international trades, it is sound to think that as exports grow, fuelled by the rise of prices, so to do imports, in particular in the Colombian case, from those neighboring countries, or with those countries with whom Colombia has active commercial agreements. Under this period nearly half of the imports came from Ecuador and Bolivia.

The second period of imports expansion in Colombia took place between 2005 and 2008. This period coincided with the implementation of the ethanol plants, therefore it is not possible to rule out that this was the trigger for an increased sugarcane demand within the domestic market, and subsequently it created a reduction in sugar exports or an increase in sugar exports for direct consumption. The most recent expansion period took place from 2009 to 2012, due to complications in domestic production because of the "la Niña" climatic phenomenon.

Despite the fact that the structure of domestic supply within the national territory has experienced a change with the running ethanol plants, there are two factors that must be considered to fully understand such performance:

1. the level of dependence on the foreign market to supply the domestic market is still significantly small
2. that despite the fall presented in 2004, the surplus in sugar production remained predominant, given that exports surpass imports by far in this sector (see previous table).

5.2.5 Transformation of sugarcane into ethanol

Bioethanol production in Colombia has been developed using sugarcane as its principal feedstock, and to a minor extent cassava. For this reason, most plants have been located in the basin of the Cauca River in the Cauca Valley, where the sugar and alcohol industry in Colombia has had its roots for more than a century.

So far, there is no feasibility for using a different feedstock, like maize or sugar beet, if efficiency rates and competitiveness are taken into account.. The only commercial alternative that has been tried is a small plant located in Puerto Gaitán (in the eastern region of Colombia in the department of Meta). This plant processes the starch that is extracted from cassava or *yucca,* to be further treated to become ethanol. The area that is used to provide the feedstock for this initiative is about 1000 hectares.

As was mentioned before, there are some efforts to use a variety of sugarcane, that otherwise are used for raw sugar or *panela* manufacturing. However, some pilot tests have not produced successful results and some others are still in the trial stage, and under close financial and technical evaluation. Current experiments have not reached production levels that allow them to be fully incorporated to the domestic biofuels market.

The Suarez River Basin initiative, which is not fully working at present, represents an alternative to cover a portion of the future ethanol demand. It has a nominal daily capacity to produce 300 thousand liters, using 40 thousand hectares of *panela* sugarcane. Nevertheless, there is one concern on the impact that this initiative might have on the security of the sugar as a food source, given that panela production itself could be seriously reduced, and it is a resource that provides a good energy source in the national diet, and moreover is one of the pillars of the traditional diet for the rural population in particular.

The industry of sugar and alcohol in Colombia accounts for 13 sugarcane processing plants (Cabaña, Carmelita, Central Castilla, Incauca, Manuelita, María Luisa, Mayagüez, Pichichí, Providencia, Riopaila, Risaralda, San Carlos y Tumaco), and they work with more than 2200 units that are engaged with the plants to provide the feedstock, and they create 36 thousand direct jobs and nearly 220 thousand indirect jobs (Asocaña, 2011).

In Colombia, there are 6 alcohol distillery plants that are sugarcane-based, with a nominal installed capacity of 1.07 million liters per day, but in reality only 942 thousand liters per day, when bearing in mind that these plants work 320 out of 365 days of the year.

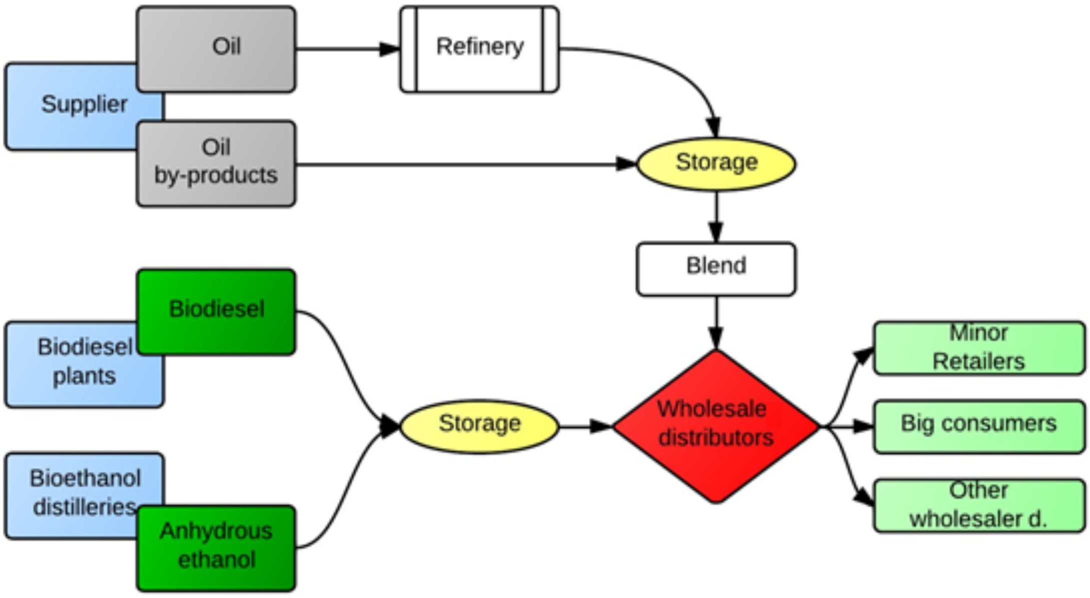
In June 2010 production capacity of alcohol fuel was actually 942 thousand liters/day, and was possible to be increased to 1,315 thousand liters/day. So the potential full capacity was 1.07 million liters/day as it was presented before. Despite of this, the national government set a goal of trying to reach a blend of E20 by the end of 2012. This would imply a production of 2.75 million l/d, which is far beyond the initial proposal of reaching E12, which was settled in the PNBc. Based on that, the question that emerges is - Is there enough sugarcane to cope with the current proposed target? If it is assumed that the plantations are going to be set on Cauca Valley soil, in order to guarantee the highest productivity, then, there would be the need to plant more than 128 thousand hectares of sugarcane , which is more than half of the planted area that is currently in that region.

Although there is a genuine interest from private investors in the biofuel industry, and with their support, it is possible to practically double the processing capacity of sugarcane for ethanol production purposes in Colombia, the main obstacle to be overcome in order to reach such levels set by the national authorities, is the surety of feedstock availability. This particular aspect is developed in a further section.

5.3 Distribution and commercialization

Colombian law establishes that biofuels must be blended with the corresponding fossil product by the wholesale distributor, and once such process is carried out these dealers can sell the blended fuel to fuel service stations, retail dealers, large consumers, or even other wholesale distributors. The blending process can be chosen by the trader as long the quality of the final product is guaranteed.

Figure 19 Distribution and commercialization chains



Adapted from (Infante & Tobón, 2010; S. Trindade, 2005)

As can be seen from the figure above, both biodiesel and bioethanol plants sell plain biofuel to the wholesale trader, which must use special storage tanks to undertake the blending task, according to the standards established by the Ministry of Mines and Energy. When biofuel, already blended with the regular fossil fuel, is sold to the retail dealer, it must undergo quality controls, and they should provide proper storage condition for the mix, before is offered to the final consumer.

5.4 The consumer sector

5.4.2 Projected consumption of biodiesel

So far, crude palm oil destined for biodiesel production has been diverted from exports and the difference was covered by national production. It is clear that a fundamental consideration to determine the degree of substitution between crude palm oil and biodiesel for domestic consumption is the resulting relationship between price of biofuel itself and price of exporting oil. Likewise, it must be taken into consideration the cost of giving up participation in international vegetable oil markets.

To illustrate this situation, the following table presents biodiesel demand during the period 2009-2015, based on the Ministry of agriculture data.

Table 8 Palm oil demand for biodiesel production

Palm oil demand for biodiesel production							
Concept	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Diesel demand (b/d)	110051.00	113684.00	117342.00	121079.00	125601.00	130587.00	135786.00
Blend Percentage (%)*	5%	10%	10%	20%	20%	20%	25%
Biodiesel demand (b/d)	5502.55	11368.40	11734.20	24215.80	25120.20	26117.40	33946.50
Biodiesel demand (t/y)	279.34	577.12	595.69	1229.31	1275.23	1325.85	1723.29
Crude palm oil (t/y)	285.62	590.10	609.09	1256.97	1303.91	1355.67	1762.06
Assumed yield (t/h)	3.60	3.70	3.70	3.80	3.80	3.80	4.10
Required productive has	79338.98	159486.06	164617.83	330780.84	343134.68	356756.15	429770.17

Recalculated by the author based on (Infante & Tobón, 2010; UPME, 2008)

Taking into account that by 2009 the proposed blend of B5 was fully achieved, it is estimated that 285.62 thousand tons of crude palm oil were used for the biodiesel blend. This target was easily achieved through diverting a substantial share of the export quota, in addition to an existing capacity capable of coping with the created demand.

According to FEDEPALMA projections, biodiesel sales in the domestic market were expected to increase on average 12,000 ton/year during the next 3 years after the commencement of the program (2008), whereas palm oil production could grow 136 thousand ton/year during the same period (Mesa-Dishington, 2007). Based on that, there would be an ongoing decline in the oil exporting surplus during the initial years of application of the B5 implementation. Once this period is finished the exporting level can be recovered, if one bears in mind that those palm trees that were planted a few years ago will enter into the production stage.

This is the main reason why it was thought that there was enough feedstock availability to move towards a mix of 10% biodiesel by 2010. In order to achieve this target, there was need for 568 thousand ton/year of crude palm oil supplied in the way that was described previously, and along with it 1,539 thousand hectares of production. Nowadays, biodiesel plants that are already working have reached a nominal production of 516 thousand ton/year.

The possibility of applying a biodiesel blend over 10% represents an immense challenge under current circumstances and it will depend on the extension of present crops in the upcoming years. Although, the initial target was B20 by 2012, it is clearly not impossible to fulfill. In order to do so, it would have been necessary to use an extensive portion of the domestic share of the crude palm oil, with obvious negative consequences on the food security.

If those palm crops that are already planted are taken into account, it was calculated that by 2012 the productive area should be near to 343 thousand hectares and annual production close to 1.34 million tons of crude palm oil, however, there is no official reports in that regard. A blend of B20 would requires near to 1.25 million tons of oil, occupying approximately 330 hectares for its production; therefore, if such a blend is pursued, a greater portion of palm oil production would be destined for biofuel manufacture, and there will be only a small remaining part of 130 thousand tons for human consumption.

5.4.3 Projected ethanol consumption

The strategy of producing ethanol based on the feedstock that once was destined for sugar exports entails some limitations that need to be considered. On one hand, to reach the goal of a mix of 15% ethanol with regular gasoline in 2010 and 2011 would have needed nearly 750 million liters per year, if the projections provided by the UPME were accurate (2008) (UPME, 2008). As it is presented in the following table, by the year 2008 alcohol fuel production only achieved a maximum of 258 million liters, so the full target is only 34% covered.

Table 9 Ethanol production in Colombia

Ethanol production in Colombia (thousand liter)								
Year	2005	2006	2007	2008	2009	2010	2011	2012
Production	28.95	268.54	274.83	258.09	326.84	291.28	336.95	370.00
Sales	23.56	258.54	279.67	249.74	338.36	292.08	351.08	NA
Remaining stock	4.61	13.07	4.81	13.19	NA	NA	NA	NA

Adapted from (Infante and Tobon, Fedebiocombustibles 2012)

It is estimated that the annual production, with the current productive capacity, is 352 million liters, which is still less than the amount required to supply the whole national territory with E10, which was supposed to be implemented in 2009. Apart from that, sugarcane in Cauca Valley yields approximately 75 liter/year of ethanol, and in order to reach that required approximately 6.9 million tons of sugarcane, that if used for the production of crude sugar could generate 815 tons for export. So, 35% of the total sugarcane production within the region is allocated to ethanol production, therefore crude sugar exports are highly affected.

In the beginning, the possibility of implementing an E15 by 2010 was considered. Nonetheless, under such a scenario the calculations presented above will increase to 10.1 million tons of sugar cane, or 1.19 million tons of crude sugar. That scenario would imply using 40% of the total production of sugarcane and it would imperil further export possibilities.

It is possible to consider that a mix of E15 is the maximum theoretical blend that can be achieved with the current production capacity installed in the Cauca Valley. In order to do so it would be necessary to forgo the possibility of exporting the crude sugar, however, it is important to stress that domestic consumption would not be affected.

The following table shows an estimation of the alcohol fuel demand for the period 2009-2015. The projections were based on information supplied by the Ministry of Agriculture in regard to the calendar established for different blends.

Table 10 Sugarcane demand for bioethanol production

Sugarcane demand for bioethanol production							
Concept	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Gasoline demand (bbl/d)	91353.00	89823.00	88966.00	88732.00	88716.00	88954.00	89893.00
Blend percentage	10%	15%	15%	20%	20%	20%	25%
Bioethanol demand (bbl/d)	9135.30	13473.45	13344.90	17746.40	17743.20	17790.80	22473.25
Bioethanol demand (million l/d)	530.12	781.87	774.41	1029.83	1029.64	1032.41	1304.13
Sugarcane (thousand t/y)	7066.56	10422.32	10322.88	13727.63	13725.16	13761.98	17384.06
Planted area required (ha)	58888.03	86852.64	86023.98	114396.96	114376.33	114683.17	144867.21

Recalculated by the author based on (Infante & Tobón, 2010; UPME, 2008)

Taking into account that the adoption of a mix with 20% of ethanol was forecasted to be applied in 2012, some constraints emerge under this scenario - in order to fulfill this target close to 13.7 million tons of sugarcane is required, which is 3.3 million tons more than the numbers registered in the previous 2 years. Based on this, an even larger area of sugarcane is needed, with only two ways to achieve this:

1. by engaging those zones where panela sugarcane is produced (which is the only area available for augmenting ethanol production in the short run),
2. by sowing sugarcane in other regions within Colombia.

Each has their own setbacks. In the first case, as was mentioned before, there is a considerable difference between the productivity of these two varieties of sugarcane. Panela sugarcane offer much reduced output if it is compared with traditional sugarcane.(Panela sugarcane at 37ton/hectare vs. sugarcane at 100 ton/hectare). Despite the less efficient performance of the panela sugarcane, its adaptability conditions make this variety the most suitable one for the harsh characteristics of the Suarez River basin. Traditional sugarcane could be planted in that area but it is uncertain what yield in terms of tons of sugarcane per hectare per annum, or sucrose content could be obtained.

In the second case, there are two regions, far from the Cauca Valley region, where the cultivation of sugarcane takes place; however, in these two regions efficiency is substantially reduced. According to data from the Ministry of Agriculture, in the department of Cesar the productivity in terms of sugar per ton of sugarcane barely achieves 68% of the one presented in the department of Cauca Valley; whereas in the department of North Santander the same indicator reaches 83%. This reduction in efficiency is due to less content of sucrose within the canes and a reduced yield of sugarcane per hectare (between 80 and 90 ton/hectare).

Furthermore, as these regions are relatively far from the consumption core, it will require some important investment in road infrastructure and basic services, to boost proper productive scales. These sugar initiatives will engage new labor in the process, while also utilizing staff that have already been trained in the Cauca Valley region and, by doing so, easing the learning curve for energy plantations and processing plants.

Although there are some isolated initiatives on paper to start an expansion of alcohol energy crops in non-traditional zones, there is no particular public policy that offers tools that contribute to creating proper short term stimuli to increase the plantation areas and bring complementary investment. Such policies must coordinate the roles between national and local authorities to implement those tools.

A complementary action to this policy, are mechanisms that promote the identification, formulation, structuration and evaluation of investment projects; providing funds for foresight studies, which consider the financial, environmental and social impacts of these initiatives.

To move forward to E15 blends and above, securing sugarcane provision turns into the most imperative condition. Thus, it is fundamental to count on an articulated program that promotes the enlargement of productive zones, as well as the upgrade of the current ethanol processing capacity. There have been several endeavors to tackle the Colombian bioethanol needs, in addition to those already established in the Cauca Valley region; however, they have not been able to overcome the pre-feasibility stage. Some other enlargement projects in the Cauca Valley have also been delayed.

Another critical factor in the promotion of investments around ethanol industry is the stability and transparency in determining regulation policies, particularly those related to the sale price.

5.4.4 Current biofuel consumption

Since 2010 (April 1st), through issue of resolutions 182368 (29/12/2009) and 180523 (29/03/2010), the consumption of biofuel in Colombia has been managed as follows:

- Atlantic Coast, Huila, Tolima Santander and Putumayo will have a blend of biodiesel of B8;
- In the western region (Cauca Valley, Antioquia, Choco, Cauca, Nariño, Caquetá, Coffee region and North of Santander) the blend is B7,
- The rest of the country will have B5.

In the case of gasoline, just as the biodiesel scenario, from April 1st, the recommended level of mix from the government is E8 for Colombia (Fedebiocombustibles, 2010a).

Based on the previous information in the next incoming chapters will be developed LCA and GIS excercises in order to test the environmental sustainablility of biofuels and to sketch to what extent can be expanded current crops under sustainable (social, economic and environmental) conditions.

6 LIFE CYCLE ANALYSIS - ENVIRONMENTAL STUDY

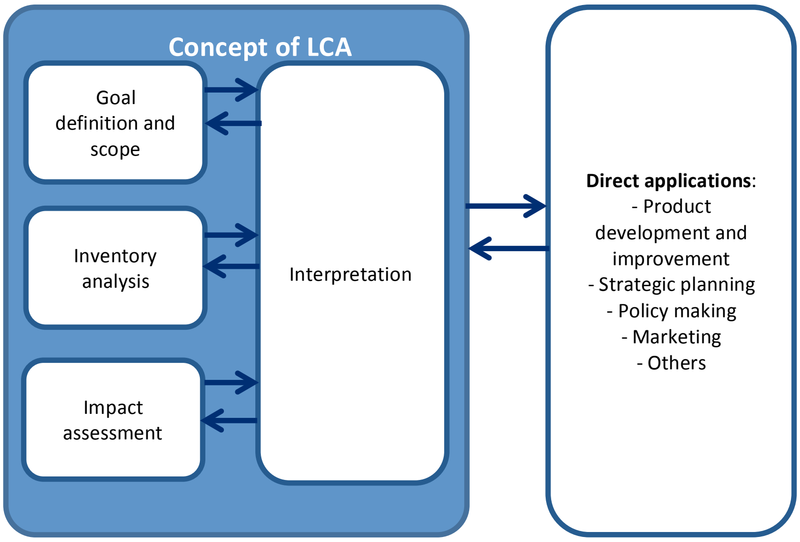
6.1 Goal

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).

6.2 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 20 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.

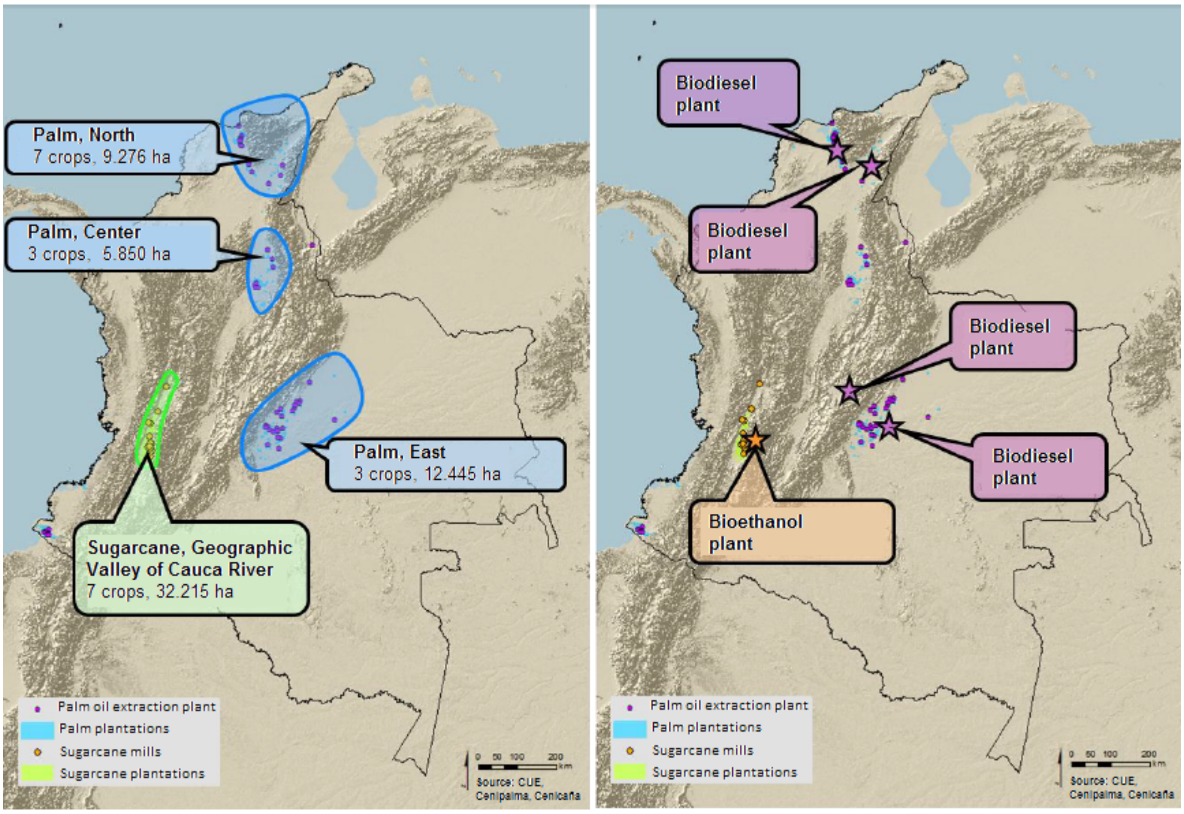
6.2.2 Scope

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 21 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).

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.

Figure 21 Studied areas for sugarcane and palm trees 2010



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.

6.2.2.1 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)

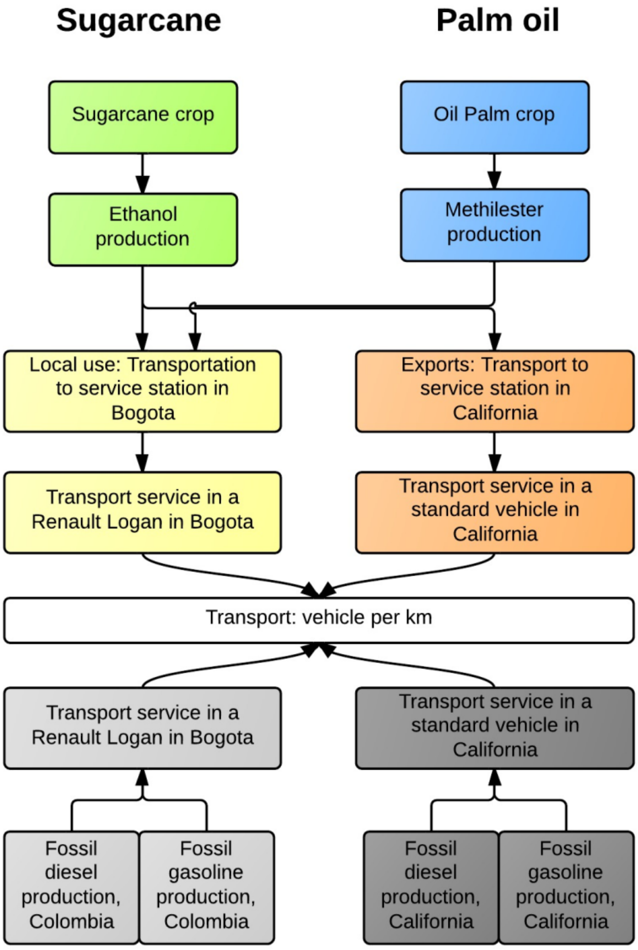
Consumption per driven kilometer in an average vehicle in Colombia (Renault Logan) and in the Unites States of America (in a standard passenger vehicle).

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.

6.2.2.2 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 22 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.

6.2.2.3 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.

6.2.3 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.

6.2.3.1 Types and data sources

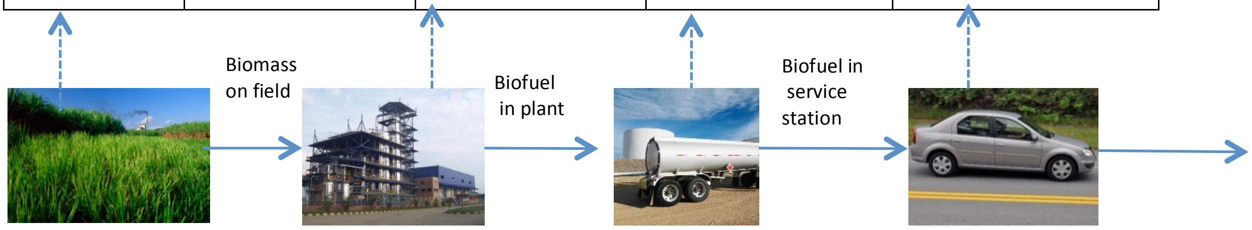
In general, the inventory of the employed data can be broken down in primary and secondary data. Primary data is related specifically with the production system, and they are real and verified, collected directly in the field, through interviews with experts and/or use of relevant publications. The figure 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 23 Inventory data sources for specific processes

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)[51].

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[51] 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.

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

6.2.3.2 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 N_2O or NO_x were calculated based on the formulas proposed by the IPCC (De Klein et al., 2006; IPCC, 2006).

$$NO_2 = \frac{44}{28} * (0.01N_{tot} + N_{cr}) + 0.01 * \frac{14}{17} * NH_3 + 0.0075 * \frac{14}{62} * NO_{3-}$$

NO_2 = *Nitrogen emission (kg NO_2/ha)*

N_{tot} = *Total Nitrogen in mineral and organic fertilizers*

N_{cr} = *Content of Nitrogen in residuals*

NH_3 = *Losses of Nitrogen in form of ammonia*

NO_{3-}= *Losses of nitrogen in form of Nitrate*

NO_x = *0.21*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 11 Emissions of NH3 - Mineral fertilizers

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).

6.2.3.3 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.

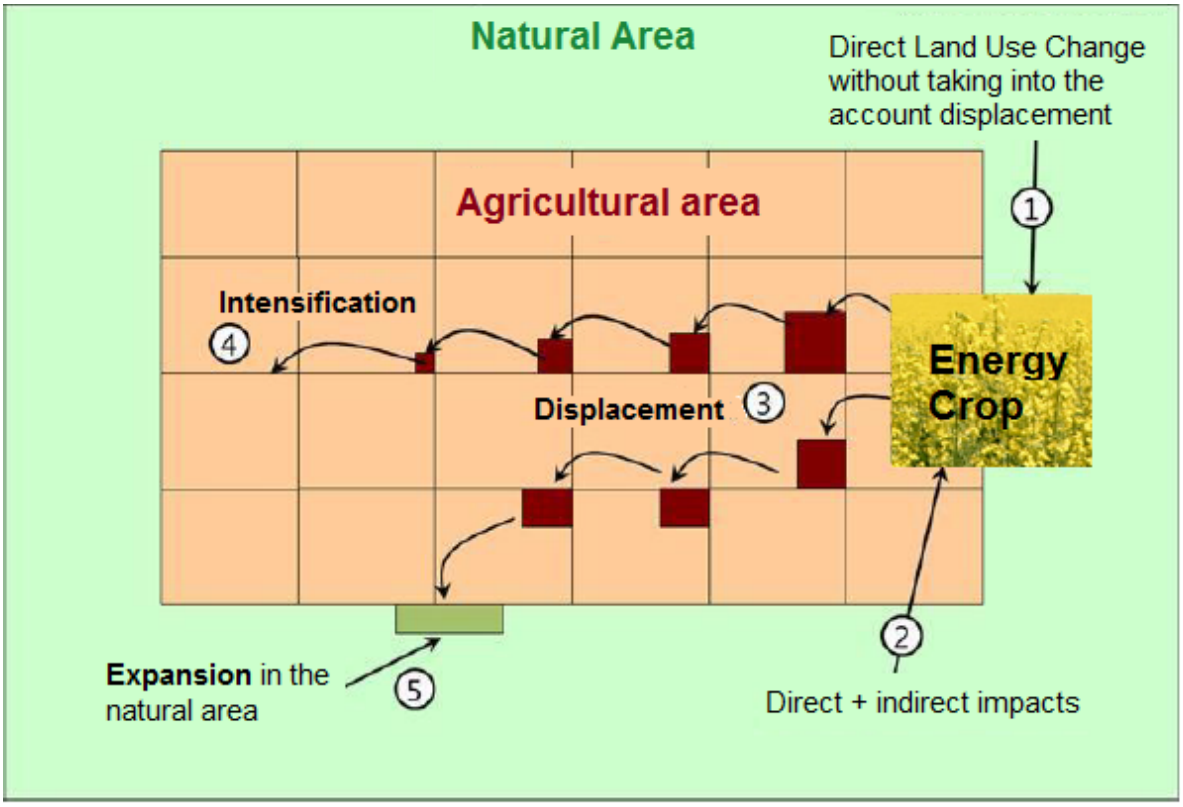
6.2.3.4 Analysis of the indirect land use change (iLUC)

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). 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).

Figure 24 Illustration of the indirect land use change (iLUC)



Source: CUE (2012)

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).

6.2.4 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.

6.2.5 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).

6.2.6 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 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.

6.3 Inventory analysis

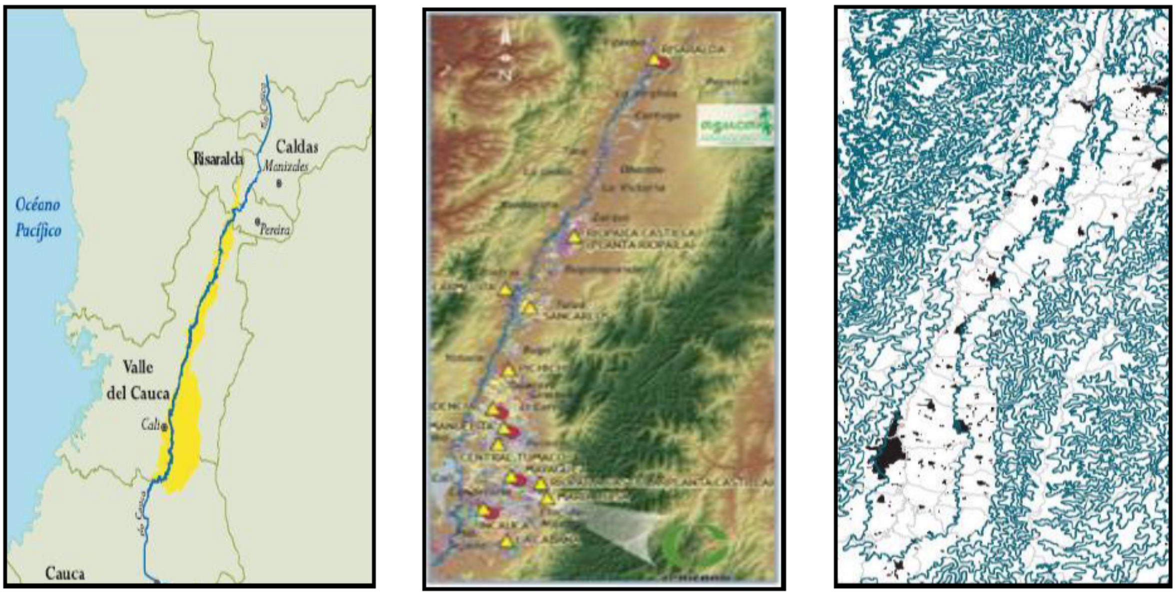
Within the following section are presented the analysis of LCI, which combines input/output data in relation with the system under study (i.e. sugarcane-based ethanol and palm oil-base biodiesel).

6.3.1 Sugarcane crop

6.3.1.1 Introduction

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 25 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).

6.3.1.2 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 12 Ethanol producing companies in Colombia

Ethanol producing companies						
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.

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 hectare s.

Table 13 Selection of agro-ecological zones

Selection criteria of the agro-ecological zones (assessed in ha)					
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 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 14 Identification of specific location (for ethanol production)

Identification of specific location (ha)								
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 15 General information on the studied location (for ethanol production)

General information on the studied location			
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 16 Area and weighting factor within the selected studied locations

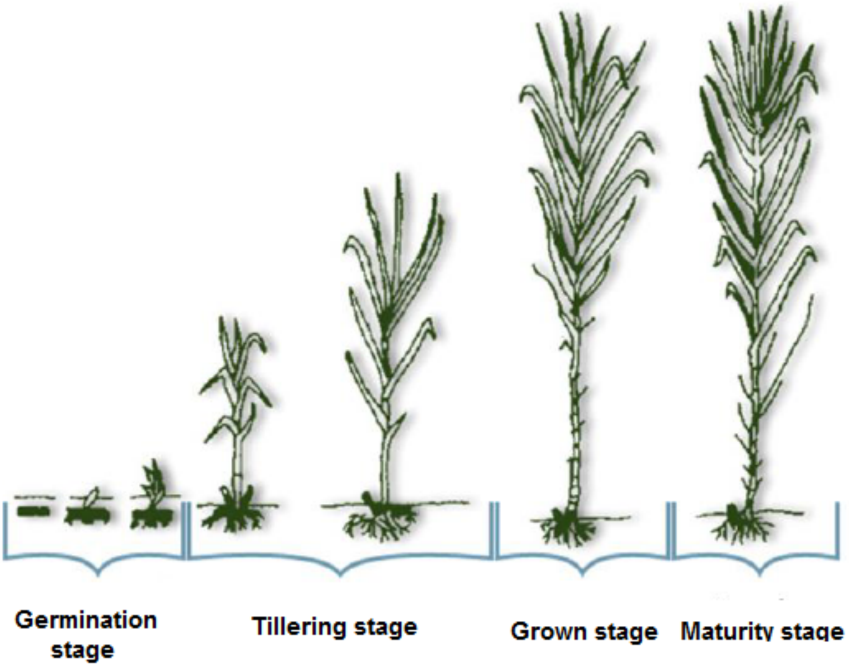
Area and weighting factor within the selected studied locations							
Parameter	Questionnaire						
	C001	C002	C003	C004	C005	C006	C007
Agro-ecologic zone	10H3 11H0 6H1 18H0	10H3 11H0 6H1 18H2	10H3 11H0 6H1 18H3	10H3 11H0 6H1 18H4	10H3 11H0 6H1 18H5	10H3 11H0 6H1 18H7	10H3 11H0 6H1 18H8
Yield (ton/ha/y)	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

6.3.1.3 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 26 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.

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 17 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

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.

Table 18 Sugarcane Collection method within de geographic Valley of Cauca River

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

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).

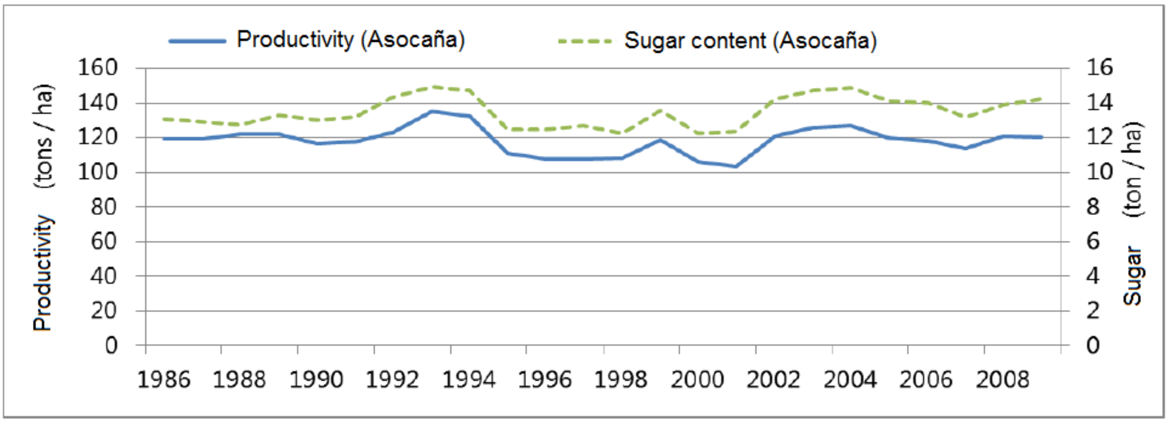
If the ratooning process is implemented (which is the agricultural practice of using sugarcane shoots from a previous cycle, as described earlier), then it is preferred to use manual cutting, rather than mechanic methods, given that mechanical equipment tends to destroy roots and the likelihood of soil 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.

6.3.1.4 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).

Figure 27 Sugarcane yield and sugar yield

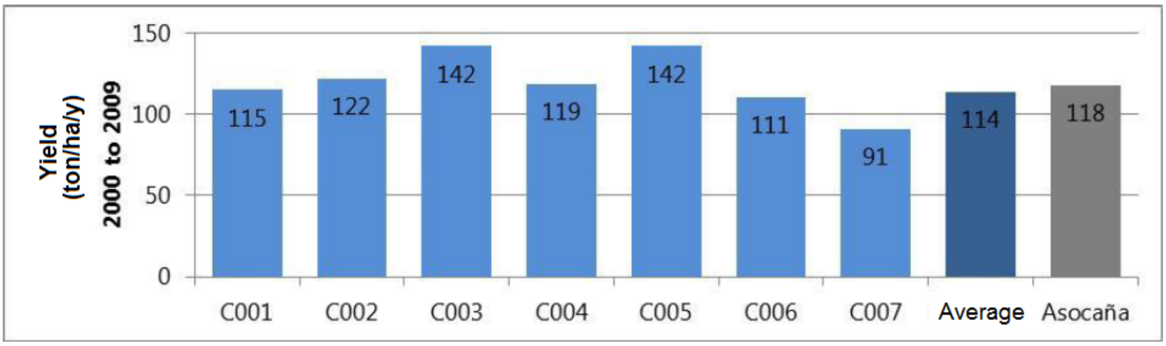


Sugarcane yield (productivity), and sugar yield (tons/ha)

Source: (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).

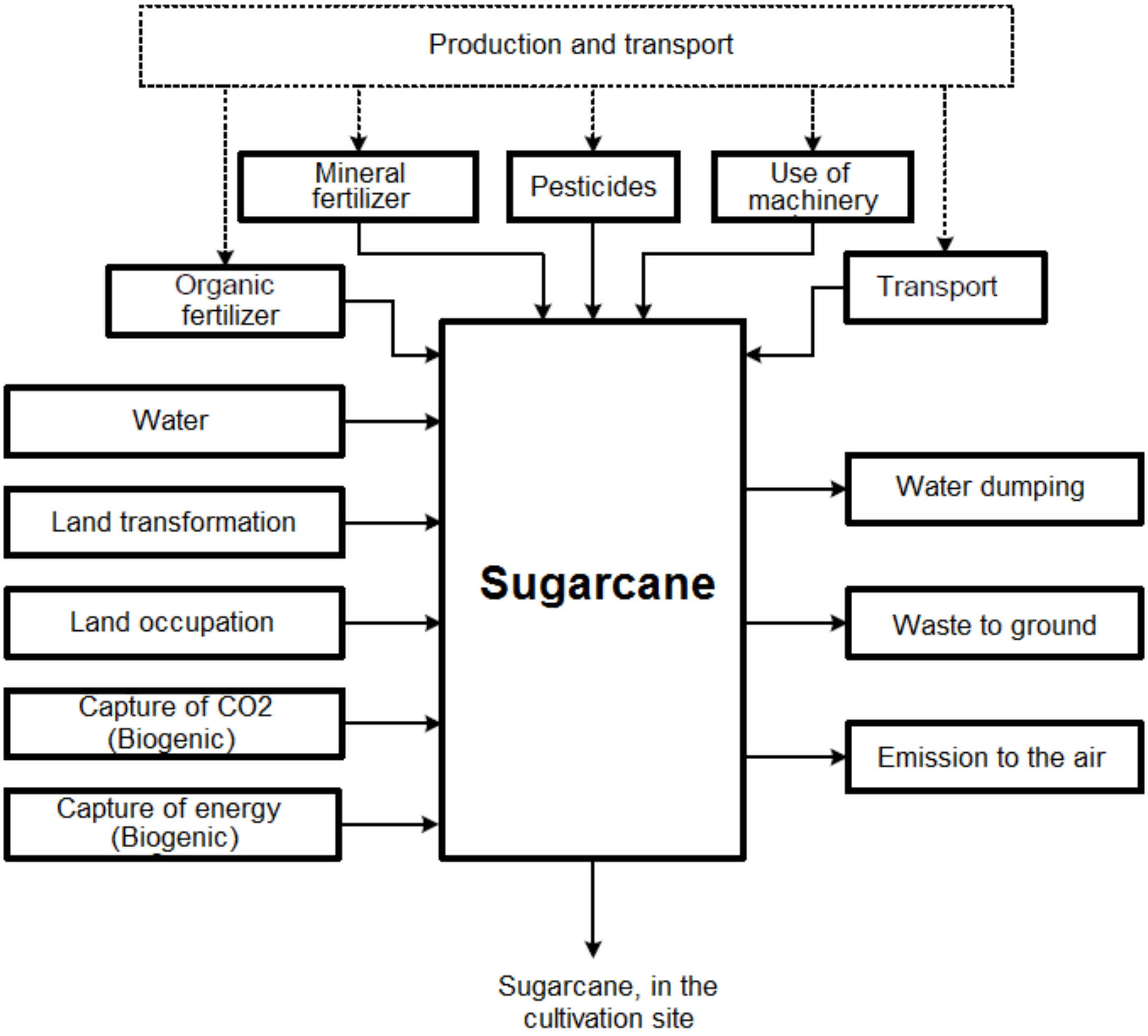
Figure 28 Sugarcane yield for the assessed plantation sites



6.3.1.5 System characterization

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

Figure 29 Sugarcane inventory overview



6.3.1.6 Feedstock and supplementary raw materials

6.3.1.6.1 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.

6.3.1.6.2 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 19 Fertilizer application in studied locations (kg / ha / y)

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 20 Recommended dose of fertilizers for sugarcane crops

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

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

6.3.1.6.3 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 21 Pesticides application per year and hectare

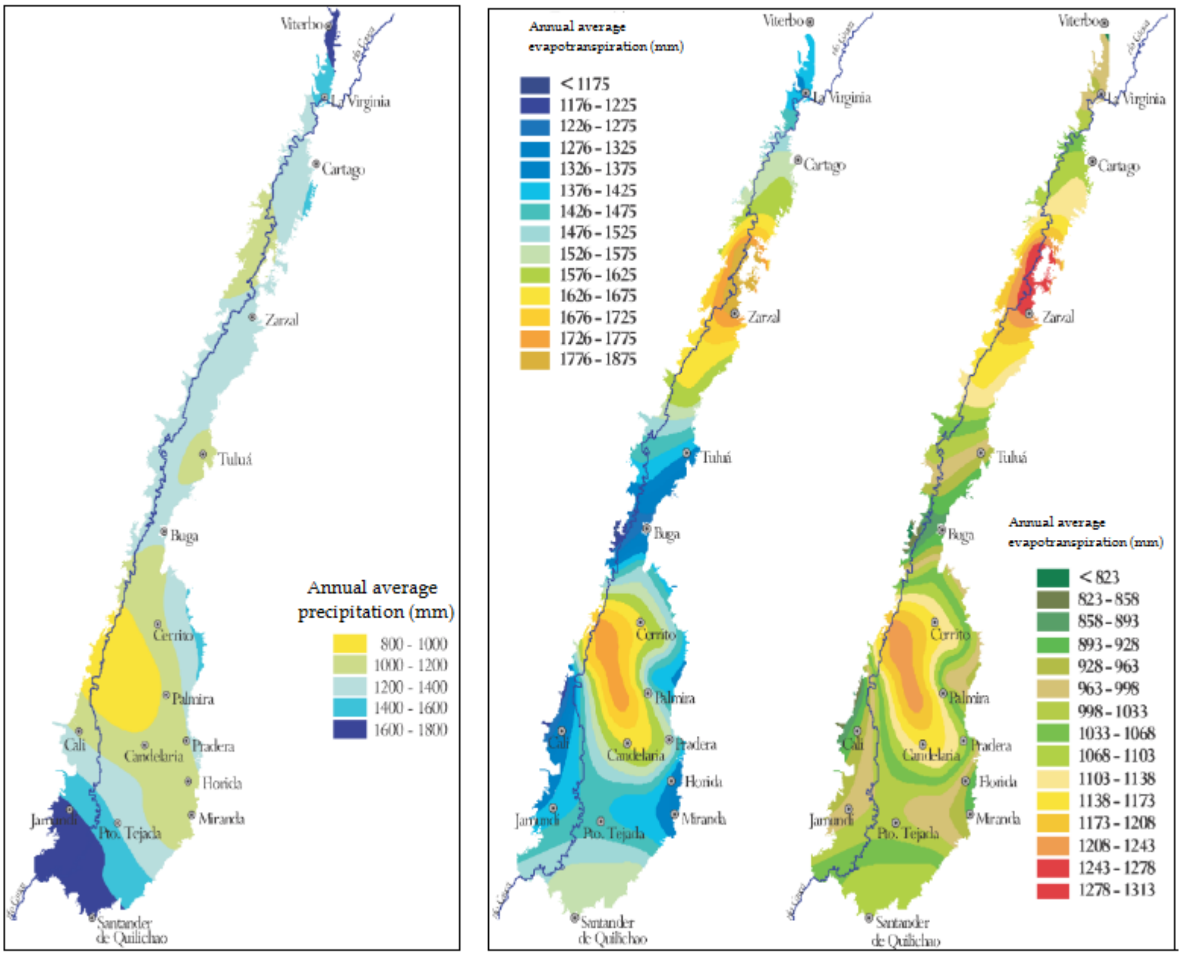
Pesticides application per year and hectare								
Entry of pesticide / herbicide	C001	C002	C003	C004	C005	C006	C007	Average
Glyphosate (kg/ha)	-	-	-	-	-	1,4	1,6	0,41
Roundup 747 (Glyphosphate) (kg/ha)	-	0,3	0,4	0,4	0,4	-	-	0,12
Sulphur (kg/ha)	-	18,8	-	-	-	-	-	0,16
Roundup (kg/ha)	-	-	-	1,3	-	-	-	0,36
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

6.3.1.6.4 Irrigation and draining

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 below, is shown precipitation and transpiration in the Geographic Valley of Cauca River.

Figure 30 Precipitation, Evaporation , in the Geographic valley of Cauca River



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

Source: (Cenicaña, 2011)

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 m3 (Cenicaña, 2010).

Table 22 Water requirements for sugarcane using different irrigation systems

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 31 Irrigation channel in sugarcane plantations

Cenicaña ©

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.

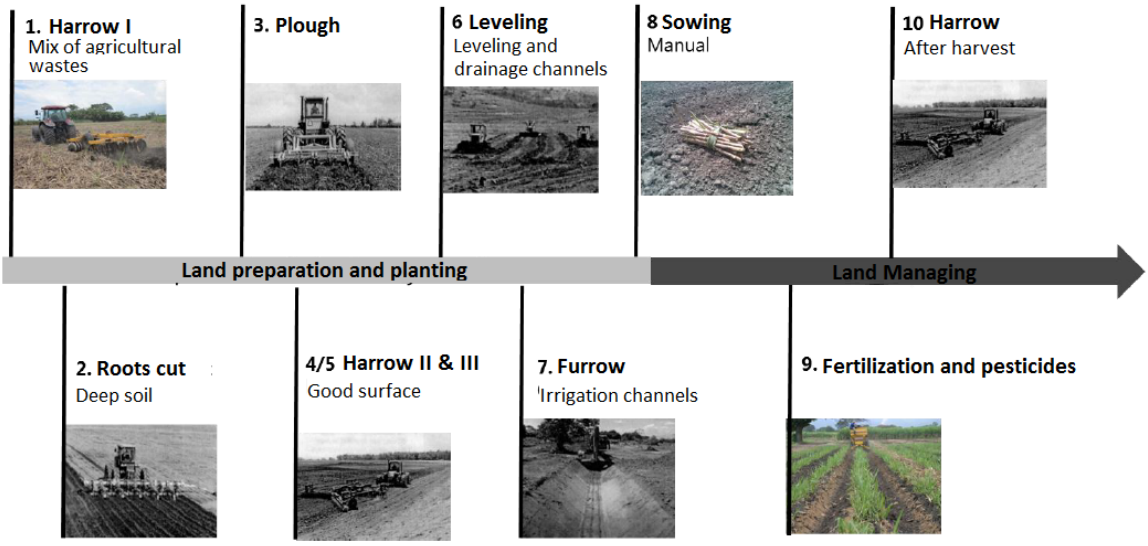
6.3.1.7 Use of machinery and energy

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 32 Machinery and equipment used for land preparation



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

Table 23 Energy requirement for land preparation

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 33 Green manual harvest. Loading of cut sugarcane after pre-harvest burning.

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 24 Energy consumption of the mechanic and manual harvesting process

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

Sources: 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.

6.3.1.8 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 25 Transformation of the Land use and occupation of the sugarcane

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.

6.3.1.9 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).

6.3.1.10 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 26 Emissions to the atmosphere from the burning process

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

Sources: (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 27 Emission to the atmosphere from fertilizers application

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 5.

6.3.2 Sugarcane processing plant (ingenio) and ethanol production

6.3.2.1 Introduction

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 28 Ethanol plants in Colombia 2009

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 m^3/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 29 Weighted average of production of different ethanol production companies

Weighted average 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

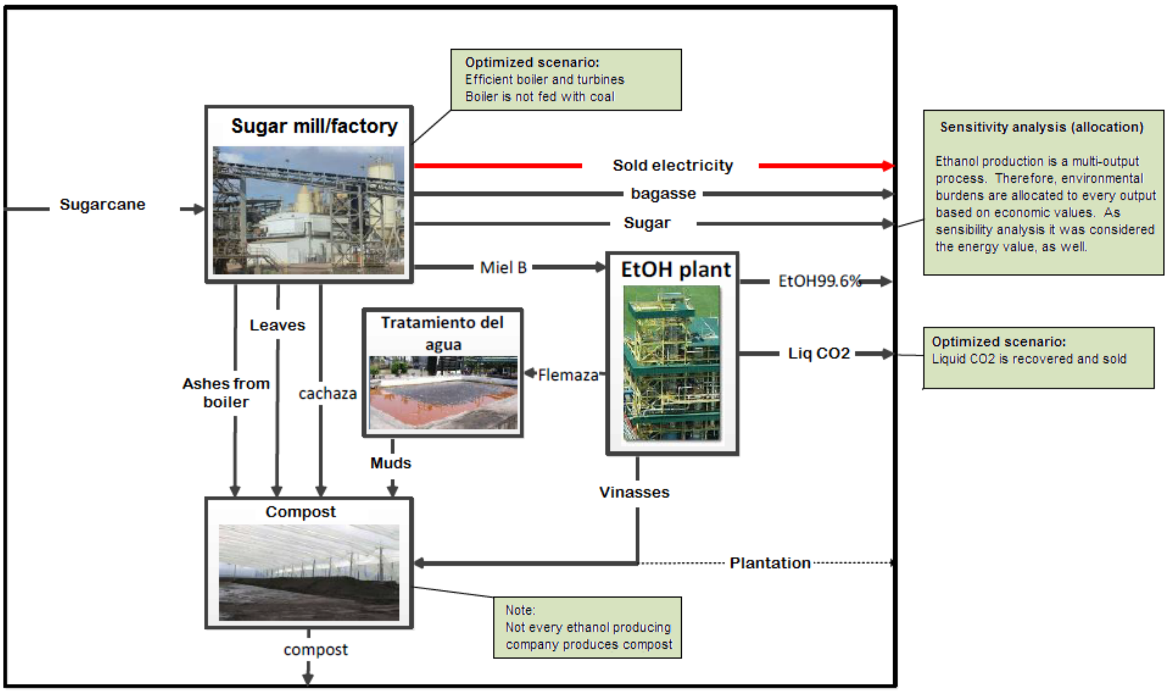
6.3.2.2 Description of the system

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 34 Illustration of ethanol production process in Colombia



Optimized scenario:
Efficient boiler and turbines
Boiler is not fed with coal

Sensitivity analysis (allocation)

Ethanol production is a multi-output process. Therefore, environmental burdens are allocated to every output based on economic values. As sensibility analysis it was considered the energy value, as well.

Optimized scenario:
Liquid CO2 is recovered and sold

Note:
Not every ethanol producing company produces compost

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 following table. 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 30 Mass flows and technologies for sugar and ethanol plants in Colombia

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

Sources: 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.

6.3.2.3 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

Figure 35 Sugarcane transformation process

Source: (MANUELITA WEBSITE, 2010)

6.3.2.3.1 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 31 Material and energy consumption of the sugar processing Factory

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.

6.3.2.3.2 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).

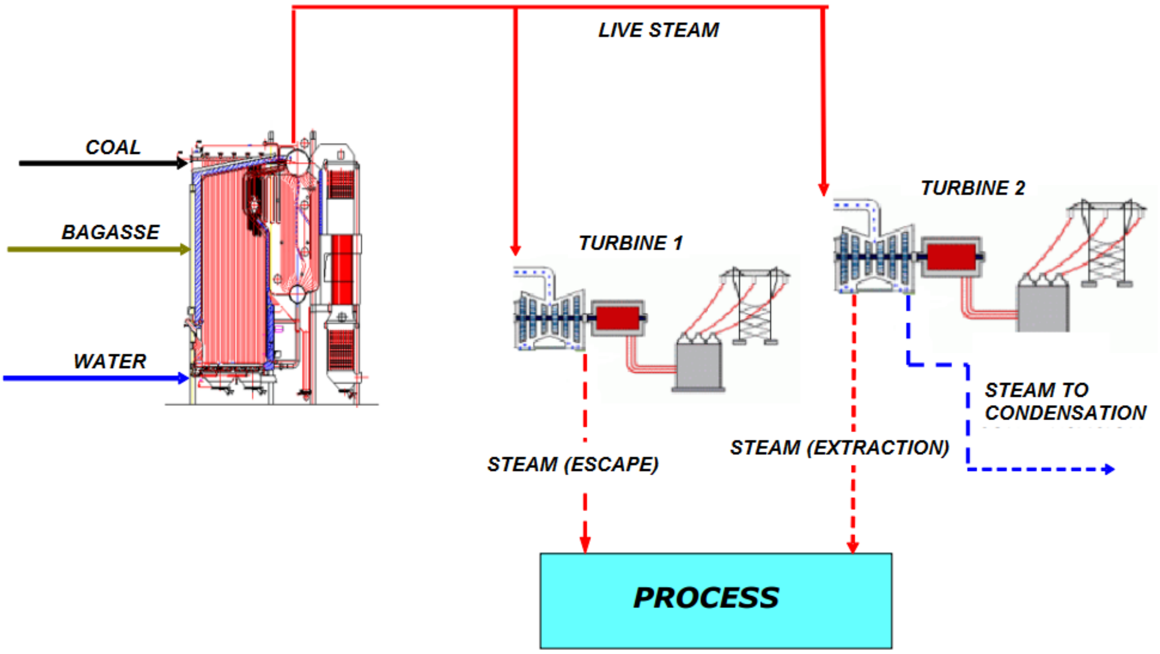
Table 32 Properties of bagasse and charcoal

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)

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 below shows a general illustration about the cogeneration system for the sugarcane processing industries.

Figure 36 Illustration of the co-generation system applied within sugar mill facilities



Source: (Castillo, 2009)

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

Table 33 Summary of cogeneration processes of the different companies

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%.

6.3.2.3.3 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 34 Infrastructure of the sugar mill, furnace and turbine

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

6.3.2.3.4 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 7).

6.3.2.3.5 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.

Table 35 Products and residuals from the sugar plant

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

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.

6.3.2.3.6 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 8.

6.3.2.3.7 Residual disposal

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

Table 36 Residuals from sugarcane

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

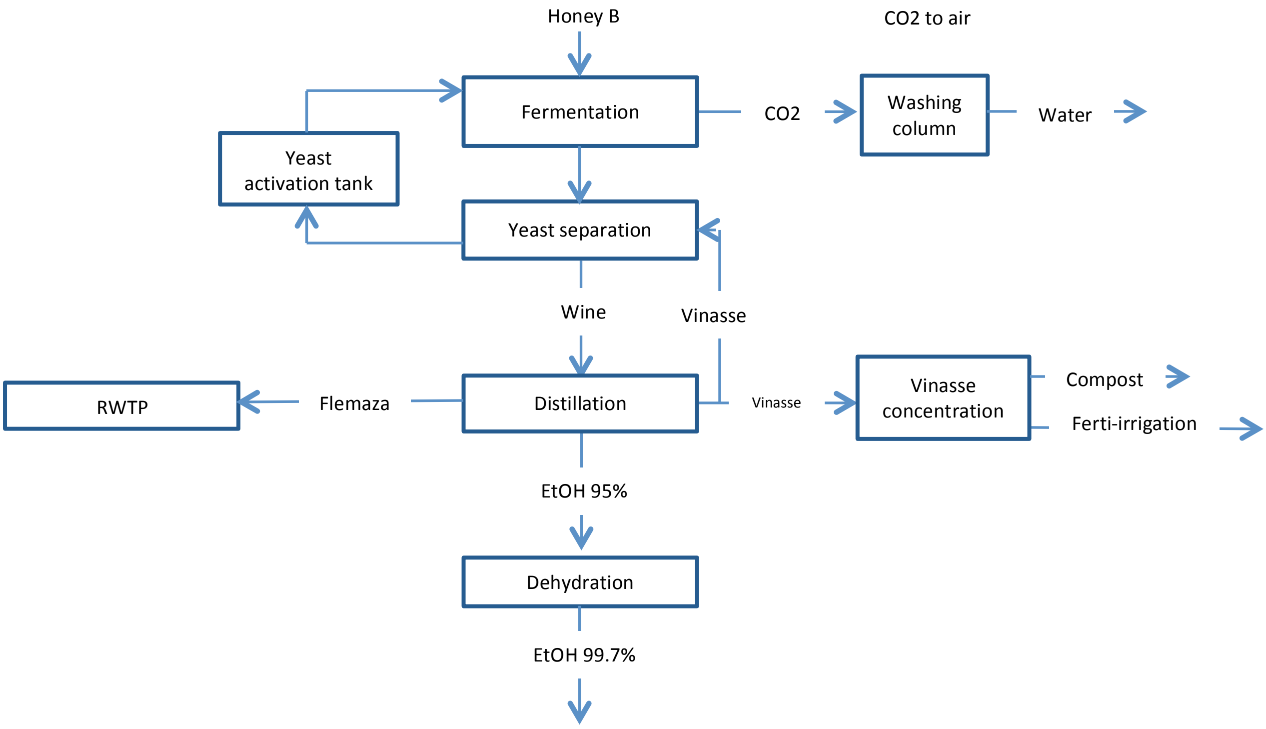
Source: Cue based on data field

6.3.2.4 Ethanol production

6.3.2.4.1 Introduction

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.

Figure 37 Summary of the sugarcane-based ethanol manufacture process



6.3.2.4.2 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 37 Inputs and energy employed in the ethanol elaboration process

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

Process	Input	Average Scenarion	SD	Optimized scenario	Ecoinvent reference
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

6.3.2.4.3 Infrastructure

The reference ethanol processing plant presented in Ecoinvent as “ethanol fermentation plant / p / CH / I” 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.

6.3.2.4.4 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 38 Transportation distances for ethanol production

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 of data field

6.3.2.4.5 Products and by-products

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

Table 39 Products, by-products, and residuals from the ethanol process

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.

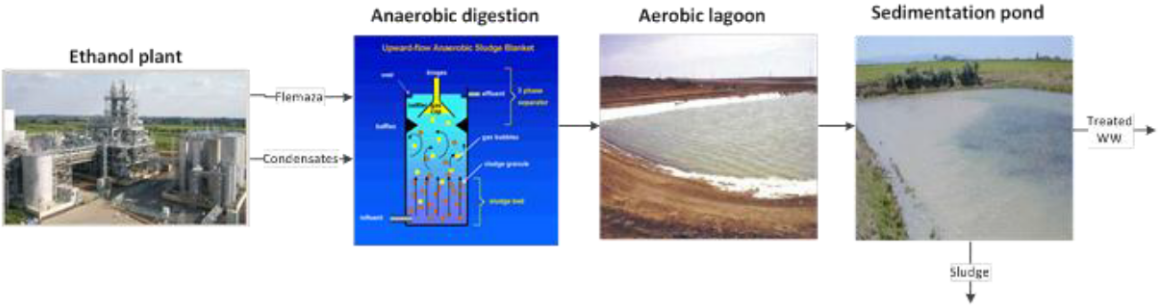
6.3.2.5 Water treatment

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 38 Residual Waters treatment.



(Source of illustrations: 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 10.

6.3.2.6 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.

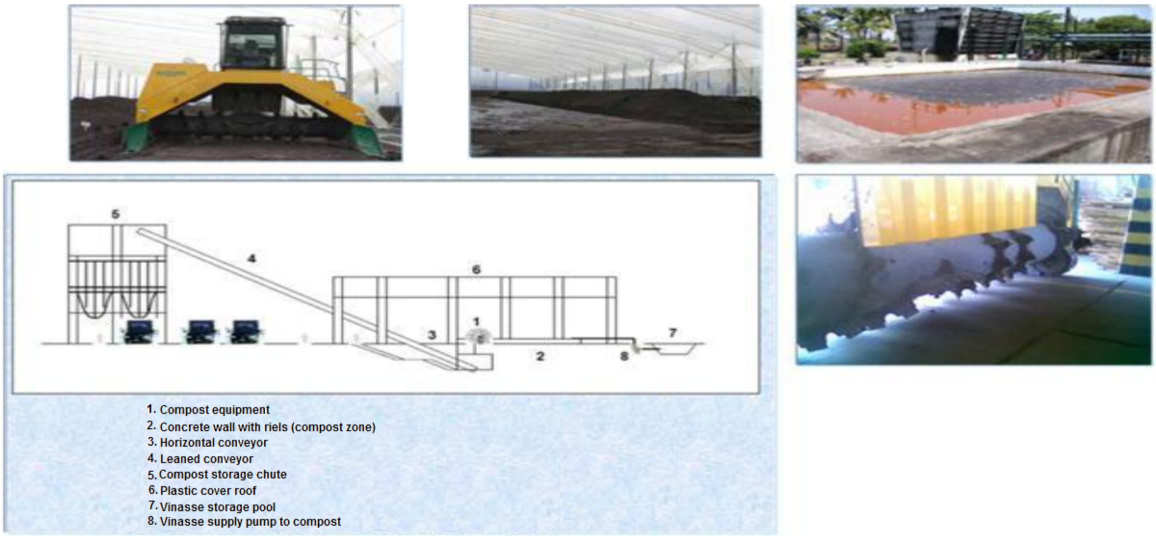
Vinasse addition (10-30 days): In the second step, the pile is mixed with vinasse in a ratio defined as a function of the humidity content of the mentioned pile. In general, it is applied in a proportion of 1:1.5. Such vinasse that comes from the evaporation processes (Flubex) is stored in a pool, from 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 39 Illustration of compost general process.



Mass balance for compost stage is presented in appendix 11.

6.3.2.6.1 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.

6.3.2.6.2 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.

6.3.2.6.3 Material outputs

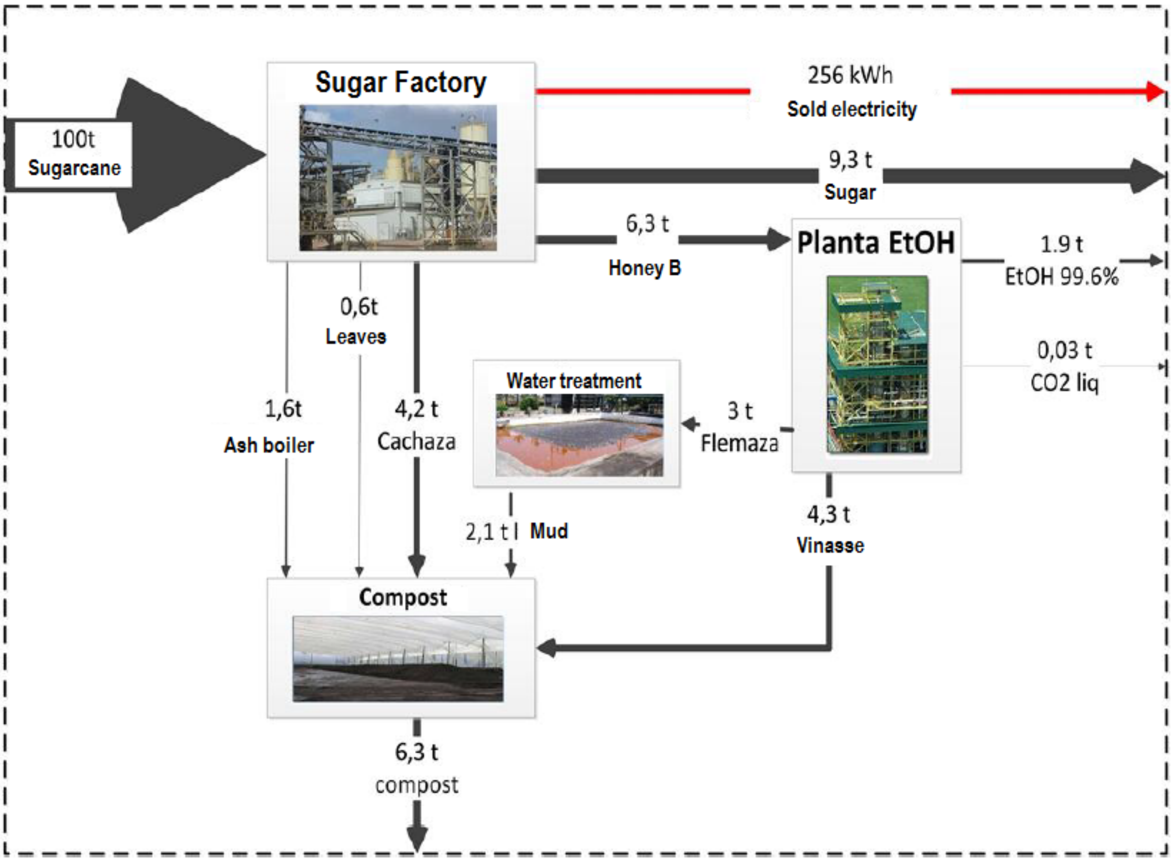
Compost is applied in the sugarcane plantation fields or in other local agricultural areas using the recommended application ratio of 9-15 tons per hectare.

6.3.2.7 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:

6.3.2.7.1 Mass flow within the ethanol value chain

Figure 40 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).

6.3.2.7.2 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 40 Allocation factors for the ethanol production (Average scenario)

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 41 Allocation factors for the ethanol production (Optimized scenario)

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 42 Economic value of the products of the sugar refinery and ethanol plant

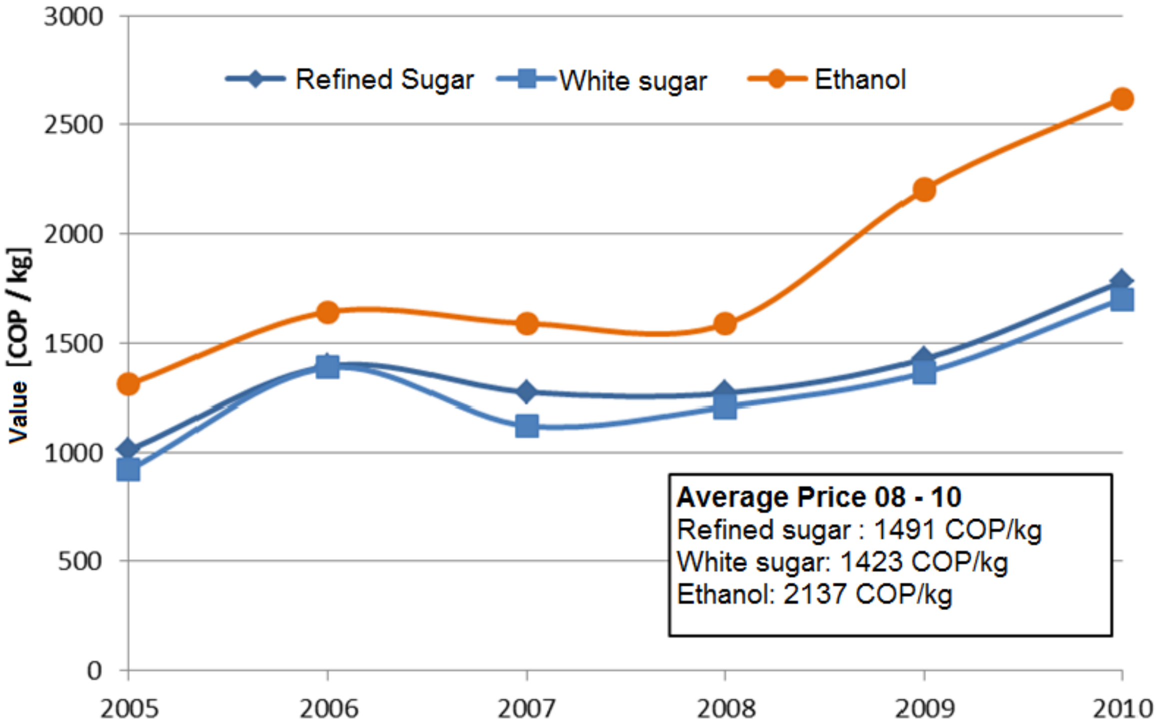
Economic values of the products of the sugar refinery and ethanol plant (COP/k unless indicated otherwise)			
Product	**Value**	**Description**	**Reference**
White sugar	1423	Average prices from 2008 to 2010. Prices were weighted regarding volumes and prices of national and export markets	(Asocaña 2011)
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 41 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).

Energy value

Table 43 Energy value of of the sugar refinery and ethanol plant

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	-	-

6.3.3 Palm oil crop cultivation

6.3.3.1 Introduction

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 42 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 43 Main cultivation zones for palm oil in Colombia 2008

Source: Fedepalma, 2009

6.3.3.2 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 48 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 44 Palm oil plantation and sampling areas (East, North and Central regions)

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

6.3.3.3 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 44 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.

6.3.3.4 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.

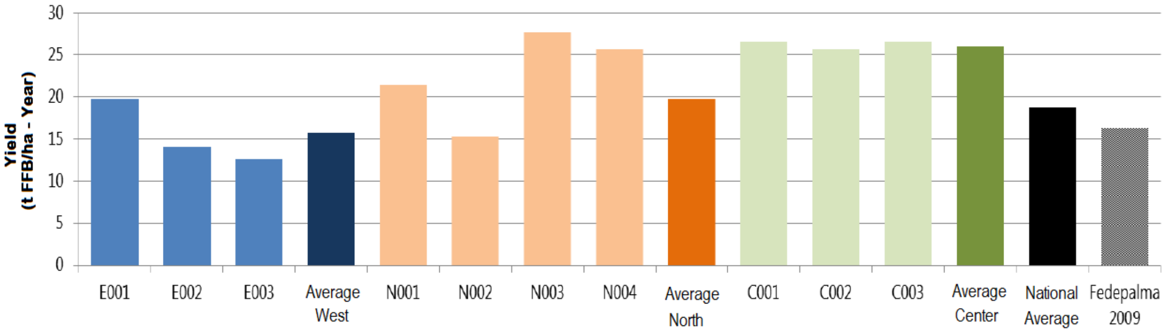
Table 45 Annual yields of production per zone

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.

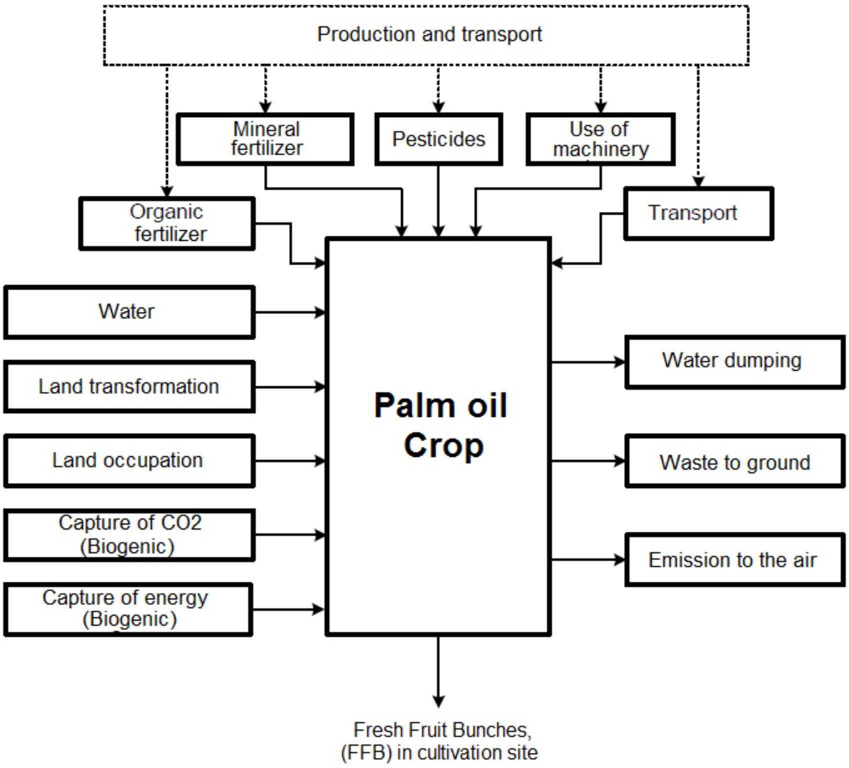
Figure 45 Palm productivity in the study locations



6.3.3.5 System characteristics

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

Figure 46 Chart on palm oil inventory process



6.3.3.6 Raw materials and auxiliary materials

6.3.3.6.1 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 P_2O_5, MgO, K_2O and B_2O_3. The amount and the type of fertilizer applied depends on local conditions and on the farmers’ budget.

Table 46 Inputs of mineral fertilizers for the different palm oil plantation zones

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

6.3.3.6.2 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 47 Nutrients composition in palm oil fruit residues in both wet and dry weights

Nutrients composition in "tusa" 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 48 Fertilizers inputs in kg/ha/y for different cultivation areas

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

6.3.3.6.3 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.

6.3.3.7 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)

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.

Figure 47 From collecting task up to loading in trucks (palm oil)

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 48 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 49 Fuel consumption of the different palm oil plantation areas

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

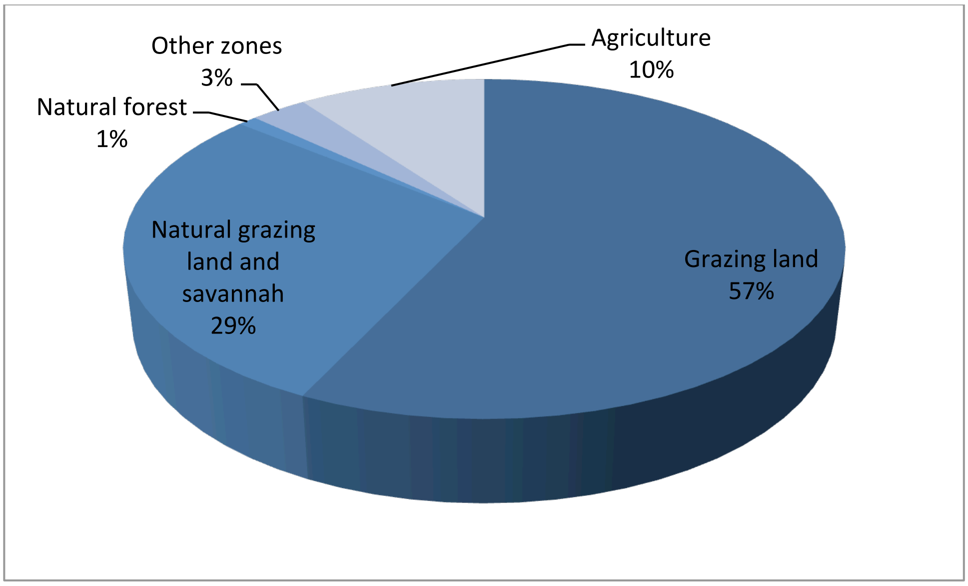
Source: CUE based on data field

6.3.3.8 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 49 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 1 of IPCC. Values of carbon reserves were also taken from the literature and calculations are presented below:

Table 50LUC Parameters for different palm oil plantations

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

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.

6.3.3.9 Carbon absorption and energy from biomass

Absorption of carbon dioxide is calculated from the carbon content of FFB’s (1.14 kg of CO_2 per kg of FFB) (Jungbluth et al., 2007).

6.3.3.10 *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 51 Emissions to the atmosphere due to fertilizer application

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

6.3.3.11 *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 52 Water dumping by use of fertilizers

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

6.3.4 Palm oil extraction and production of biodiesel

6.3.4.1 Introduction

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 53 Biodiesel plants and installed capacity

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	

Those companies labeled with a star (*) took part in the study

Source: MADR 2011

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 54 Average weight of the different palm oil producing companies

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

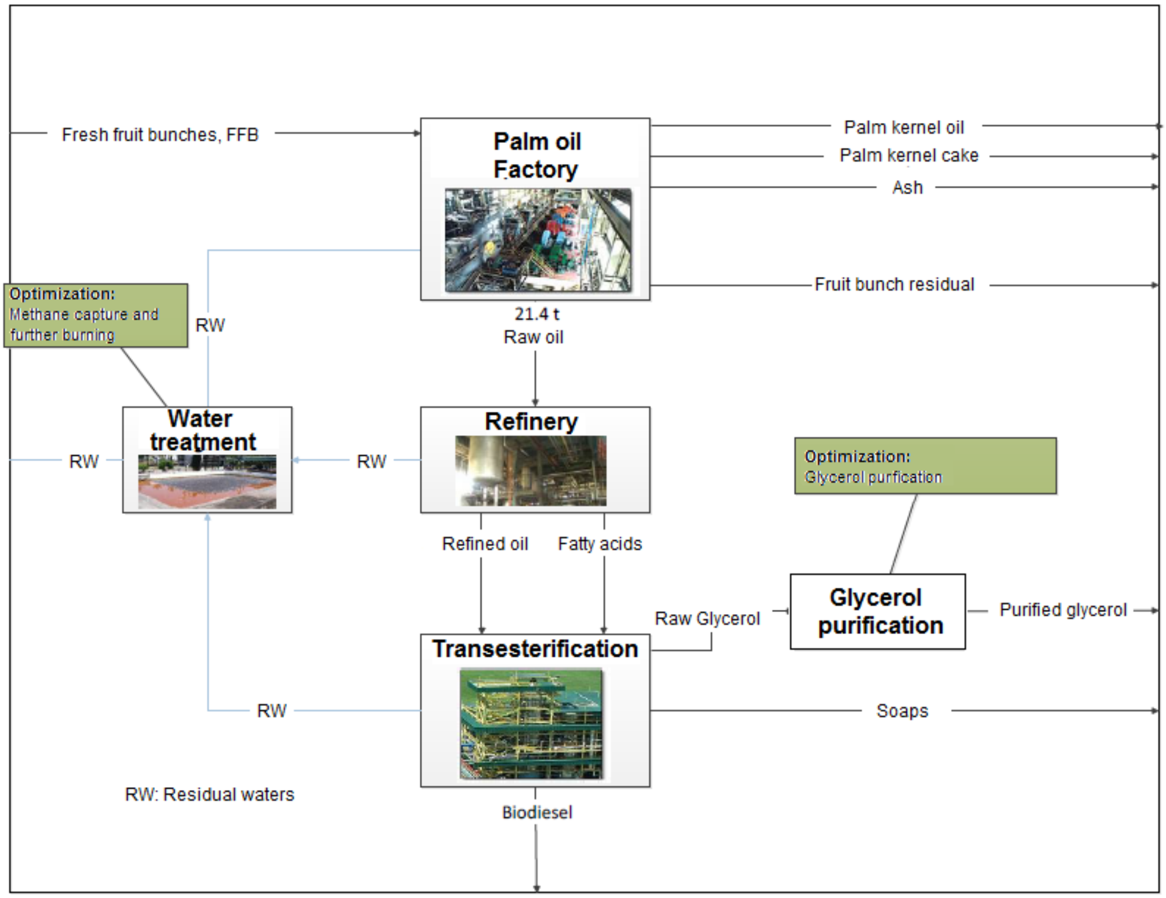
6.3.4.2 Description of the system

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 50 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.

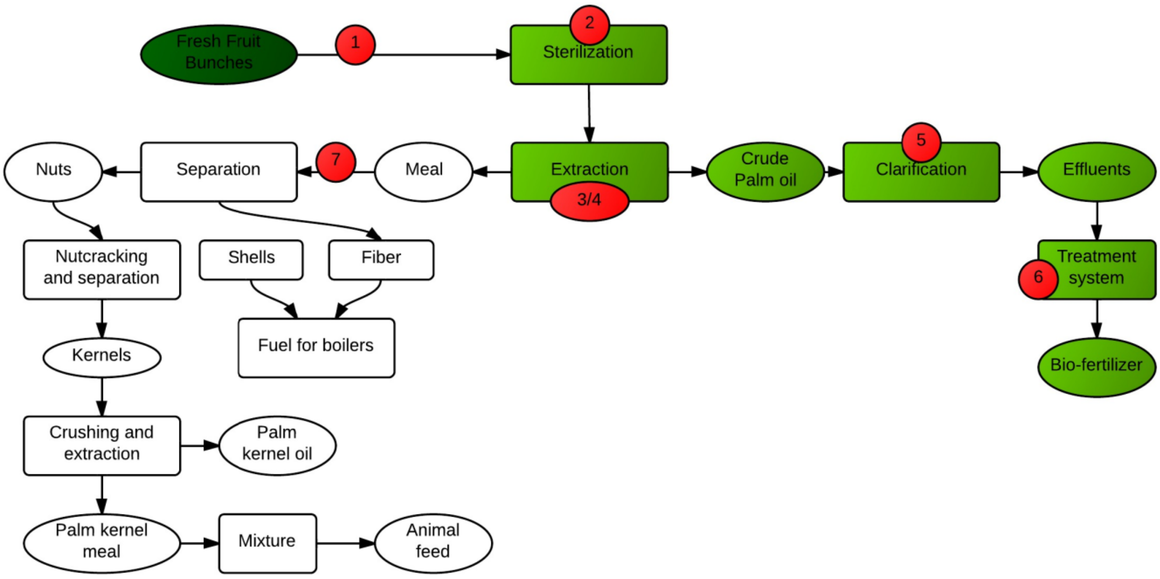
The average biofuel production inventory in Colombia was calculated in two stages. Firstly, all inputs and outputs of oil extraction plants and biodiesel production plants per every 100 tons of FFB's were calculated. Due to the fact that FFB's processing is an activity with multiple outputs, the share 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.

6.3.4.3 Palm oil extraction

6.3.4.3.1 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 51 System characterization for palm oil extraction



6.3.4.3.2 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 55 Inputs and energy requirements

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).

6.3.4.3.3 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 56 Outputs from oil extraction of 100 tons of FFB (ton)

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

6.3.4.3.4 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 57 Properties of the FFB, fiber and shells

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 14.

6.3.4.3.5 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 58 Process Infrastructure of the Palm oil mill plant

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

6.3.4.3.6 Transport

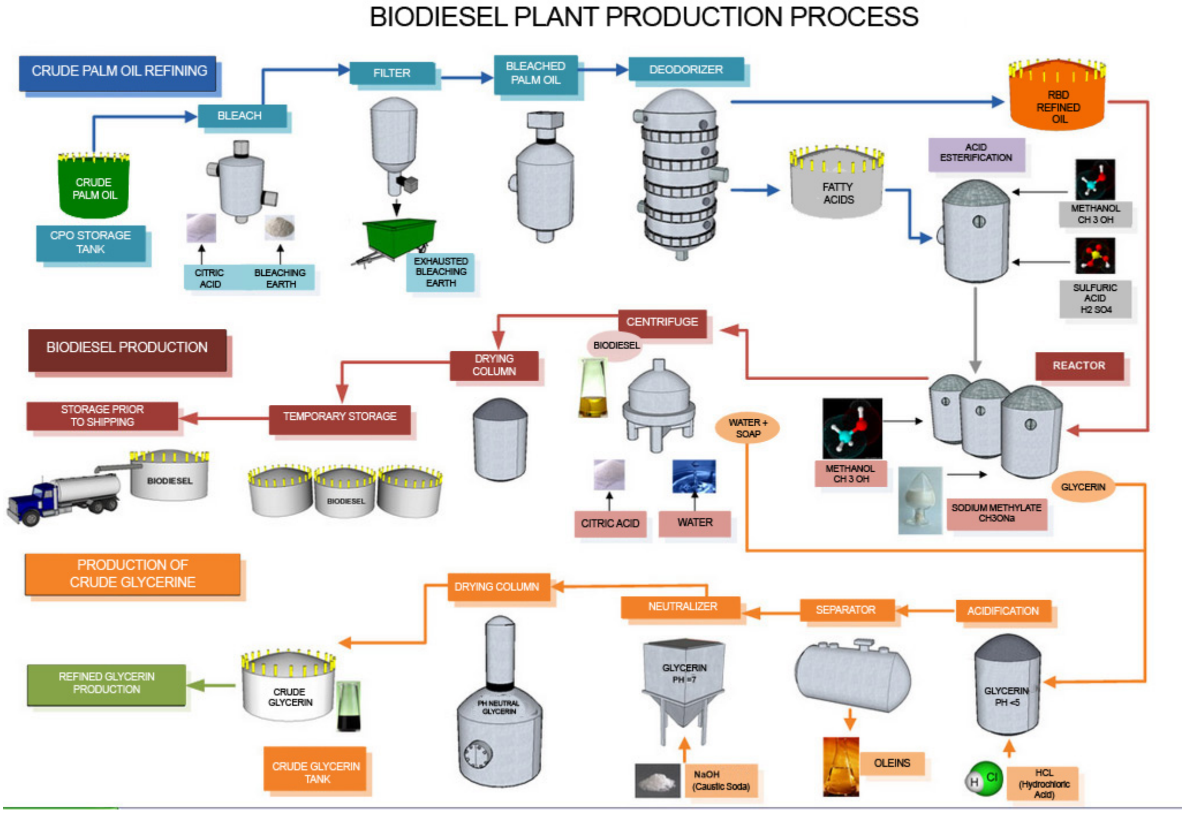
Transportation of FFB's from the crop field to the extraction plant is already considered in the cultivation stage. Transportation of machinery and equipment is embedded within the set of data for infrastructure.

6.3.4.4 Refinery and biodiesel plant

6.3.4.4.1 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 52 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 59 Processes description of palm oil refining and biodiesel processing

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)

6.3.4.4.2 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 60 Inputs and energy requirements of a palm oil refinery

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 61 Inputs and energy requirements for the biodiesel plant

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

6.3.4.4.3 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 62 Outputs from the refining oil plant per 1 ton of oil

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 63 Outputs from the transesterification process per 1 ton of palm oil biodiesel

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

6.3.4.4.4 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).

6.3.4.4.5 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.

6.3.4.4.6 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.

Table 64 Transportation distances for palm oil refining and transesterification

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

6.3.4.5 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.

6.3.4.6 General vision of the inventory and allocation process

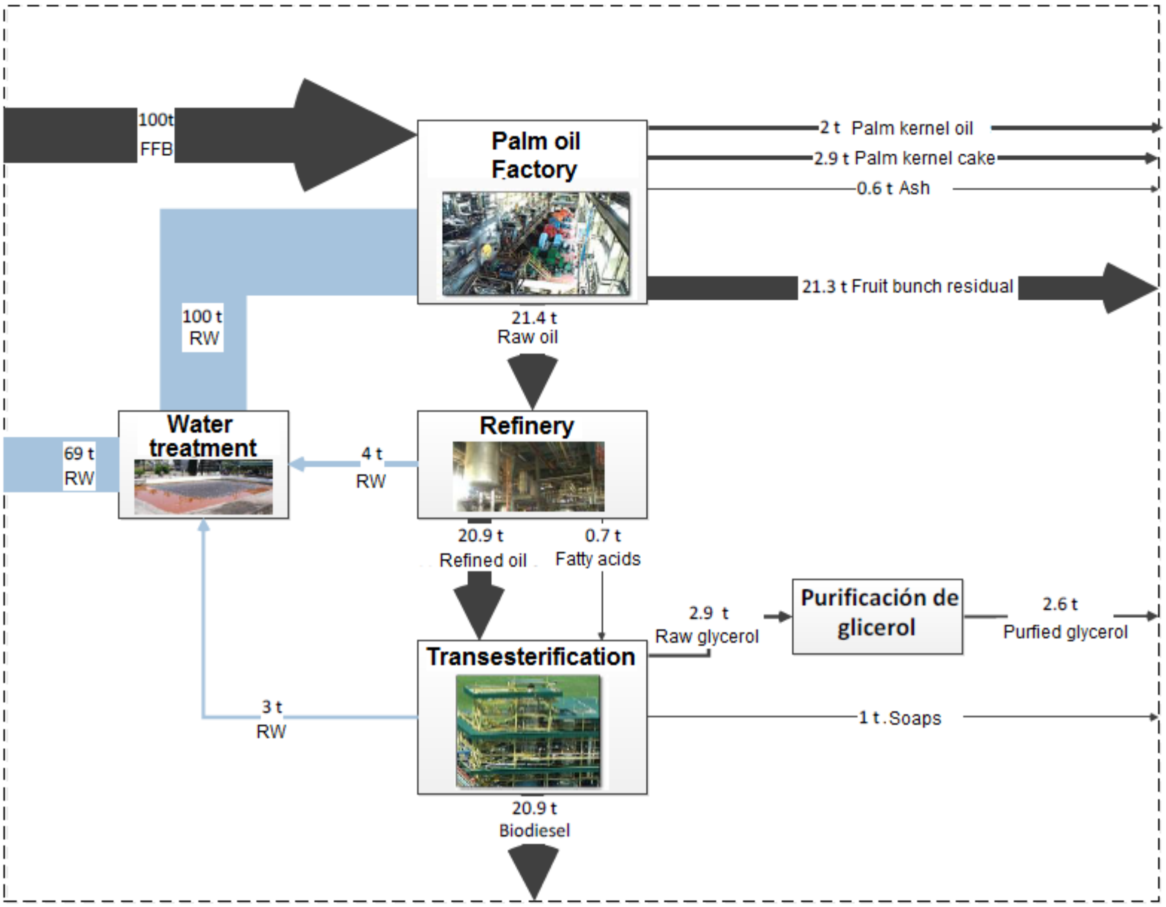
The following section will present data referred to as 'main flows of materials, prices and energy values'. This collection of data, in turn, determines allocation factors.

6.3.4.6.1 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.

The following 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.

Figure 53 Mass flow for biodiesel production (per every 100 tons FFB)



6.3.4.6.2 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 65 Economic Value of those by-products from Fresh fruit bunches

Economic Value of those by-products from 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

Energy allocation

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

Table 66 Energy Value of those by-products from Fresh Fruit Bunches

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

6.3.5 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.

6.3.5.1 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.

6.3.5.2 Transportation of palm oil-based biodiesel to Bogotá

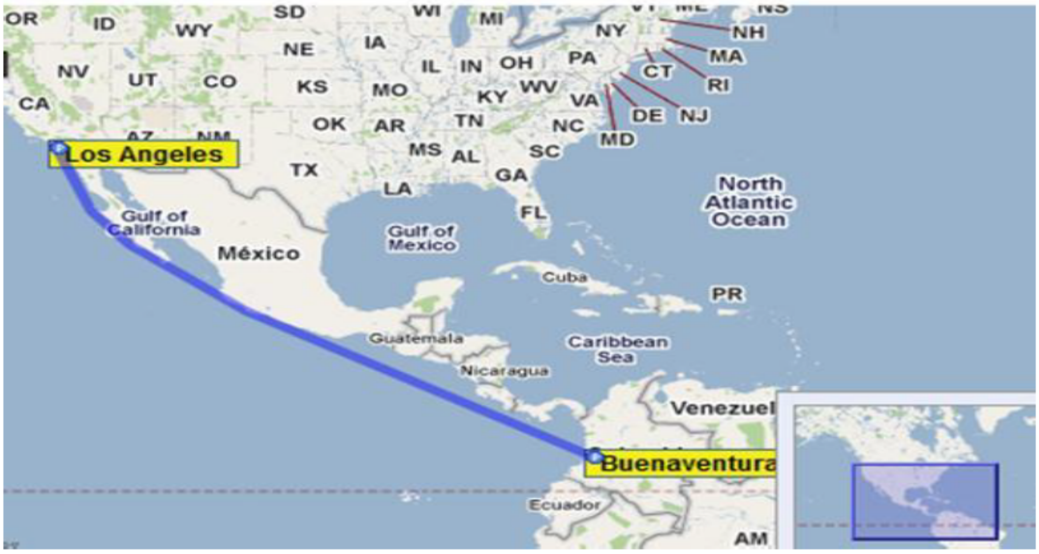
Biodiesel is normally transported in a tank truck. Moving distances from a specific biodiesel plant to the blending station in Bogota (Puente Aranda) are presented as follow:

• 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.

6.3.5.3 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 54 Distance from Buenaventura port to Los Angeles



Source (www.searates.com)

6.3.6 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 55 Distance from Santa Marta to Los Angeles

6.3.7 Use of fuels in vehicles

6.3.7.1 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.

6.3.7.2 Fuel use and consumption of a Renault Logan

6.3.7.2.1 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 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.

6.3.7.2.2 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".

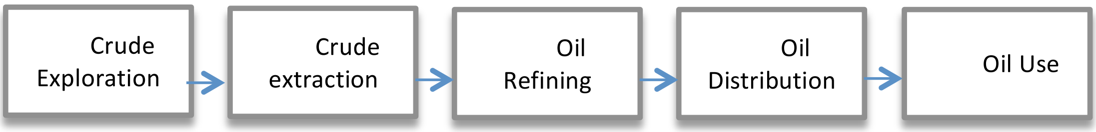
Fuel consumption is 0.055828 kg/km (6.65 L/100 km) in comparison with 0.0444 kg/km (5.29 L/100 km) for the diesel based Renault Logan.

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.

6.3.8 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 56 Chart of the LCA for fossil fuels



6.3.8.1 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.

6.3.8.2 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 67 Fossil fuels production in Colombia

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 68 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

Compiled by the Author. Data source ANH website

6.3.8.3 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).

6.3.8.4 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 57 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)

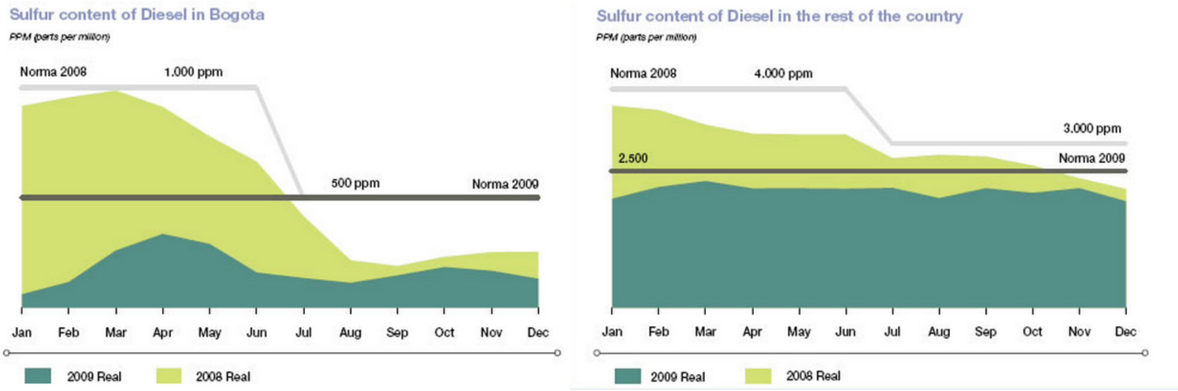
6.3.8.5 Transportation to the service station

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 below). 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 58 Sulphur content for Diesel (Colombia)



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

6.3.8.6 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 69 Fuel specification regarding Ecopetrol study

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:

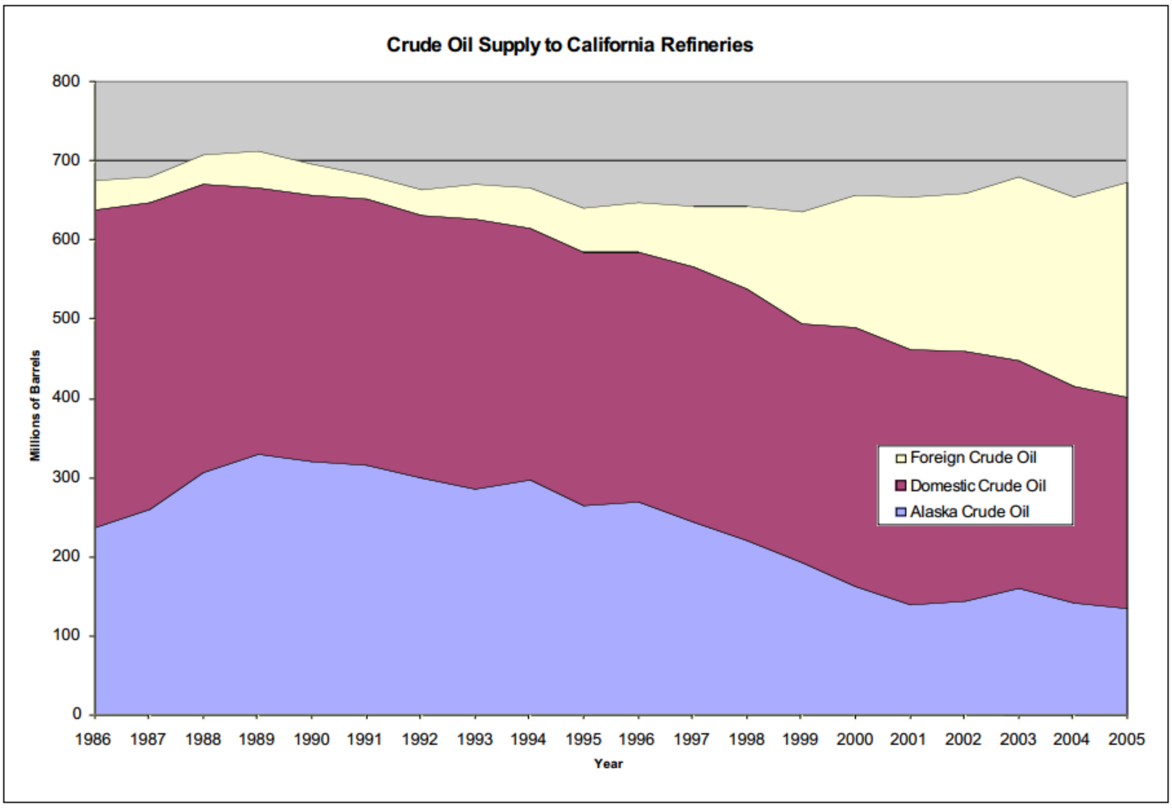
- crude extraction,
- transportation to refining facilities,
- refining and fuel transportation to blending station (Puente Aranda, Bogotá),
- Note: fuel distribution to final retailer’s station and infrastructure (i.e. buildings and machinery) are beyond the scope of this study.

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.

6.3.8.7 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 59 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 70 Crude oil composition from California

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.

6.3.9 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 71 Electricity matrix for Colombia

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		-

IEA (2010)

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

Table 72 Emission factors for generation and transmission of electricity

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 previous table.

6.4 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).

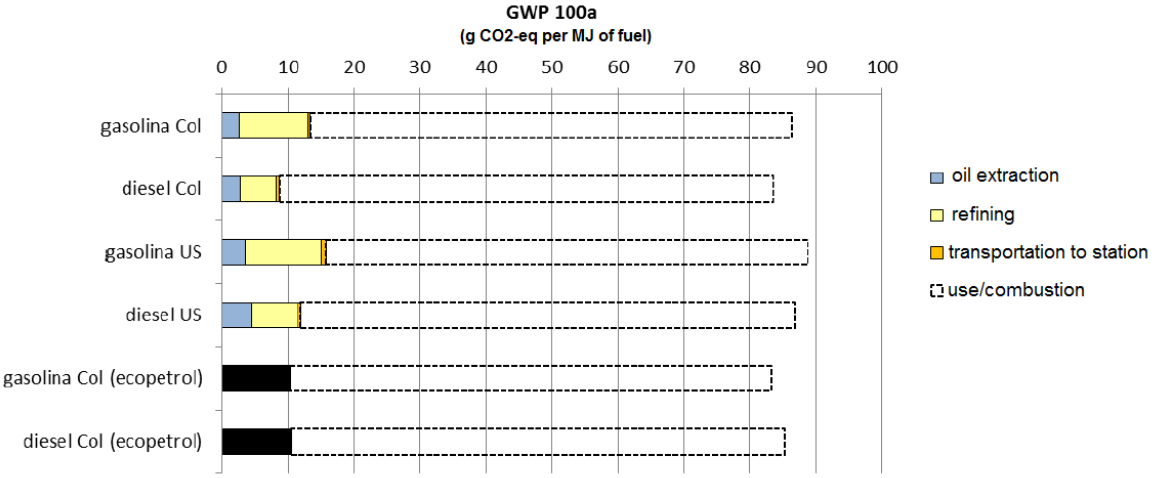
Midpoint indicators such as acidification eotriphication, ecotoxicity and particulate matter are discussed in appendix 4

6.4.1 Fossil fuels

6.4.1.1 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 60 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 73 Comparison of CO2 emissions from fossil fuels from different studies

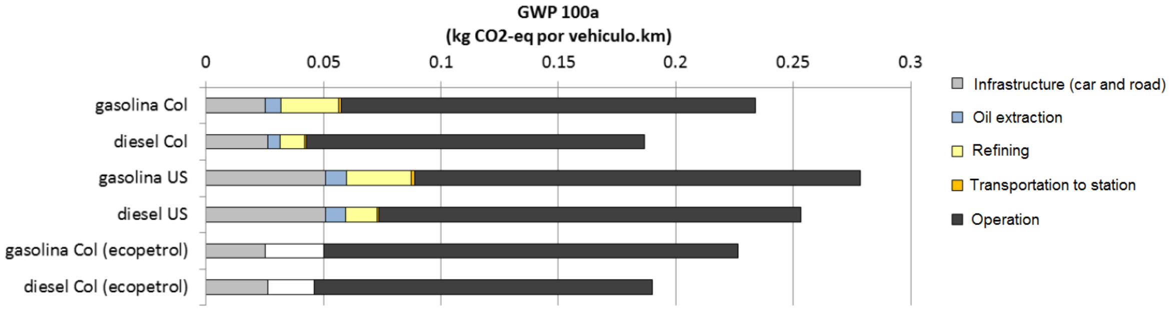
Comparison of CO2 emissions from fossil fuels from different studies				
Country	**GHG's emissions (g CO2/ MJ fuel). Without combustion**		**GHG's emissions (g CO2/ MJ fuel). With combustion**	
	Gasoline	**Diesel**	**Gasoline**	**Diesel**
Colombia	13.43	8.73	86.39	83.5
Colombia (Ecopetrol data)	10.3	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.

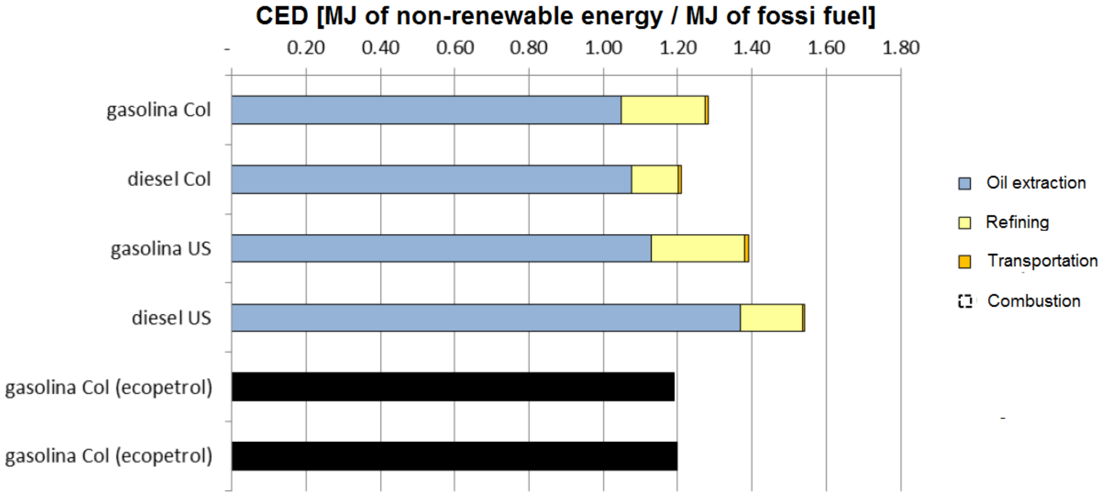
Figure 61 GHG emissions for fossil fuels per v.km



6.4.1.2 Cumulative energy demand

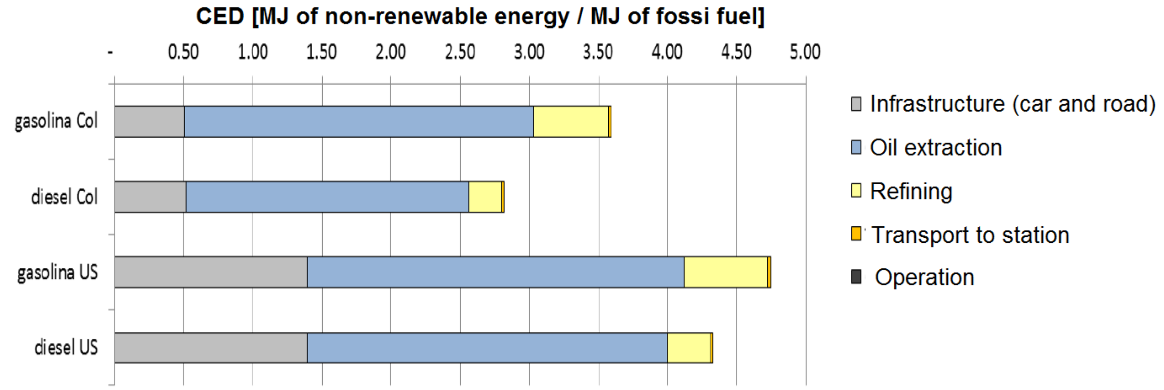
As it is shown in the figure below, production of 1 MJ of fossil fuel requires an entry of 1.2 to 1.5 MJ, depending on the mix of crude oil and the chosen transformation path (technological treatment).

Figure 62 Cumulative non-renewable energy demand per MJ of fossil fuel



The previous figure 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 63 Cumulative non-renewable energy demand per v.km

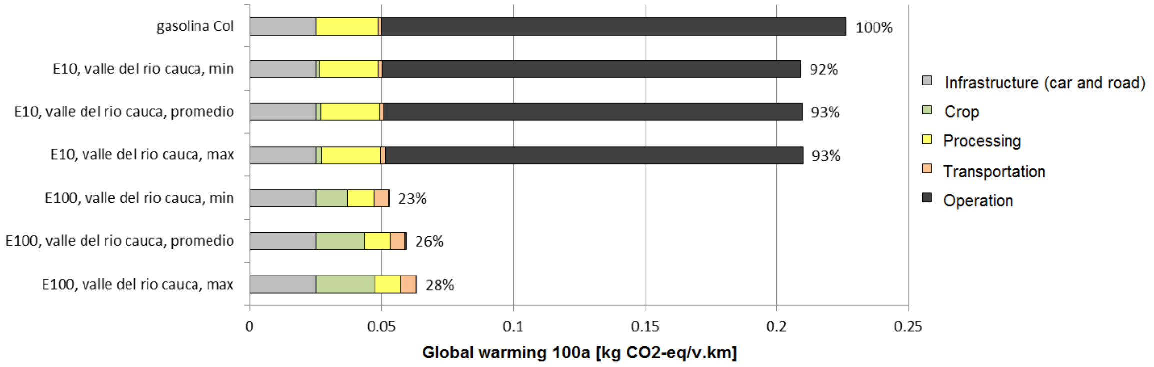


6.4.2 Sugarcane-based ethanol

6.4.2.1 Global warming potential

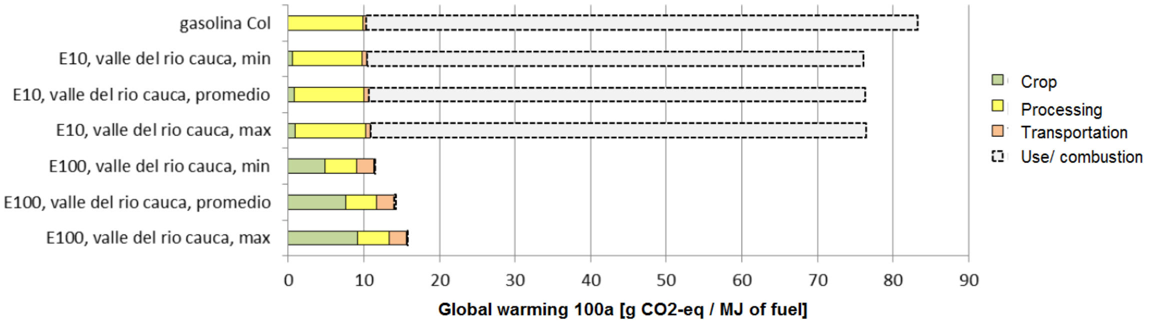
In a very broad sense, sugarcane-based ethanol production and use, emits less GHG in comparison with regular fossil-based gasoline. Per vehicle km. it emits between 53g to 63g of CO2 equivalent in comparison with fossil fuel (226g of CO2 eq. per v.km). If E100 is employed it is possible to reduce to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

Figure 64 Global warming potential of sugarcane ethanol in CO2 eq v.km



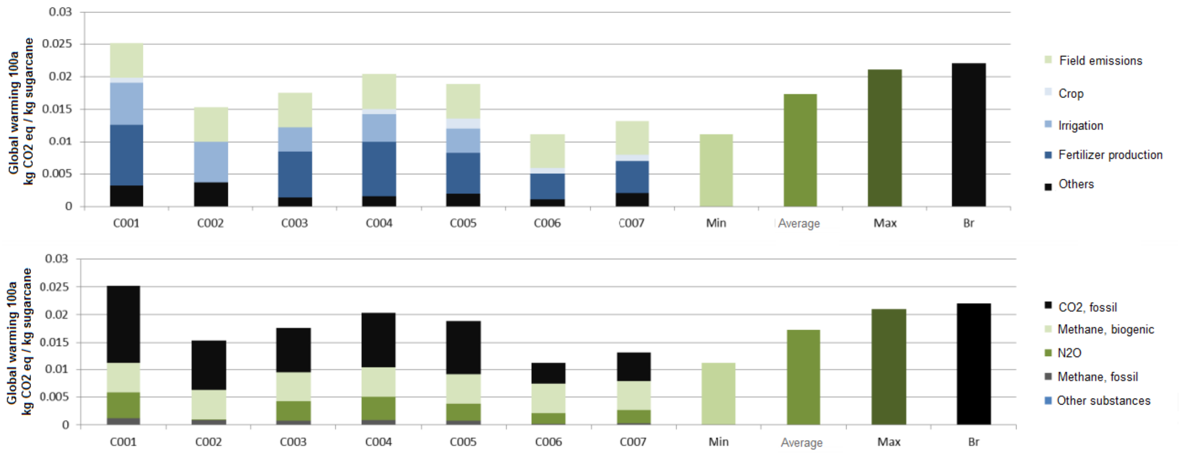
The figure below reveals impacts of ethanol transportation to the service station in Bogotá and they are shown in g per MJ. Each MJ of fuel (excluding infrastructure) composes between 12g to 16g per MJ. The GHG emissions of the ethanol production are superior to fossil fuels production, but the former creates a high contribution of gases during combustion. Notwithstanding, if combustion is taken into the account the figure 65 appears again.

Figure 65 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.

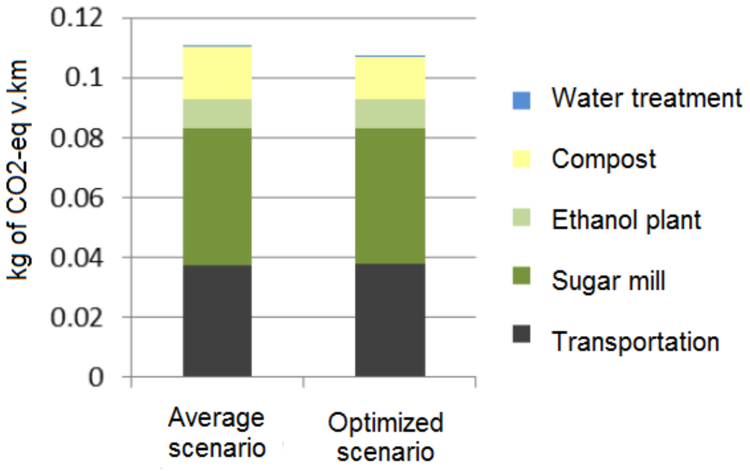
Figure 66 Global warming potential for sugar crop in CO2 eq per Kg of sugarcane



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.

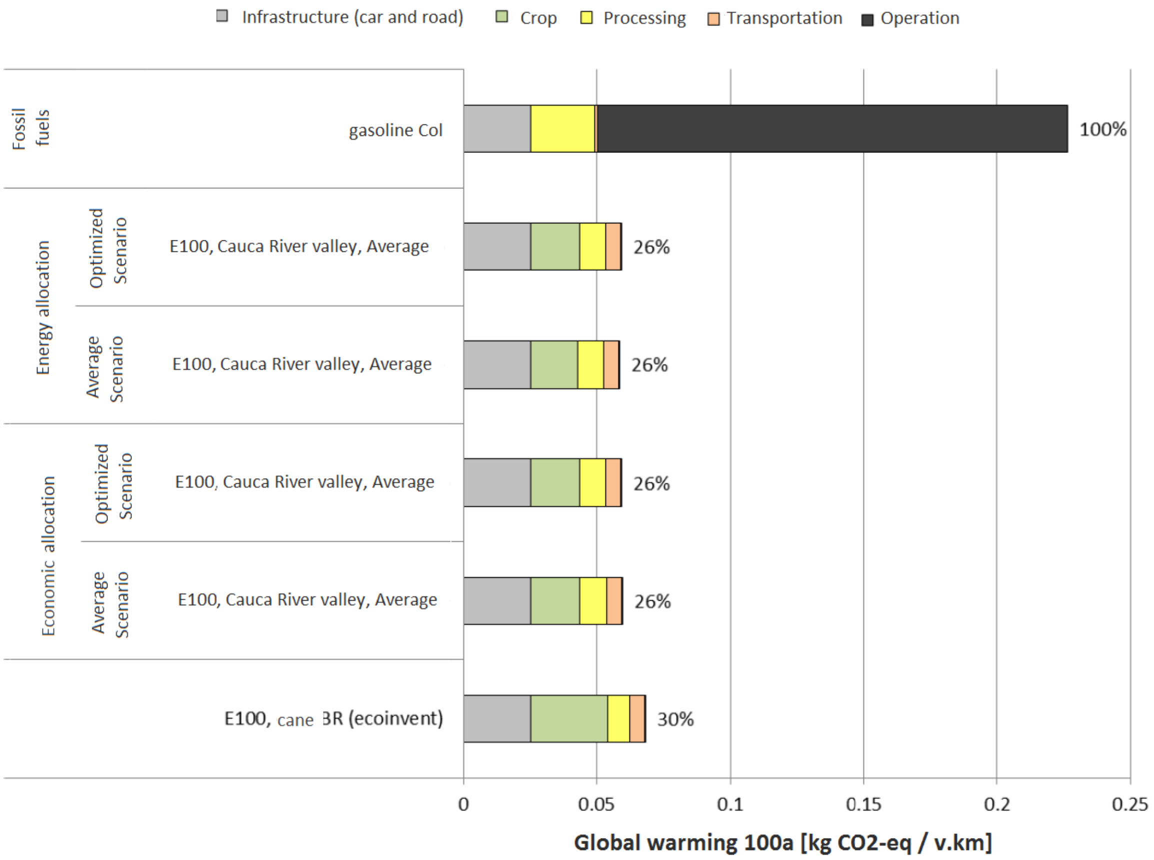
Figure 67 Global warming potential for sugar processing divided by process



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 68 Sensitivity analysis of the allocation method for ethanol

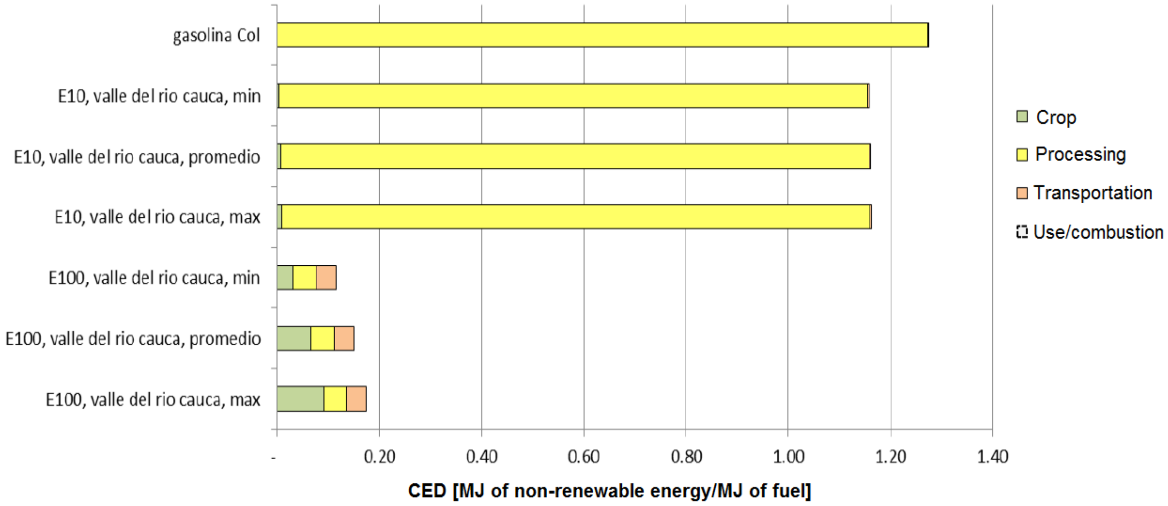


The figure above exhibits impacts on the economic and energy allocation for the average national scenario and also for the optimized one in comparison with fossil fuels.

6.4.2.2 Accumulated energy demand

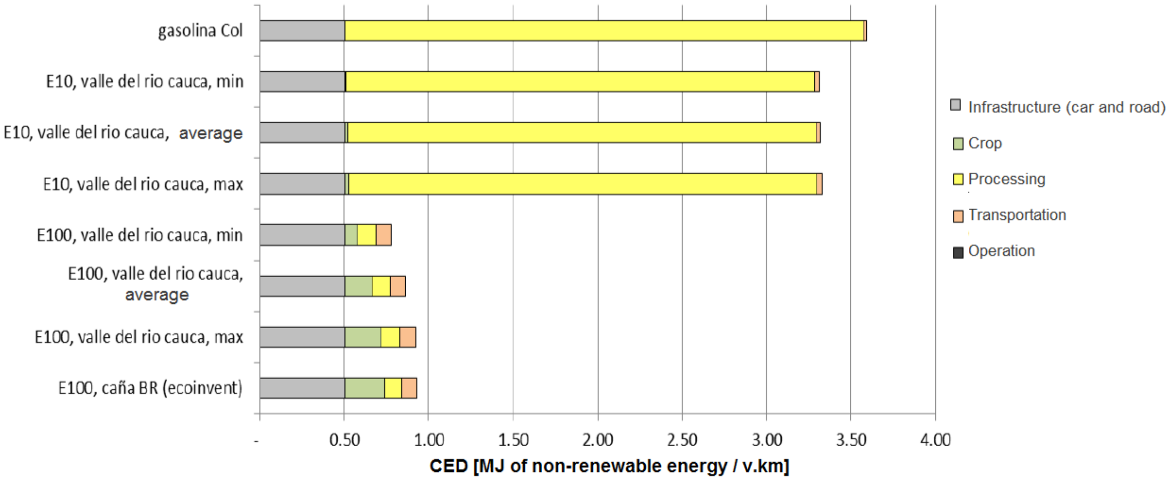
Accumulated energy demands of non-renewable energy for ethanol fuelled vehicles is less than the one presented by those fed by fossil energy (with a factor between 7 and 11). Energy return, assessed as the amount of MJ as output per every MJ used as input fluctuates between 6 and 8, depending on the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

Figure 69 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 70 CED of sugarcane ethanol in MJ of non-renewable energy per v.km

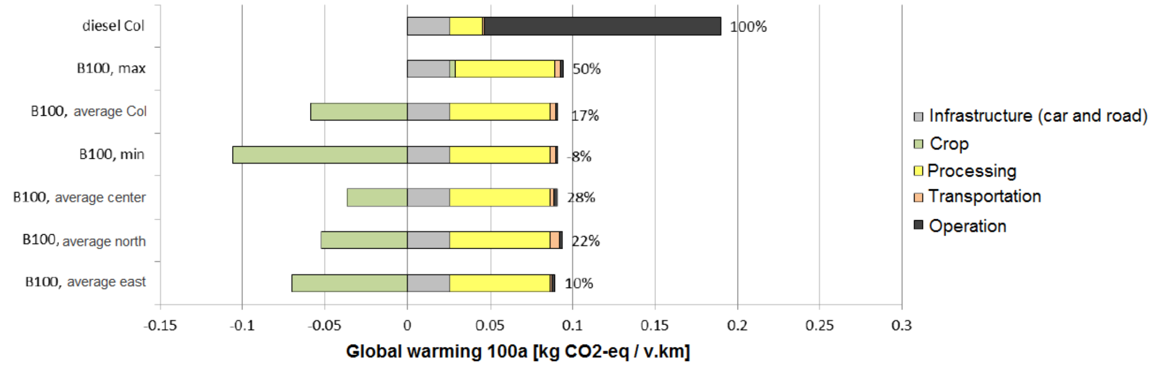


6.4.3 Palm oil biodiesel

6.4.3.1 Global warming potential

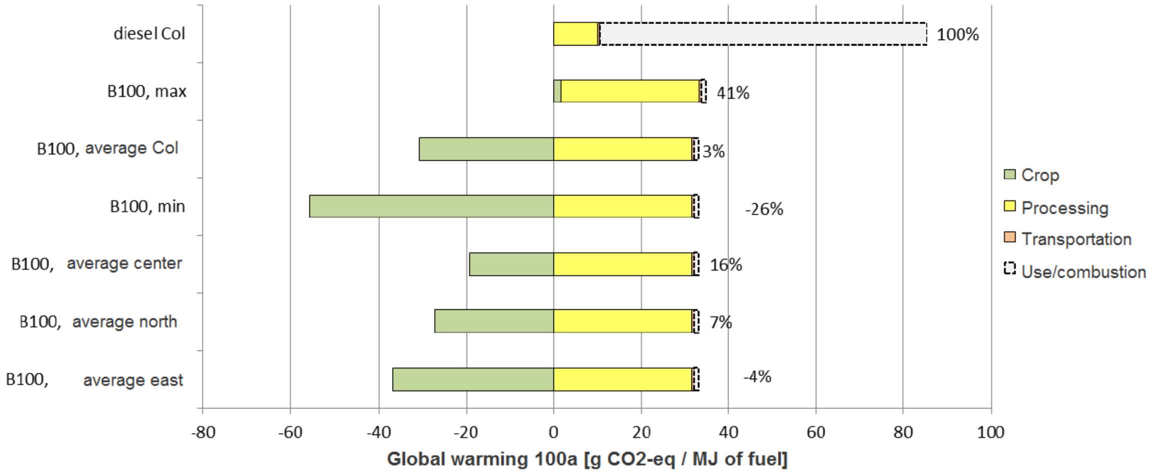
In a very broad sense, it is possible to assert that production and use of diesel from biological origin creates fewer emissions in comparison with its equivalent fossil substitute. Per vehicle km there is an emission between 14g and 94g of CO2 equivalent in comparison with fossil fuels (190g of CO2 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 71 GWP for palm oil biodiesel in CO2 eq per v.km



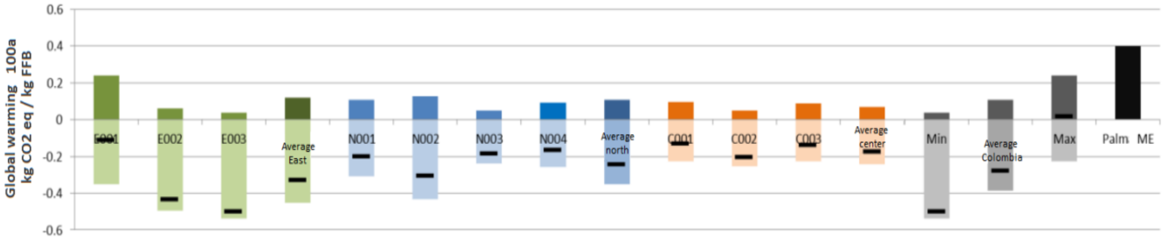
In the figure below the impact of biodiesel transported to the service station in Bogota are shown, is shown in g of CO2 per MJ of fuel. Per MJ of fuel and excluding the infrastructure, GHG emissions oscillate between 23 and 35 g of CO2 per MJ. GHG generation in biodiesel production exceeds the one corresponding 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 72 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.

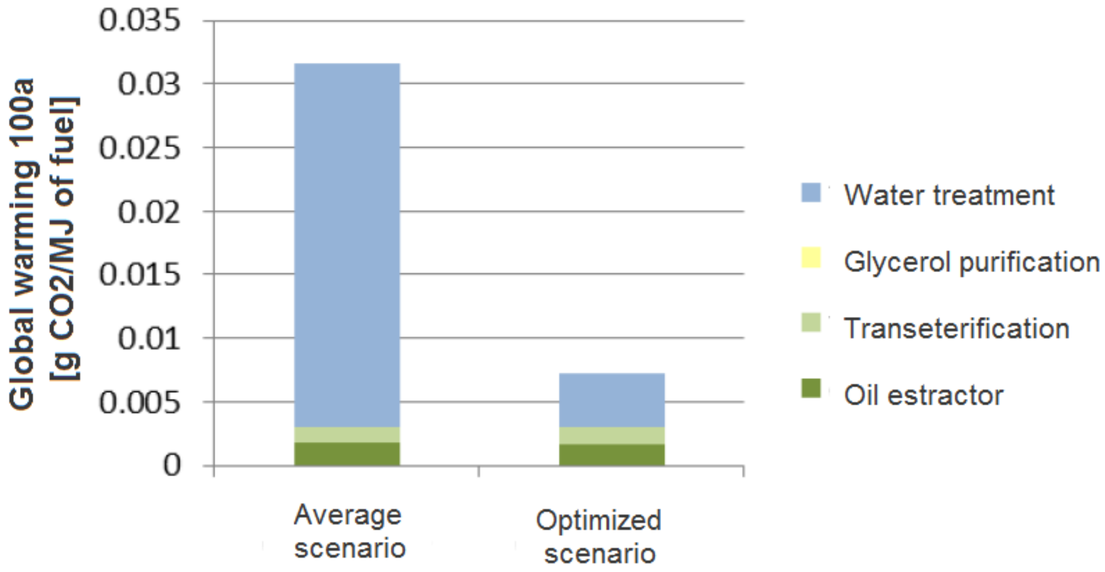
Figure 73 GWP for palm oil biodiesel in kg CO2 eq per kg of Fresh Fruit Bunch



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.

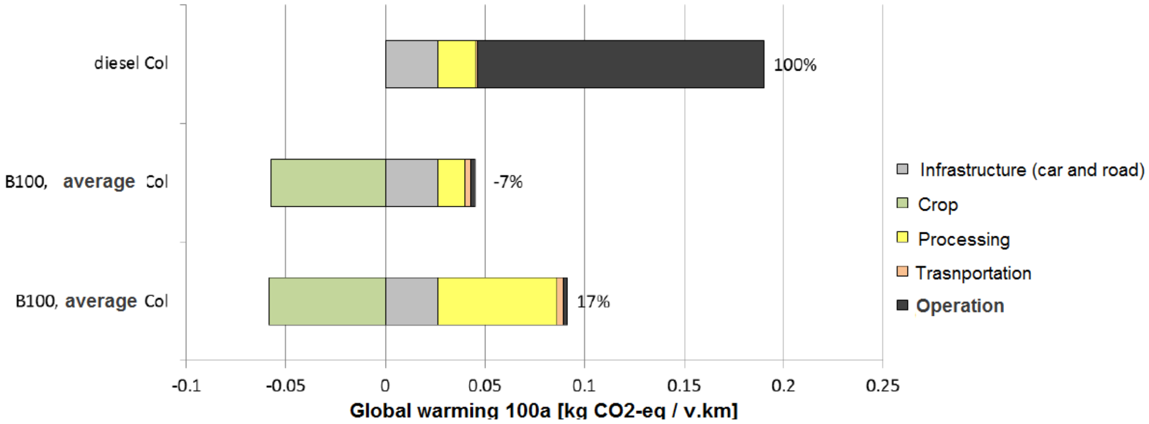
GHG emissions associated to palm oil processing (biodiesel production) are caused mainly by residual water treatment (90%), due to high emissions of methane. As is shown in the figure below, these impacts might be reduced 77% if the emitted biogas is captured and burned (therefore is emitted CO2 instead 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 74 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%).

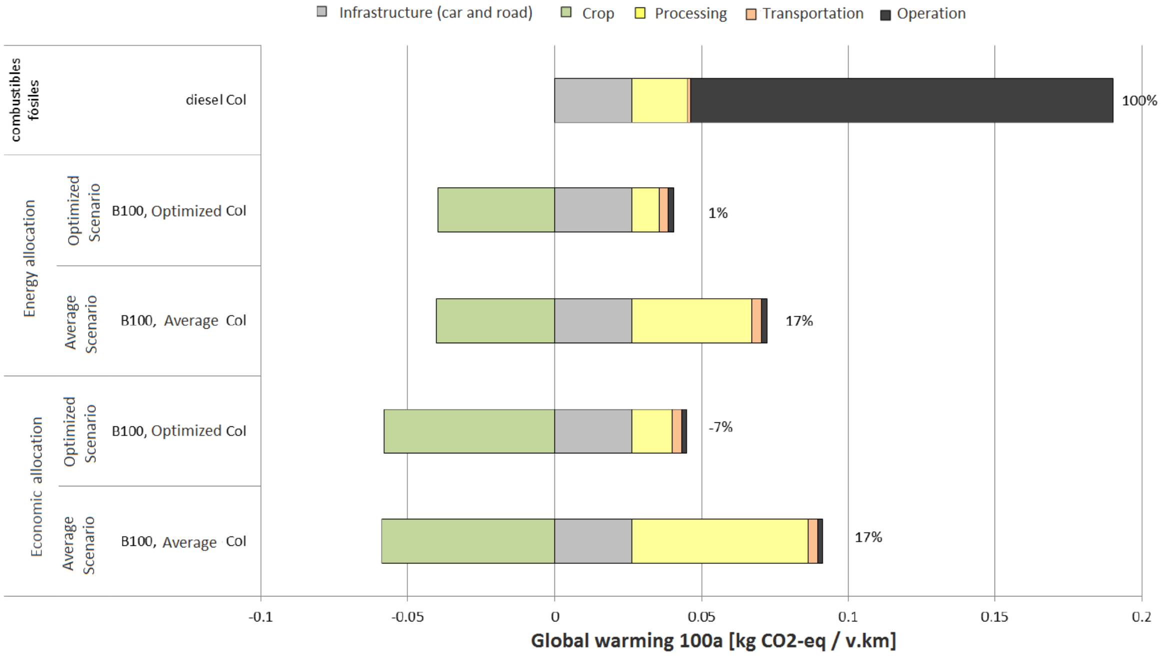
Figure 75 GWP for average and optimized scenarios in comparison with fossil fuels



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 76 Sensitivity analysis of the allocation method for palm oil biodiesel

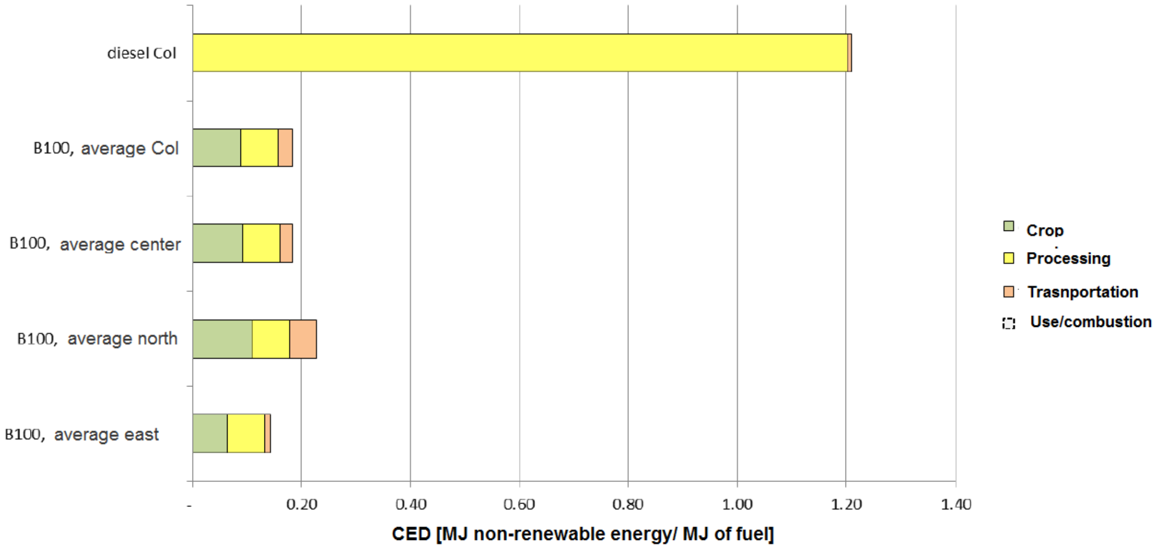


The figure shows the impact based on both economic and energy allocation for the two studied cases: average and optimized ones in comparison with fossil fuels.

6.4.3.2 Accumulated energy demand

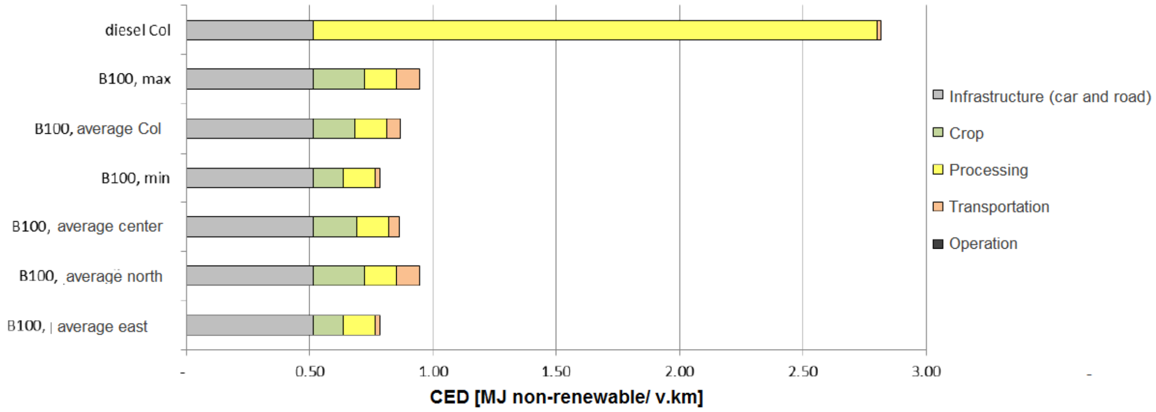
Accumulated energy demand for diesel fuelled vehicles is less than the one presented by those fed by regular diesel (with a factor between 7 and 11). Energy return, for the biodiesel case, fluctuates between 4 and 7, depending on the plantation intensity and on the productivity.

Figure 77 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 78 CED for palm oil biodiesel in MJ of non-renewable energy per v.km



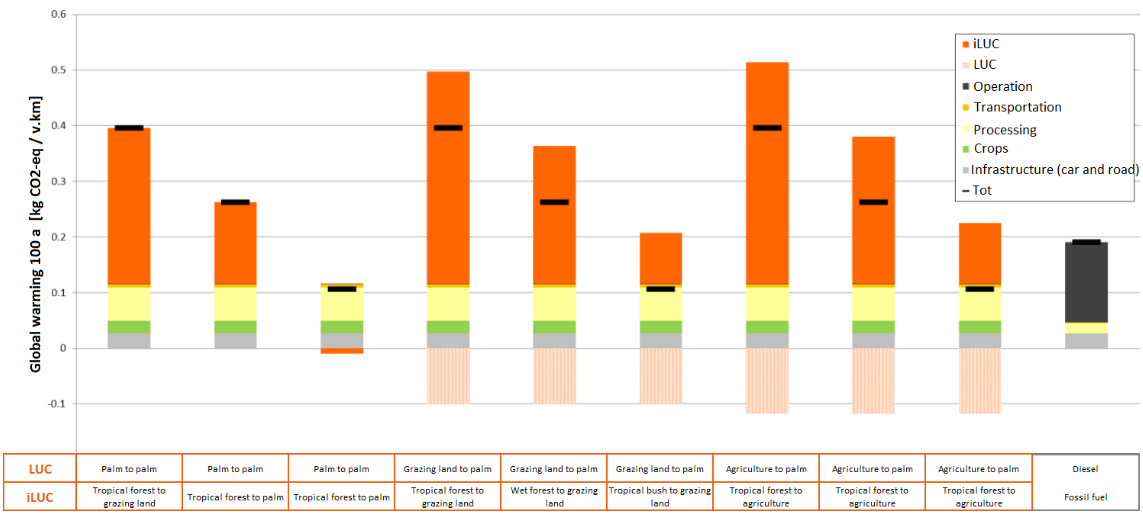
6.4.4 Indirect land use changes (iLUC)

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.

The next figure, 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.

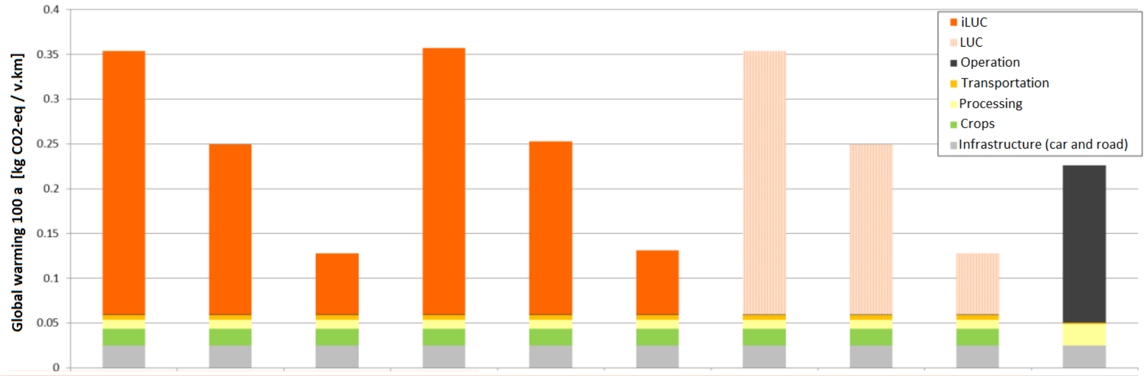
If the indirect displacement takes place in tropical or wet forests, the GWP of biofuels is even higher than in comparison with fossil references. On the contrary, if the displacement occurs in bushes or scrubland, the extent of impact will be less and the GHG balance of biofuels will be positive in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

Figure 79 Potential effects of iLUC caused by palm crops in Colombia



A similar situation is presented for the case of sugarcane, as is illustrated in the figure below. 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 80 Potential effects of iLUC caused by sugarcane crops in Colombia



LUC	S.cane to S.cane	S.cane to S.cane	S.cane to S.cane	Grazing land to S.cane	Grazing land to S.cane	Grazing land to S.cane	Tropical forest to S.cane	Wet forest to S.cane	Tropical bush to S.cane	Gasoline
iLUC	Tropical forest to S.cane	Wet forest to S.cane	Tropical bush to S.cane	Tropical forest to grazing land	Wet forest to grazing land	Tropical bush to grazing land	No	No	No	Fossil fuel

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.

6.4.5 Blending options and exports to California

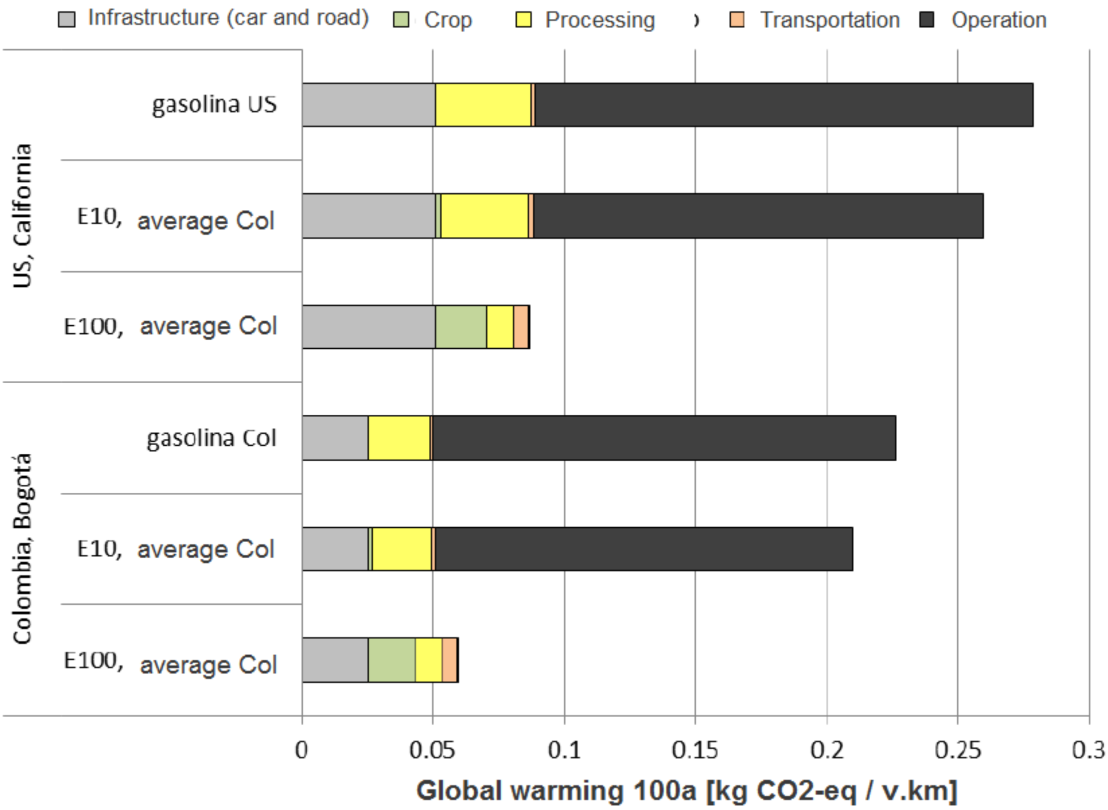
6.4.5.1 Global Warming Potential

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.

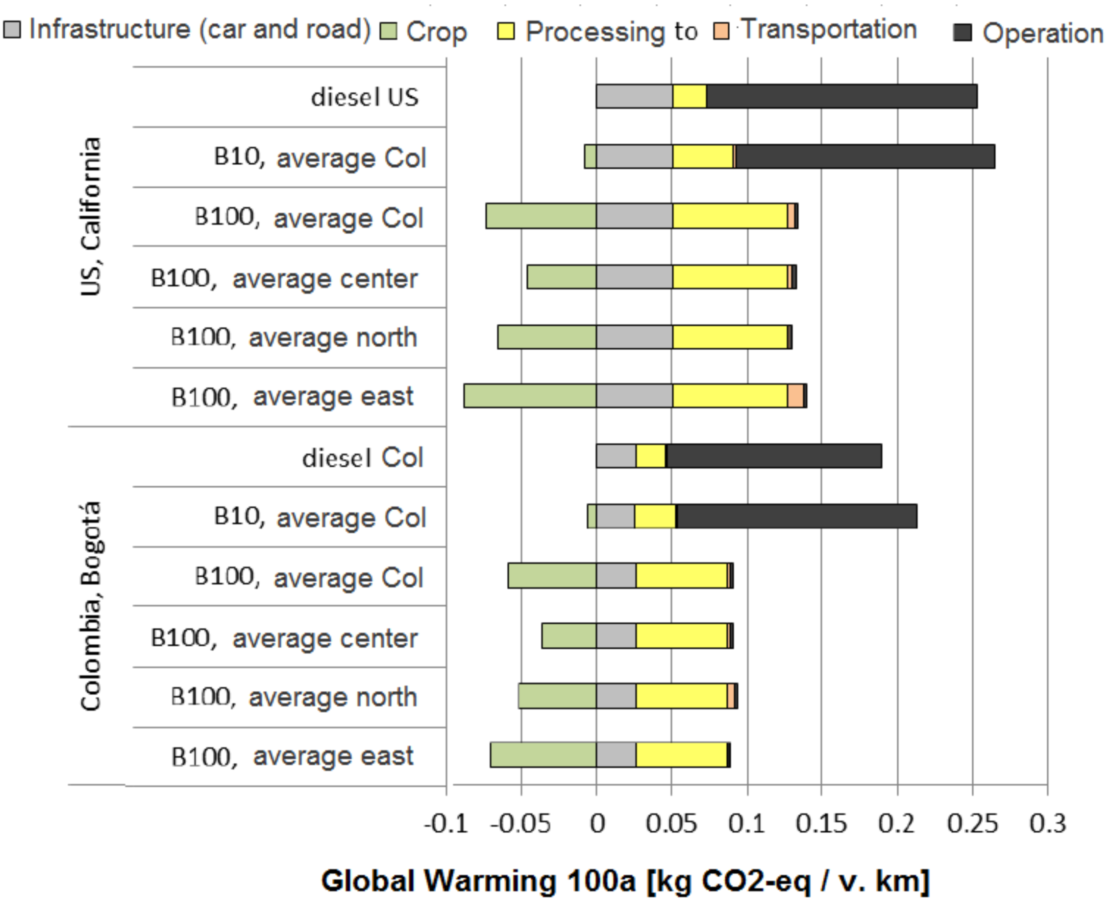
Figure 81 GWP for Ethanol
(Colombian Average E10 E100). Ethanol used in Bogota and California



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 82 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.

6.4.6 Comparison of Colombian biofuels with some other biofuels

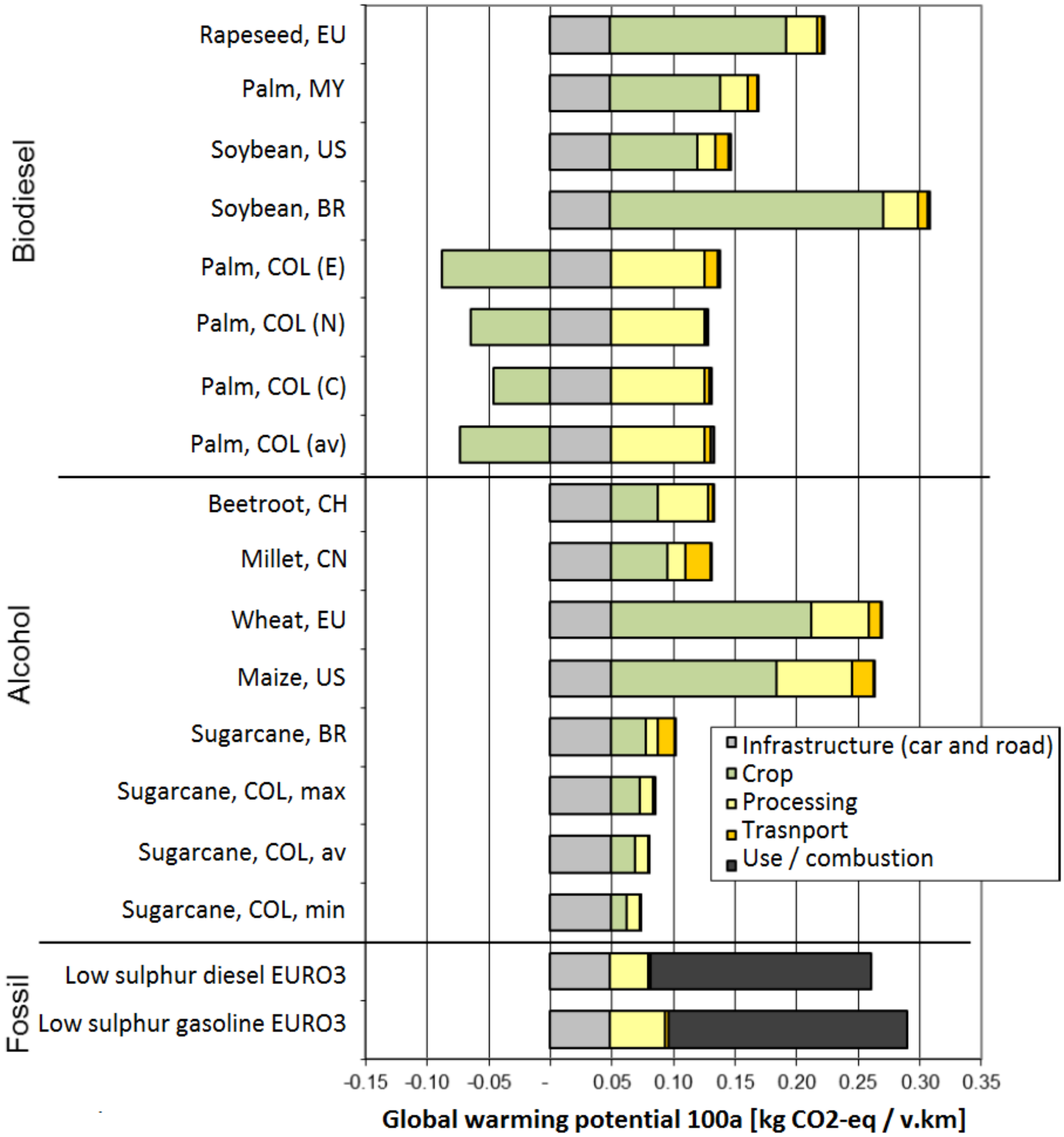
6.4.6.1 Global warming potential

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 CO_2eq (kg/pkm) and a performance of other crops (corn, beetroot, wheat) between 0.1 and 0.195 CO_2eq (kg/pkm). Lignocelullose ethanol fluctuates between 0.025 and 0.05 CO_2eq (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 CO_2eq (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 83 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).

6.5 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.

6.5.1 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:

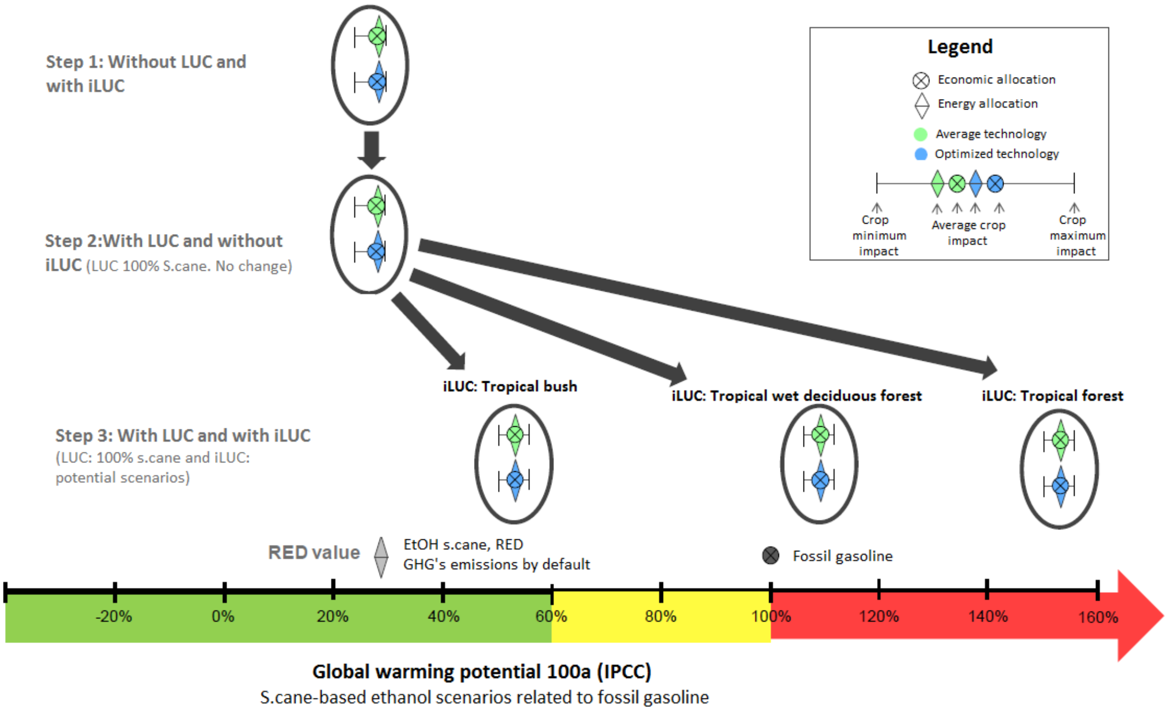
- different allocation factors (economic and energy ones),
- different technologies (average and optimized ones),
- different cultivation methods (minimum impact, average impact and maximum impact),
- changes in land use (either direct or indirect)

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

Table 74 GHG's emission potential. Different scenarios of sugarcane-based ethanol

GHG's emission potential. Different scenarios of sugarcane-based ethanol per v.km and relative to 100% gasoline						
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 84 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).

6.5.2 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.

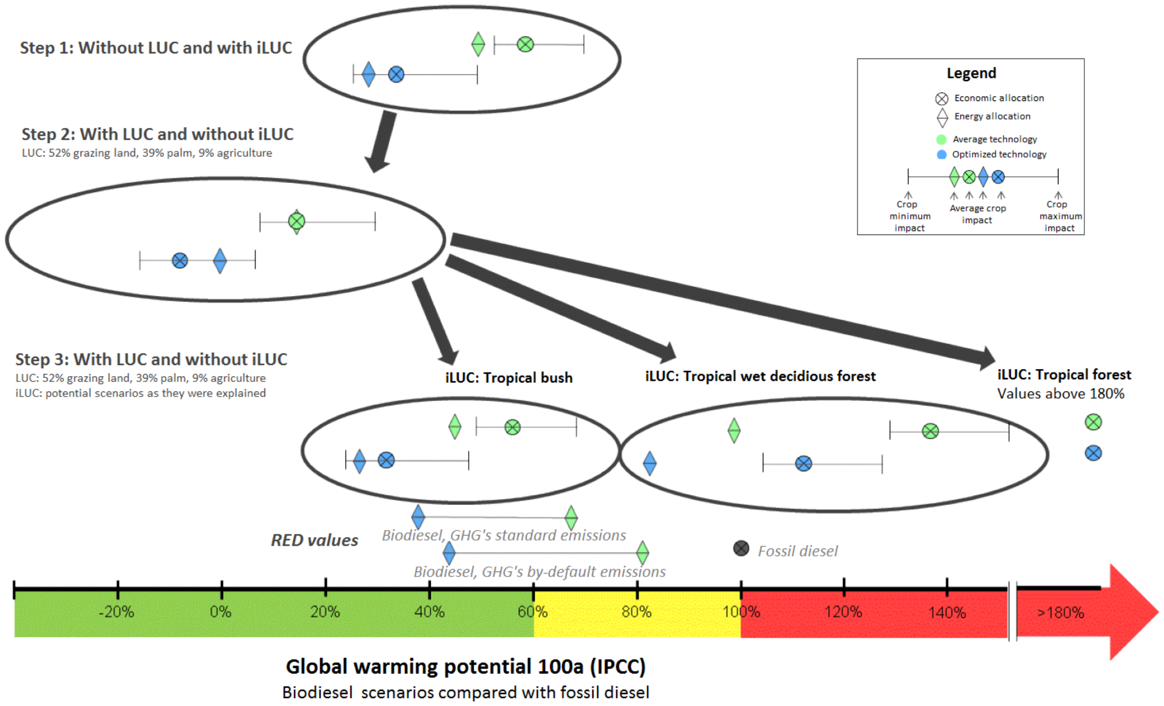
The following table and figure gather results for:

- 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 75 GHG's emission potential. Different scenarios of palm oil-based biodiesel

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



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 cogeneration 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.

6.5.3 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.

7 EXPANSION POTENTIAL

7.1 Aim of the study

One of the main issues in growing energy crops for the production of liquid biofuels, at global level, is the availavility of land to do so (S. C. Trindade, 2010). Some nations in temperate areas do not count on those productivity rate as those as the ones presented by tropical countries(S. Trindade, 2005).

Despite the fact the area for energy crops in Colombia, nowadays, is quite limited as can be seen in the following map, it is expected that the growing demand of biofuels, and some other by-products that come from sugarcane and palm oil, lead to a great expansion of cultivation areas for these particular feedstocks and some others that can be considered as well.

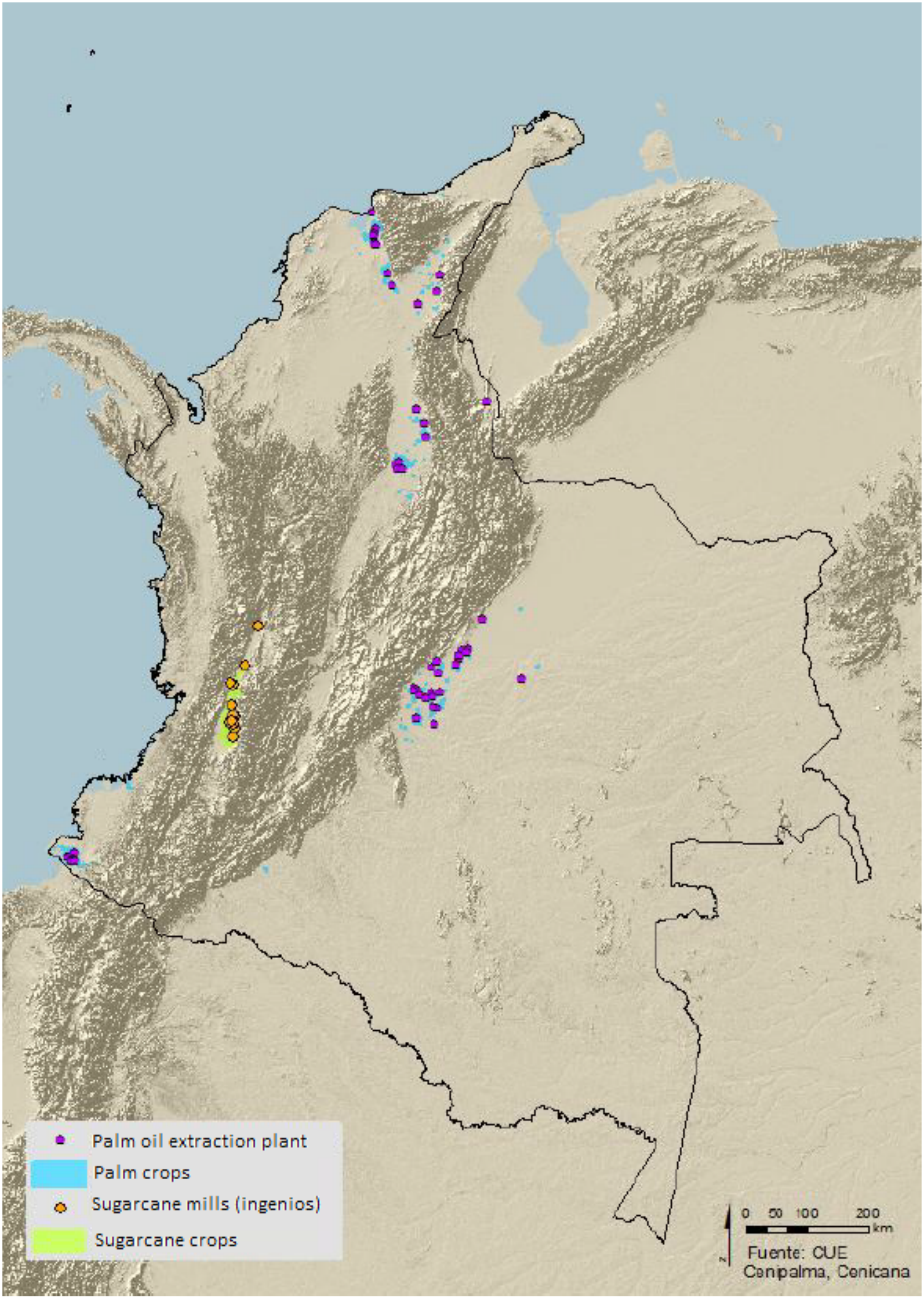
Nevertheless, potential benefits from increased biofuel production, can be achieved only if a sustainable expansion of feedstock cultivation is guaranteed.

Thus, the purpose of this section is to provide a first filter of the areas that exhibit potential to cultivate either sugarcane or palm oil at a national level. The suitability of these selected regions for growing energy crops is determined by a set of physical variables, along with legal, environmental and socio-economic aspects, all of these framed within sustainability key issues. Thus, this should be understood as a mapping exercise that distinguishes potential suitable areas for palm oil and sugar plantations and contrastes initial plans provided by the national government some years ago (as it can be seen in section 7.7.3).

The LCA of Colombian biofuels have proven the importance of the LUC in terms of the carbon balance. Therefore, special attention has been given to this in the map of emissions of greenhouse gases (GHG's) that emerge by LUC effects.

Suitability maps given by the study allow identifying general patterns of suitable zones, which provide a scientific knowledge base, for better land planning strategies and investment in sustainable biofuel production initiatives (however, such analisys are out of the scope of this particular research). In addition, it points out areas of interest, where further research for specific projects can be of great use.

Figure 86 Existing sugarcane crops and palm oil crops in Colombia in the year 2008



Existing sugarcane crops (green) and palm oil crops (blue) in Colombia in the year 2008

(Source: Cenicaña and Cenipalma)

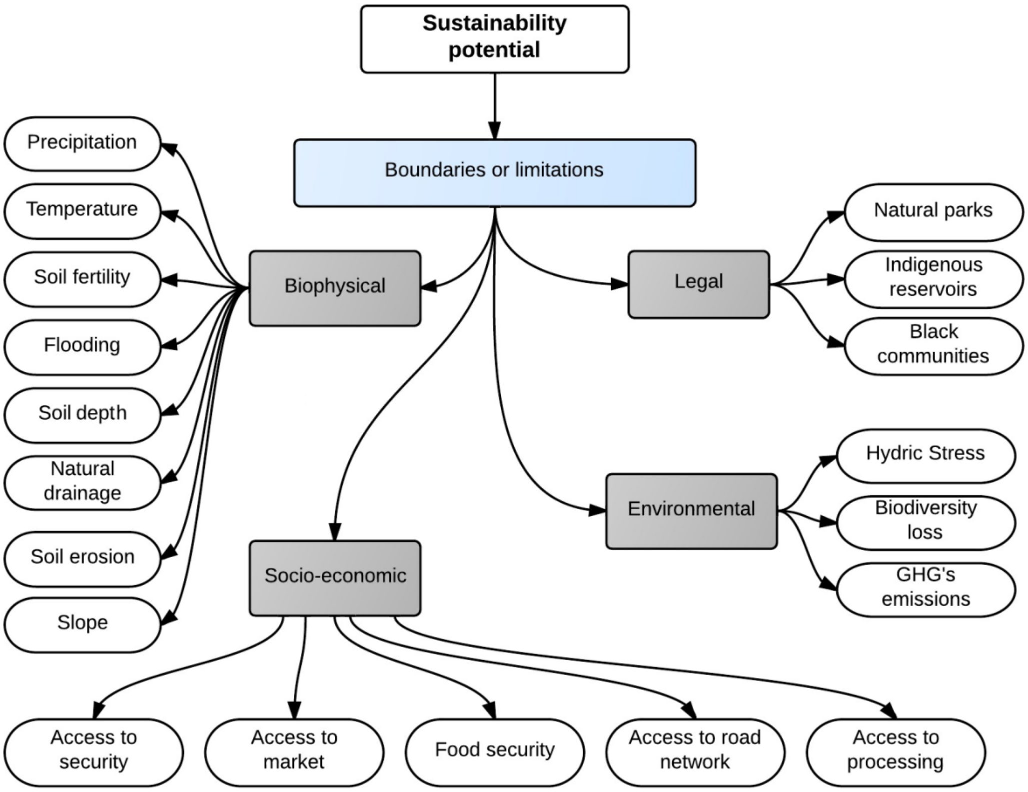
7.2 Methodology

The following section describes the general methodology framework to evaluate the potential of sustainable expansion for sugarcane and palm oil, as well as the geographic and temporal scope of it. Furthermore, some of the constraints in the methodology are presented as well.

7.2.1 Conceptual framework

Evaluation of potential suitable areas for sugarcane and palm oil expansion is based on a multi-criteria approach, inducing biophysical, legal, environmental, and socioeconomic aspects (see figure below).

Figure 87 General overview of the Geographic Information system GIS



- First of all, climatic and biophysical factors are assessed with the purpose of determining where these feedstocks can be cultivated.
- The second filter is that of law and regulation: these areas with high legal restriction are excluded, i.e. those national parks and indigenous reservoirs.

- Next, those areas affected by potential impacts on biodiversity, or with a strong presence of water scarcity and GHG's emissions. This particular study has been focused on GHG's related with the Land Use Change (LUC), given its relevance to satisfy standards of certification in sustainability, and that quite often have been neglected by current Geographic Information Systems (GIS)
- Next, socio-economic aspects that have been extracted from literature review were taken into consideration.
- Finally, all the maps that were obtained through the study are presented here.

In the upcoming sections a more detailed explanation of each suitability map will be given.

7.2.2 Scope

This study covers Colombian national territory, and use as reference the year 2009. All the maps presented are based in the system of forecasted coordinates "MAGNA-SIRGAS / Zona Bogotá, Colombia". This software can be downloaded for free from IGAC website.

7.2.3 Limitations of this study

The model based on GIS used to obtain the potential expansion areas for biofuel feedstock is based in a multi-criteria approach. The methodology of unitary steps, and the implicit implications and improvement options are described further down in following sections. Nevertheless, here are presented some of the limitations of this particular approach.

First, there are several definitions of a sustainable biofuel production, and even though numerous key aspects were taken into consideration, there is always the possibility of including more criteria (for example, human rights). In addition, each criterion that was used within this study can be put in operation in several ways. For instance, should biodiversity be measured as the number of species of vascular plants, animals, species under protection, or none of the above? Something similar happens to climatic suitability, which in fact depends on various factors (precipitation, solar radiation, temperature, humidity, wind speed, etc.) of which not all are in the study.

Likewise, changes and temporal fluctuations in climate (e.g. annual average precipitation versus quantity of dry months) are relevant to determine the suitability of the crop but it is not always possible to include them. This study relies on a temporal scope, therefore it requires constant updating of the base maps, in order to give a proper reflection of future developments.

The resolution of original maps is enough to identify general patterns of suitability at a national level. However, low resolution maps do not accurately reflect local circumstances, so the maps allow suggesting general guidelines for policy, but they are not suitable for specific biofuel initiatives. Scholars, such as Batidzirai et. al. , have suggested that former studies of this nature often are incomplete, due to the fact that they not incorporate important side-effects like LUC and iLUC effects (Batidzirai, Smeets, & Faaij, 2012). In this particular study those effects are included but due to data availability it has not been possible to report more comprehensive results, as it is asked by the scholars mentioned earlier in an ideal expansion analysis.

Given the limitation in the resources and the limited availability of the required maps, the study, despite all this, is able to identify focused areas where biofuel feedstock cultivation is suitable to a great extent. Notwithstanding, further studies, based on high resolution maps, will be required to allow proper planning of specific projects within the identified areas. Even more, not all sustainability aspect can be covered adequately trough a spatial analysis (like child labor) and consequently the study needs to be complemented with other approaches.

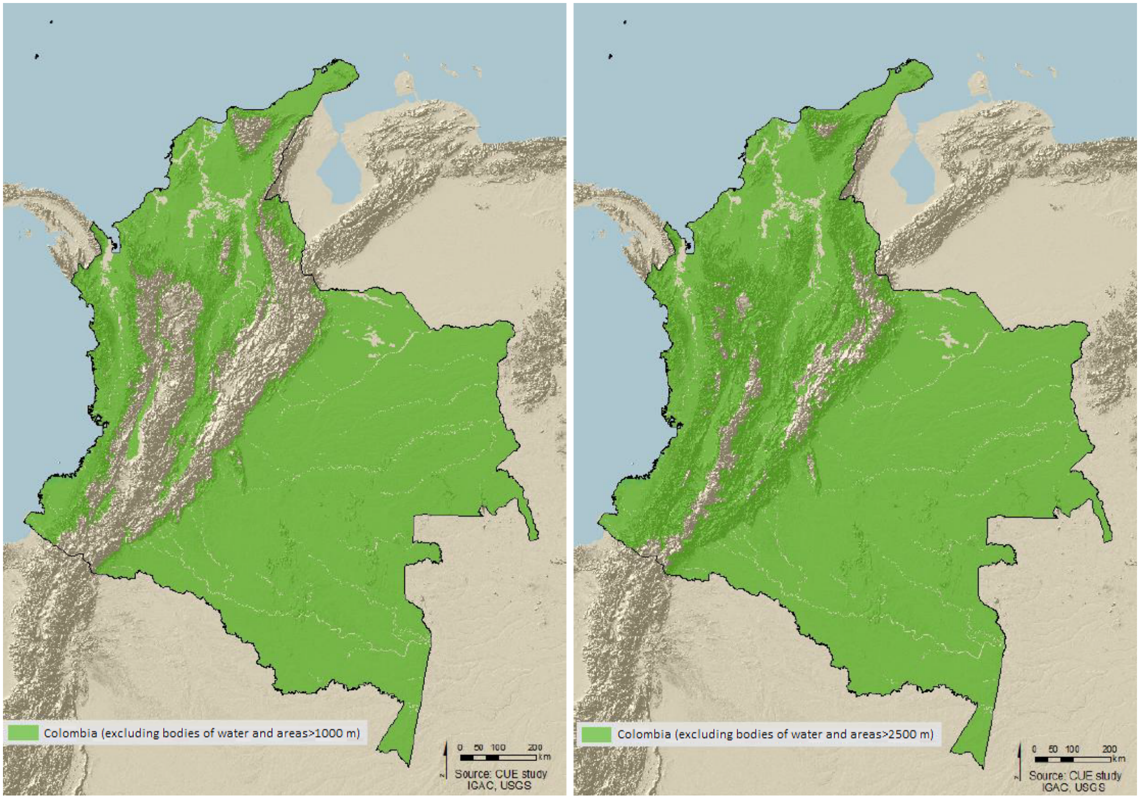
So, as mentioned before, it becomes crucial that both methodology and its inextricable limitations are born in mind by the reader, in order to avoid misinterpretation of the results presented.

7.3 Biophysical aptitude

Based on crop specific requirements, potential areas are subjected to assessment and classified in different levels of suitability. Potentially suitable land is determined by climatic and agronomic factors, using FAO classification (FAO, 1981)

The first step was to exclude bodies of water and urban territories within the Colombian national territory for the analysis. Later, the factor of altitude was used as an exclusion criterion, indicating in this way the climatic constraints that are experienced by these crops. In the case of the oil palm tree, the maximum altitude that can it bear is 1000 meters above sea level (m.a.s.l) (IDEAM, 2009b).

Figure 88 Exclusion of zones regarding altitude, urban areas, and bodies of water.



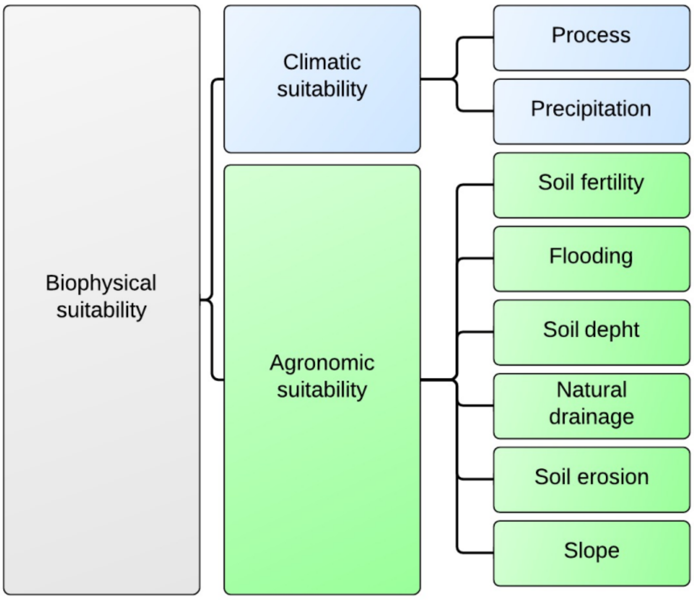
Left panel for palm oil crops and right panel for sugarcane crops. Excluded areas are those which are not green.

(Source IGAC)

In the case of sugarcane crop the resistance in terms of thermal tolerance is higher and it can deal with conditions less than 2500 m.a.s.l. Due to different climate conditions, in Brazil sugarcane is cultivated in areas that are under 1000 m.a.s.l. (Netafim, 2011b). So, in the previous figure are presented those areas in Colombia without bodies of water, nor urban zones and excluding all areas above 1000 m.a.s.l. (on the left side for palm trees) and above 2500 m.a.s.l. (on the right side for sugarcane).

In a second step, climatic and agronomic factors are taken into consideration to determine the crop conditions potential (see next figure). Criteria were chosen regarding the selection made by the IDEAM, including average annual temperature, annual precipitation, soil fertility, floods, soil depth, natural draining, soil erosion and slope.

Figure 89 General overview on employed biophysical criteria



The maps used were created by IDEAM in 2005, and agronomic maps provided by the *Agustin Codazzi National Geographic Institute* (IGAC, 2003). The suitability of each crop was determined for each climatic and agronomic factor. Suitability classification system is based on former classifications suggested by FAO as can be seen below.

Table 76 Types of soil suitability defined by FAO

Types of soil suitability defined by FAO. Colors of these different types are reflected in suitability maps.		
Type of aptitude	**Description**	**Value**
S1 Suitable	Soils that do not present significant limitations for continuous applications of a given use, or minor limitations that do not compromise in a significant way either benefits or productivity. They do not lead to a rise in agricultural input use above an acceptable level either.	8
S2 Suitable with moderated restrictions	Soils that exhibit slight limitations that in an aggregated manner are moderately severe for the continuous application of a given use; limitations will reduce the productivity or benefits to the extent that, despite this, it is still profitable, it is less profitable in comparison with the S1 scenario.	4
S3 Suitable with severe restrictions	Soils that exhibit limitations that in an aggregated manner are severe for the continuous application of a given use and in consequence productivity or benefits will be reduced. Thus the use of agricultural inputs will be increased; therefore additional expenditures are marginally justified.	2
N1 Non suitable (conditional)	Soils that exhibit limitations that can be overcome in the future but that immediately cannot be corrected under the existent knowledge with acceptable costs. For that reason, these limitations are considered severe to maintain a sustained use of a given purpose in a successful way.	1
N2 Non suitable in a permanent way	Soil that exhibit severe limitations to undertake any possible and successful use of land in a given purpose.	0

Source: (FAO, 1981)

Parameters to determine suitability of palm crops are extracted and slightly adapted from IDEAM’s study (IDEAM, 2009b). The study that evaluate soil suitability for palm tree cultivation was implemented by IDEAM, IGAC, MAVDT, MADR, IAvH, WWF, CENIPALMA and FEDEPALMA (IDEAM, 2009a, 2009b). This multi-disciplinary project has brought benefits to the involved parties, individually in different perspectives and experiences, but yet, there is no consensus on all aspects that were evaluated, and some of them are at the core of controversial discussions.

Sugarcane used the same suitability parameters that were employed in the case of palm oil. In the next section every suitability parameter for sugarcane and palm will be described and discussed within the context of other scientific studies.

7.3.1 Climatic factors

The most important climate factors that have direct impact in crop growth are.

- temperature,
- precipitation,
- brightness and solar radiation,
- wind
- and relative humidity.

Daily, seasonal or annual variations of these parameters will define harvest yields. Nonetheless, average annual temperature and precipitation are the most common factors used to assess climate suitability for specific crops. Therefore those two factors are described in more detail here.

However, it is important to bear in mind that those factors that were not taken into account in this particular study might affect climatic suitability. If more indicators are included in further studies it is possible to be more accurate. So, variables such as droughts and rainy seasons can use quarterly assessments of precipitation accumulation. In the same way the inclusion of maximum and minimum temperature might prove relevant and should be included in studies of larger scope.

On the other hand, climatic conditions differ widely between regions; subsequently a better resolution in those maps that are used as a base in this particular exercise can bring more accuracy in the map of climatic suitability.

7.3.1.1 Precipitation

This variable expresses the volume of water that falls in an area within a certain period of time (assessed in millimeters per year, mm/y). Precipitation is considered as a climatic factor that is strongly linked to suitability of land for sugarcane and palm oil cultivation. This assumption is given by the effects that arise as a consequence of the lack of moisture in the growth and potential reduction in yields due to droughts.

Precipitation map is taken from IDEAM (IDEAM, 2005a) and the range of sugarcane and palm suitability are presented here.

Table 77 Precipitation amount and relationship with the suitability categories

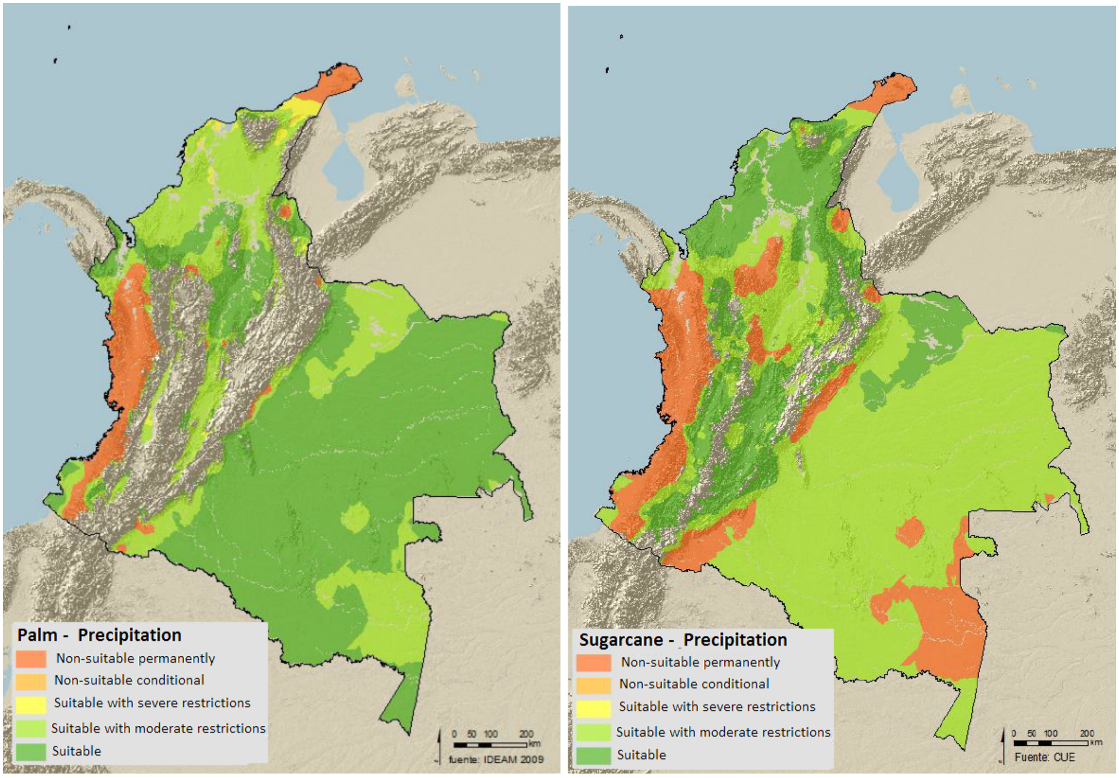
Precipitation amount and relationship with the suitability categories described by FAO for biofuel feedstock					
Attribute	**Variable**	**Palm oil**	**Value**	**Sugarcane**	**Value**
Precipitation Annual average (mm/ha)	<500	N2 - Non suitable in a permanent way	0	N2 - Non suitable in a permanent way	0
	500-1000	S3 - Suitable with severe restrictions	2	S2 - Suitable with moderate restrictions	4
	1000-2200	S2 - Suitable with moderate restrictions	4	S1- Suitable	8
	2200-3500	S1- Suitable	8	S2 - Suitable with moderate restrictions	4
	3500-4500	S2 - Suitable with moderate restrictions	4	S2 - Suitable with moderate restrictions	4
	>4500	N2 - Non suitable in a permanent way	0	N2 - Non suitable in a permanent way	0

Source: Precipitation map from IDEAM (IDEAM, 2009b) and Cenicaña 2011

Palm oil: Values of the previous table come from the study done by IDEAM in 2009 for the specific case of the palm oil tree, and they indicate that palms require a uniform precipitation distribution all year long, dry periods cannot exceed more than 3 months and it is required to have annual precipitation above 1000 mm/y. In fact, these findings are coincident with the ones presented in previous literature references (Ogunkunle, 1993), indicating that dry periods should not exceed 4 months and annual precipitation must be near to 1250 mm/y or above. Some other authors (Corley & Tinker, 2008; Goh, 2000; Hartley, 1988) consider that the ideal level must be over 2000 mm/y (references), while other studies give a range between 1500 mm/y and 2000 mm/y as valid for palm cultivation (if it is equally distributed all year long) (Lubis & Adiwiganda, 1996).

Sugarcane: Variables of suitability and categories were defined by experts on sugarcane. The ranges of values for precipitation are slightly different than the ones found in the literature. According to EMBRAPA, sugarcane crops easily adapt to tropical regions, which have a humid climate and grow basically in those areas where rain in evenly distributed, for rains levels that are above 1000 mm/y (Freitas Vian, 2005-2007). There are some other studies where it is considered that any area with precipitation levels below 900 mm/y are not suitable for sugarcane cultivation (Paiboonsak, Chanket, Yommaraka, & Mongkolsawat, 2004). Nevertheless, if there is enough irrigation all year round, precipitation requirements can be balanced, even those areas below 1000 mm/y; therefore, these areas also can be considered suitable for sugarcane cultivation in this study.

Figure 90 Precipitation suitability map.



Palm oil crop (left), Sugarcane crop (right).

Source: (IDEAM)

Large areas of Colombian territory are suitable in terms of precipitation for both oil palm and sugarcane crops (see figure above). However, extremely high precipitation levels like those exhibited in some areas located in the Pacific Coast that can reach up to 7000 mm/y, are not suitable for energy crops.

7.3.1.2 Temperature

This variable makes reference to the amount of thermal energy accumulated in the air, expressed in degrees Celsius and it is assessed in spatial data continuously by the Colombian weather stations.

Temperature is a crucial factor to determine proper growth and development of palm trees, due to its direct effects in the average speed of most physiological processes for this plant. The study used average temperature to determine crop suitability, while areas with extreme temperatures were not taken into account.

Temperature map is based on IDEAM material (IDEAM, 2005a) and ranges of suitability for sugarcane and palm oil are listed and described below:

Table 78 Temperature suitability across Colombia

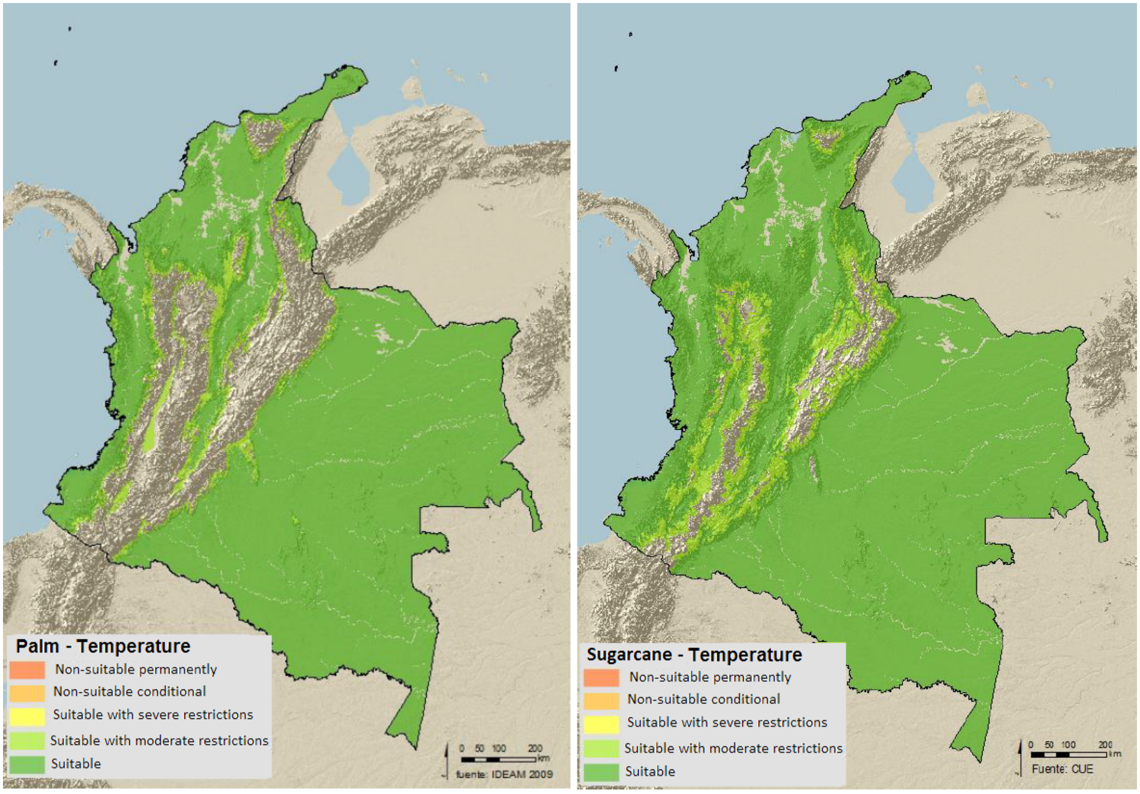
Table: Temperature suitability across Colombia					
Attribute	**Variable**	**Palm oil**	**Value**	**Sugarcane**	**Value**
Annual average temperature (°C)	<10	N2 - Non suitable in a permanent way	0	N2 - Non suitable in a permanent way	0
	10-15	N2 - Non suitable in a permanent way	0	S2 - Suitable with moderate restrictions	4
	15-20	N2 - Non suitable in a permanent way	0	S2 - Suitable with moderate restrictions	4
	20-25	S2 - Suitable with moderate restrictions	4	S1- Suitable	8
	25-30	S1- Suitable	8	S1- Suitable	8
	30-35	S2 - Suitable with moderate restrictions	4	S2 - Suitable with moderate restrictions	4
	>35	N2 - Non suitable in a permanent way	0	S2 - Suitable with moderate restrictions	4

Source: (IDEAM, 2005a, 2009b) Cenicaña 2011

Palm oil: palm does not tolerate wide variations in temperature and it grows best between 20 and 35°C (IDEAM, 2009b). In the reference given by Ogunkunle it is stated that apt temperatures are above 22°C and non-apt temperatures are those below 18°C (Ogunkunle, 1993). Other authors point out that in order to guarantee optimal conditions for palm cultivation average maximum temperatures must be between 29 y 33°C and average minimum temperatures must be between 22 and 24°C (Corley & Tinker, 2008; Hartley, 1988).

Sugarcane: variables and suitability categories are defined by experts of CENICAÑA. Ranges of values for these temperatures used in this study are consistent with the ones reported in the literature. According with EMBRAPA, sugarcane crops find tropical conditions an easy environment to adapt to, because of its warm weather, therefore, this cane grows for the most part in temperatures that vary between 19 and 32°C (Freitas Vian, 2005-2007).

Figure 91 Temperature suitability map.



Palm oil crop (left), Sugarcane crop (right).

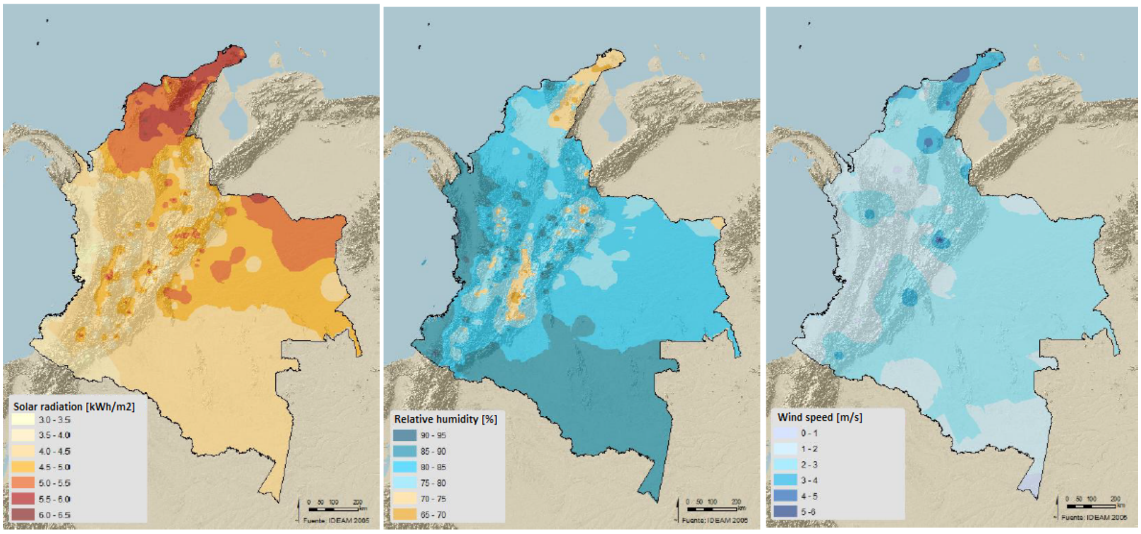
Source: IDEAM and CUE maps

Colombia has optimal conditions for sugarcane and oil palm tree cultivation. Just the most elevated areas are considered not suitable, but they were already excluded under altitude criteria.

7.3.1.3 Other climatic factors

As was mentioned before, climatic suitability for sugarcane or palm oil is not only determined by annual temperature and precipitation. There are other factors such as solar radiation, daily hours of sunlight exposure, wind exposure, and relative humidity, which might also affect productivity. Below are presented those maps of annual solar radiation provided by the IDEAM (IDEAM, 2005b, 2006). The other factors that were mentioned before will be discussed in the next section.

Figure 92 Daily solar radiation, relative humidity, and wind speed



Daily solar radiation (left), relative humidity (middle), and wind speed (right).

Source: IDEAM 2005, 2006.

In addition to those climatic factors that were just presented, seasonal or temporary variations can influence crops growth. Hence, annual temperature and precipitation are not the only ones that are relevant, but also distribution of rain in time (daily and seasonal fluctuations) affects biomass production. This implies that if this sort of information is included, for instance maximum and minimum temperature in dry periods, the sustainability map can be improved in the future. Notwithstanding, based on the available resources and data those kinds of considerations were not taken into account in the study.

7.3.1.4 Aggregation of climatic map

Based on precipitation, temperature, and altitude, the suitability map is based on the matrix presented in table below. Climatic suitability is a consequence of temperature and precipitation, so it is drawn from the aptitude values of these parameters (N2:0, N1:1, S3:2, S2:4, S1:8).

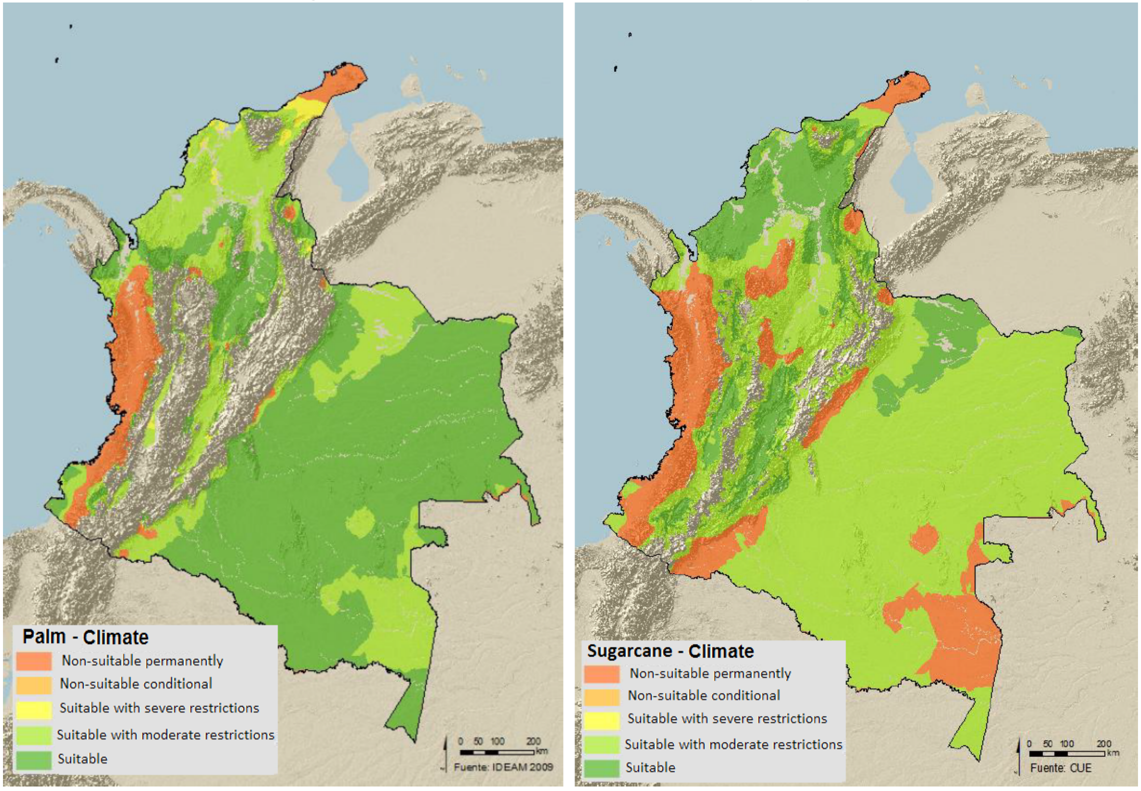
Table 79 Matrix to determine climatic suitability.

Matrix to determine climatic suitability						
		Precipitation				
		0	1	2	4	8
Temperature	0	N2	N2	N2	N2	N2
	1	N2	N1	N1	N1	N1
	2	N2	N1	S3	S3	S3
	4	N2	N1	S3	S2	S2
	8	N2	N1	S3	S2	S1

Source: (IDEAM, 2009b)

The figure below shows that the Colombian Llanos region, the Andean valleys and northern region are suitable for sugarcane and palm oil cultivation, from a climatic point of view. The Guajira peninsula and Pacific coast present extreme patterns of precipitation (very low in the case of the former and extremely high in the case of the latter). In this sense, these areas are not considered as suitable for feedstock cultivation with bioenergy purposes.

Figure 93 Climate conditions suitability map.



Palm oil crop (left), Sugarcane crop (right).

Source: IDEAM and CUE

For palm oil, optimal radiation patterns are between 4 and 5kWh/m^2, while solar radiation that exceeds 6 kWh/m^2 is not apt for palm oil cultivation (Corley & Tinker, 2008). Guajira peninsula exhibits high solar radiation, so this region is ruled out by this factor as well. This factor combined with the wind and low relative humidity in this region is not favorable for palm crops. On the other hand in some areas of the Department of Arauca the suitability for palm crops is low, due to similar conditions to the Guajira region, particularly solar radiation.

Sugarcane can grow optimally if relative humidity is around 55 to 85% and solar radiation in a range between 18 to 36MJ/m^2 (Netafim, 2011a). Therefore, Colombian Pacific coast along with some parts in the Amazon region are not suitable for sugarcane cultivation.

7.3.2 Agronomic factors

In addition to climatic conditions, there are other factors that are important for sugarcane and palm oil cultivation, such as the availability of nutrients, oxygen and moisture in soil. Among those optimal conditions it is possible to find controlled erosion, adequate moisture, draining of excessive water, low potential of flood, and a proper and balanced nutrients supply. For that reason, the following factors are considered: Flooding, natural drainage, soil erosion, soil depth, land slope.

7.3.2.1 Flooding

Flooding is dependent on soil drainage, and directly related with the slope of every geomorphologic unit and areas that provide conditions for water to exceed natural drainage. Damage caused by floods might occur for two different reasons: stagnated water and running water. When water remains stagnated the available oxygen dissolved in it tends to decrease. Running water, in turn, can knock down, tear apart or cover with mud biomass for bioenergy. When floods take place with salt water there is a high risk of soil salinization. Flood risk depends on soil properties, and hydrologic and climatic conditions of the region. There are several types of flooding, and based on the information provided by the IGAC they can be broken down as follows (IGAC, 2003):

Without inundation: Characteristics of a unit of land where water excess is removed easily.

With inundation: Characteristics of a unit of land where water excess is removed slowly and floods happen regularly. Areas that have likely conditions to ease a potential surplus of natural drainage can be sub-divided into permanent and occasional floods. The former makes reference to constant inundated areas, while the latter indicates that flood take place to a minor extent in terms of the magnitude and length.

Given that floods can be prevented to some extent, through implementing some technical actions, just only bodies of water are considered not suitable permanently. Besides, those areas that are flooded occasionally are considered by FEDEPALMA as suitable with severe restrictions, for obvious reasons. In the palm report presented by IDEAM these areas are considered as not suitable (IDEAM, 2009a).

Table 80 Flooding - Crop specific classification

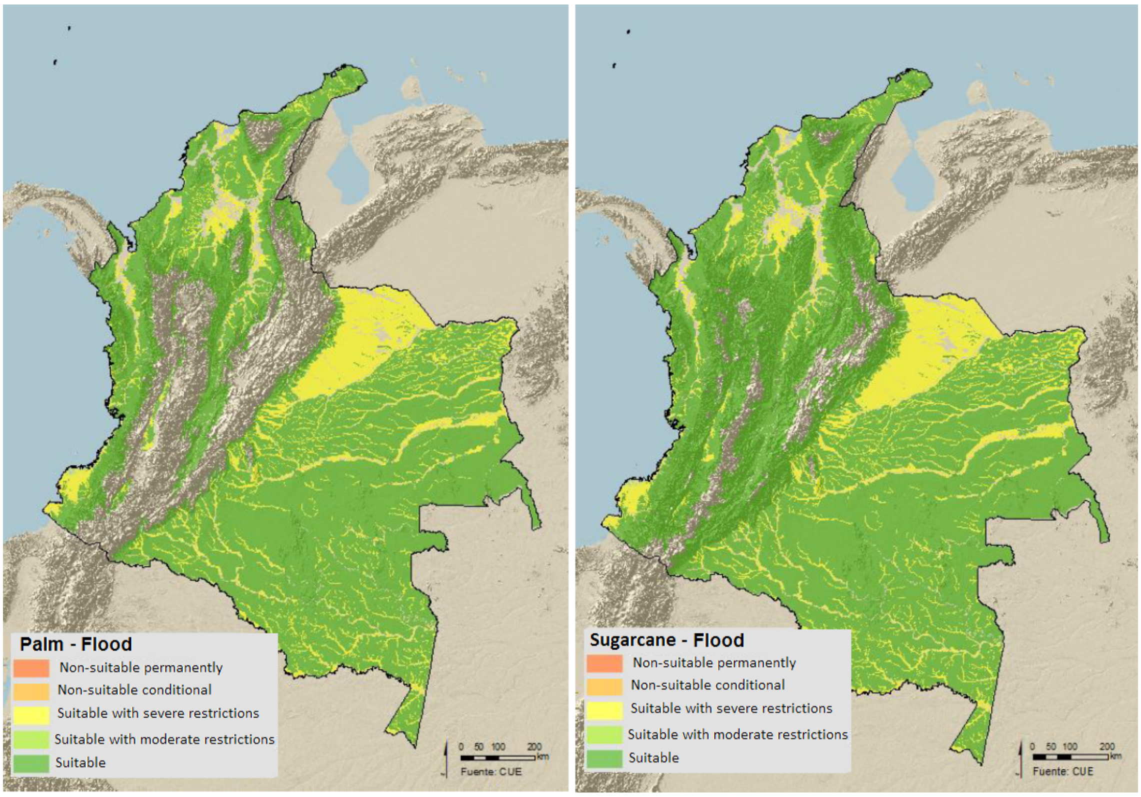
Flooding - Crop specific classification					
Attribute	**Variable**	**Palm oil**	**Value**	**Sugarcane**	**Value**
Flooding	Without flooding	S1- Suitable	8	S1- Suitable	8
	Permanent flooding	N2 - Non suitable in a permanent way	0	N2 - Non suitable in a permanent way	0
	Occasional flooding	S3-Suitable with severe restrictions	2	S3-Suitable with severe restrictions	2

Source: Flood map from IGAC, (IDEAM, 2009b) and Cenicaña 2011

Palm oil: Palm oil crops are suitable for those lands that are not flooded frequently (IDEAM, 2009b). In the Ogunkunle et al. study is shown where those areas that remain flooded more than 2 or 3 months in five out of ten years, are not suitable for palm oil cultivation (Ogunkunle, 1993).

Sugarcane: According to EMBRAPA, soils with permanent floods are not suitable for sugarcane cultivation whatsoever (Freitas Vian, 2005-2007). As a matter of fact, flat lands must be drained properly before starting the sowing stage. That factor, though, will be considered in the natural drainage indicator.

Figure 94 Flooding suitability map.



Palm oil crop (left), Sugarcane crop (right).

Source: IDEAM and CUE

Main inundation areas are located in those terrains that are relatively flat and close to rivers and/or mountain chains, particularly in those mountain bases of the Andes, and the area of those rivers that flow towards the Pacific coast near Tumaco. However, in those geographic areas it is possible to find substantial extensions that have a low flood risk, as actually happens in Casanare. Those maps that were used to build this study have a resolution (1:500.000) cannot give precise local conditions in high detail. With better cartographic information (i.e. maps with resolution higher than 1:100.000), and taking into consideration seasonal or temporary variation (e.g. frequency, magnitude, or length of floods) it would be possible to refine this study, providing more accuracy in final conclusions.

7.3.2.2 Natural erosion

Land degradation is associated to the loss of layers of fertile soil caused by gravity, water or wind. Land degradation has a strong influence on crop growth and therefore in its productivity.

This study used the base map of soils from IGAC (IGAC, 2003), so natural erosion is classified as follows:

None or minor: Not significant or there is presence of small and disperse furrows in the soil.

Minor to moderate: There is presence of deteriorated furrows in advanced state (there is a combination of small neglected furrows).

Severe to very high: Exposure of underground horizons in the soil surface.

At first, it employed the methodology developed by IDEAM in order to categorize suitability of palm oil crops. Nevertheless, minor erosion to moderate was classified as moderately suitable, instead of suitable with severe restrictions (following suggestions provided by experts of CENIPALMA).

Table 81 Soil erosion - Crop specific classification

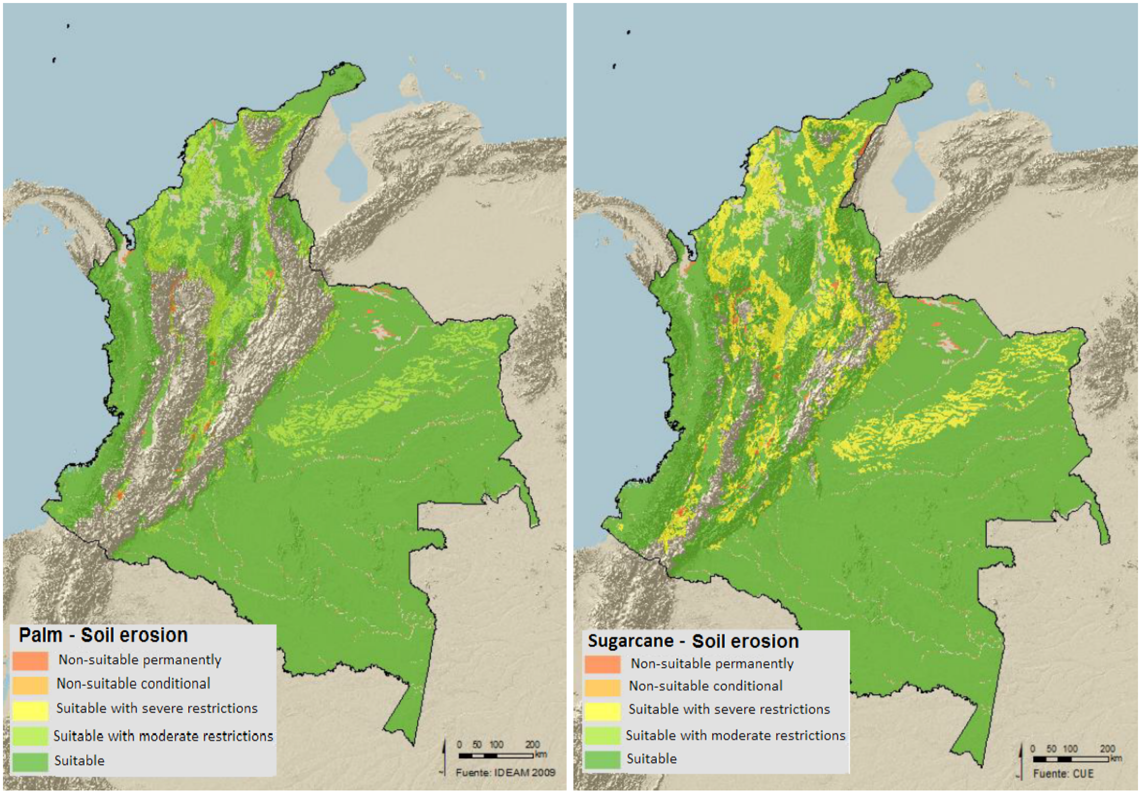
Soil erosion - Crop specific classification					
Attribute	**Variable**	**Palm oil**	**Value**	**Sugarcane**	**Value**
Erosion	Without erosion	S1- Suitable	8	S1- Suitable	8
	Moderate erosion	S2- Suitable with moderate restriction	4	S3-Suitable with severe restrictions	2
	Severe erosion	N2 - Non suitable in a permanent way	0	N2 - Non suitable in a permanent way	0

Source: Erosion map from IGAC, (IDEAM, 2009b) and Cenicaña 2011

Palm oil: Available literature about effects of erosion on palm oil productivity is limited. Nevertheless, some authors consider that soils that are excessively dry and porous are not favorable for palm oil cultivation (Corley & Tinker, 2008).

Sugarcane: It has been reported that suitable soils are those that do not exhibit great topographic or erosion problems, while those that do so are ruled out of this selection (Chartres, 1981)

Figure 95 Soil erosion suitability map



Palm oil crop (left), Sugarcane crop (right).

Source: IDEAM and CUE

Sugarcane and palm oil tree cultivation in Colombia is not highly constrained by the effect of soil erosion. Risk of erosion is present in some isolated areas in the Andean mountains and along great rivers (see figure above). Furthermore, there is some risk of erosion in forest areas that are turned into food or energy crops, given the fragility of soil in rainforest.

7.3.2.3 Soil depth

Among the more relevant physical and chemical aspects for sugarcane and palm oil production is soil depth, which is determined by thickness of fertile soil. Effective depth is the one that is limited by other sorts of materials such as rocks and gravel. According to the information registered in soils map provided by IGAC (IGAC, 2003) and the requirements established by CENIPALMA, the following classifications were established:

- **Very shallow**: roots that penetrate less than 25 centimeters.
- **Shallow**: roots that penetrate a depth up to 50 centimeters.
- **Moderately deep**: roots that penetrate a depth up to 100 centimeters.
- **Deep**: roots that penetrate a depth more than 100 centimeters.

Table 82 Soil depth - Crop specific classification

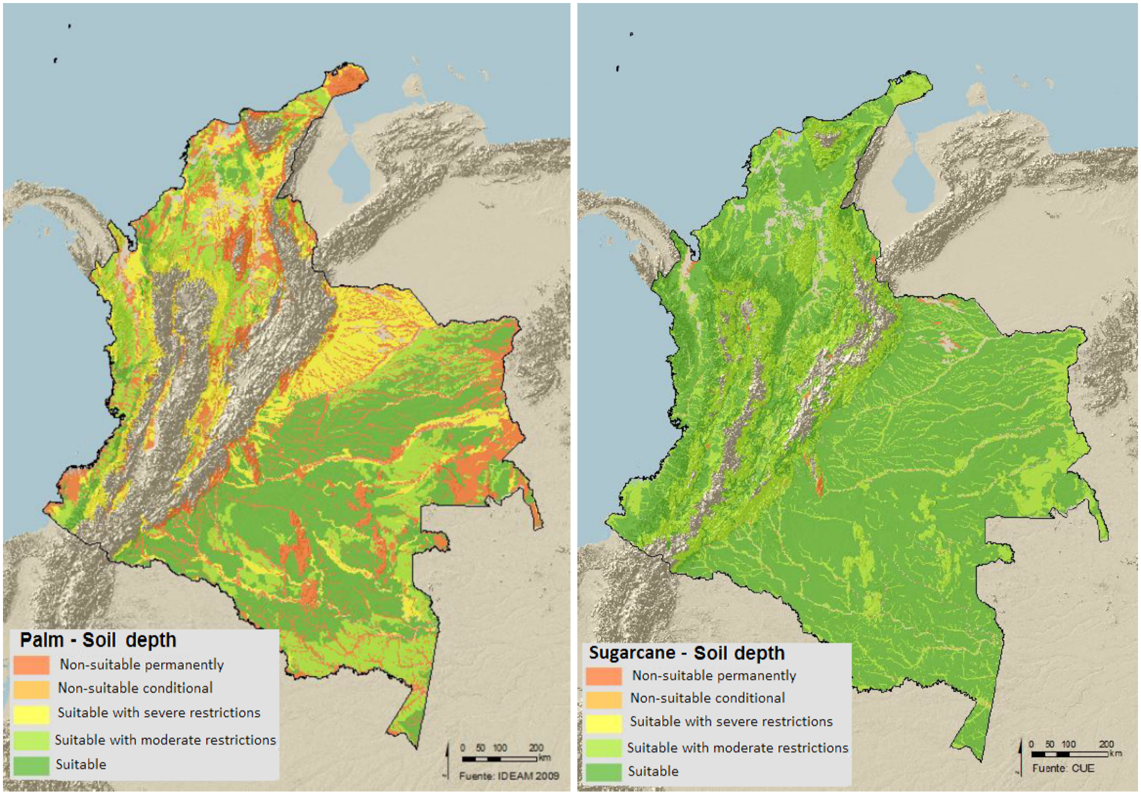
Soil depth - Crop specific classification					
Attribute	**Variable**	**Palm oil**	**Value**	**Sugarcane**	**Value**
Soil depth (cm)	>100 cm	S1- Suitable	8	S1- Suitable	8
	50-100	S2- Suitable with moderate restriction	4	S1- Suitable	2
	25-50	S3-Suitable with severe restrictions	2	S2- Suitable with moderate restriction	4
	<25	N2 - Non suitable in a permanent way	0	S2- Suitable with moderate restriction	4

Source: Soil depth map from IGAC, (IDEAM, 2009b) and Cenicaña 2011

Palm oil: In countries like Malaysia the effective depth of soil is considered optimal when it is equal and higher than 100 cm (Balasundram, Robert, Mulla, & Allan, 2006). This criterion also applies to Colombia. In the case of the study undertaken by Ogunkunle et. al. it is said that those lands that provide a depth of 90cm or superior are considerably suitable, however, those that are above 100cm are ideal for this crop (Ogunkunle, 1993). Just the thinner part of some roots is able to exceed the limit of 100cm and most roots are concentrated in the first 30cm (Corley & Tinker, 2008). These authors assert that palm oil can only grow in soils that offer an effective depth of 50 cm if it has a substantial provision of nutrients and water.

Sugarcane: According with EMBRAPA, the ideal depth for sugarcane cultivation is more than 100cm (Freitas Vian, 2005-2007). Chartres considers suitable those soils that exceed 100cm and moderately suitable for depths between 50 and 100cm (Chartres, 1981). Values defined by CENICAÑA are more modest due to the fact that sugarcane can be also grown in areas with little depth but that can be adapted.

Figure 96 Soil depth suitability map.



Palm oil crop (left), Sugarcane crop (right).

Source: IDEAM and CUE

In general sugarcane requires less soil depth than palm oil, therefore the potential area for sugarcane cultivation is larger (see figure above). Notwithstanding, soil depth is highly linked to local circumstances and when maps with a resolution of 1:500.000 big areas, such like Casanare, tend to be generalized. So, with the risk of appearing reiterative it is recommended to update information from maps with at least 1:100.000 as the resolution.

7.3.2.4 Soil fertility

This attribute refers to the natural composition of the soils basic elements, taking into consideration nutrients retention capacity, basic saturation and salinity. The fertility map is taken from the IGAC and it is classified by experts in the following categories (IGAC, 2003):

Table 83 Soil fertility - Crop specific classification

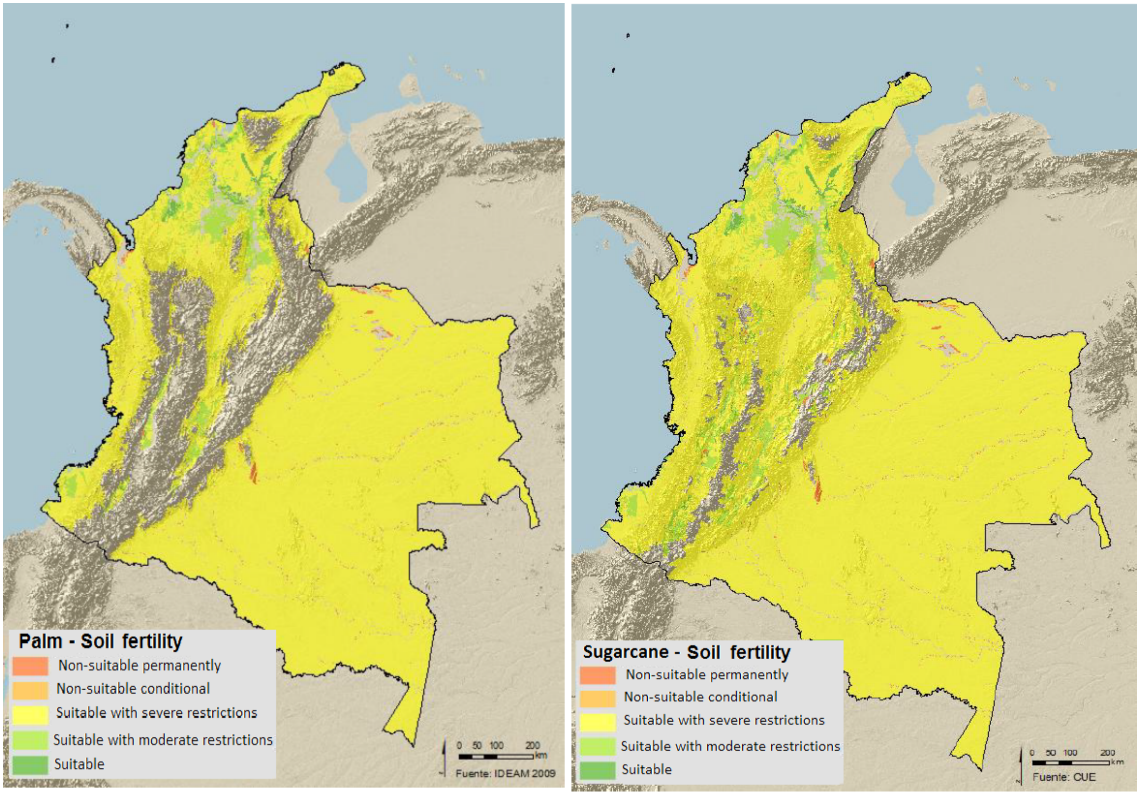
Soil fertility - Crop specific classification					
Attribute	**Variable**	**Palm oil**	**Value**	**Sugarcane**	**Value**
Fertility	High	S1- Suitable	8	S1- Suitable	8
	Moderate	S2- Suitable with moderate restriction	4	S2- Suitable with moderate restriction	4
	Low	S3-Suitable with severe restrictions	2	S3-Suitable with severe restrictions	2

Source: Soil fertility map from IGAC, (IDEAM, 2009b) and Cenicaña 2011

Palm oil: classification was suggested by CENIPALMA (IDEAM, 2009b). Authors like Ogunkunle and Mutert consider an important soil requirement the cationic interchange, organic carbon content, total nitrogen and level of phosphorous (Mutert, 1999; Ogunkunle, 1993).

Sugarcane: classification was provided by experts of CENICAÑA. Based on the EMBRAPA report, the sugarcane's root development depends of the PH, basic saturation, percentage of aluminum and calcium content in the deeper layers of soil. Several authors stress the importance of nitrogen, potassium, phosphorous among other chemicals as critical element in terms of soil fertility for sugarcane (Chartres, 1981; Kuppatawuttinan, 1998; Paiboonsak et al., 2004). In spite of this, lack of or low levels of nutrients can be offset by the use of mineral or organic fertilizers; therefore soils with low levels of fertility are capable of cultivation.

Figure 97 Soil fertility suitability map



Palm oil crop (left), Sugarcane crop (right).

Source: IDEAM and CUE

Most soils in Colombia are considered moderately suitable for sugarcane and palm oil cultivation. However, alluvial planes in Andean valleys located in the Northern region of Colombia are considered as the most fertile ones, therefore more suitable for energy crops cultivation (see figure above).

Yet again, low resolution of maps (scale 1:500.000) leads to generalize local variables. Thus, apart from the incorporation of other maps of higher resolution, additional information is required such as nutrients availability determined by some indicators like soil texture, carbon content, pH, and retaining of nutrients capacity (basic saturation, action exchange capacity and clayey formation capacity) in future research programs, in order to improve knowledge on fertility of the soil.

7.3.2.5 Natural Drainage

Natural drainage refers to the natural capacity of soil to evacuate or retain water of the terrestrial surface or in the zone where roots are located. Plants need to absorb oxygen through its roots, but as oxygen propagates ten times faster in the air embedded in the soil that in the water, a flood situation constraints drastically oxygen absorption and therefore plants might face damage. The drainage base map is taken from IGAC (IGAC, 2003) and it is broken down in the following categories:

Drainage good to moderate: Water excess is easily removed and soil does not exhibit conditions of oxidation-reduction.

Moderated drainage: Drainage is slow, phreatic stratum mildly deep, or the superior layer has saturated hydraulic conductivity moderately low.

Excessively drained: Water that is removed excessively fast and has a deep phreatic stratum, rough texture and high saturated hydraulic conductivity

Marshy or bad drainage: Soil remains wet close to surface for long periods of time. This sort of soil requires artificial drainage, but if the selected land is properly drained, they can be considered as suitable for cultivation. Therefore, classification as non-suitable permanently, as it was defined by the IDEAM study in this case become a to non-suitable conditional (IDEAM, 2009b).

Table 84 Natural drainage - Crop specific classification

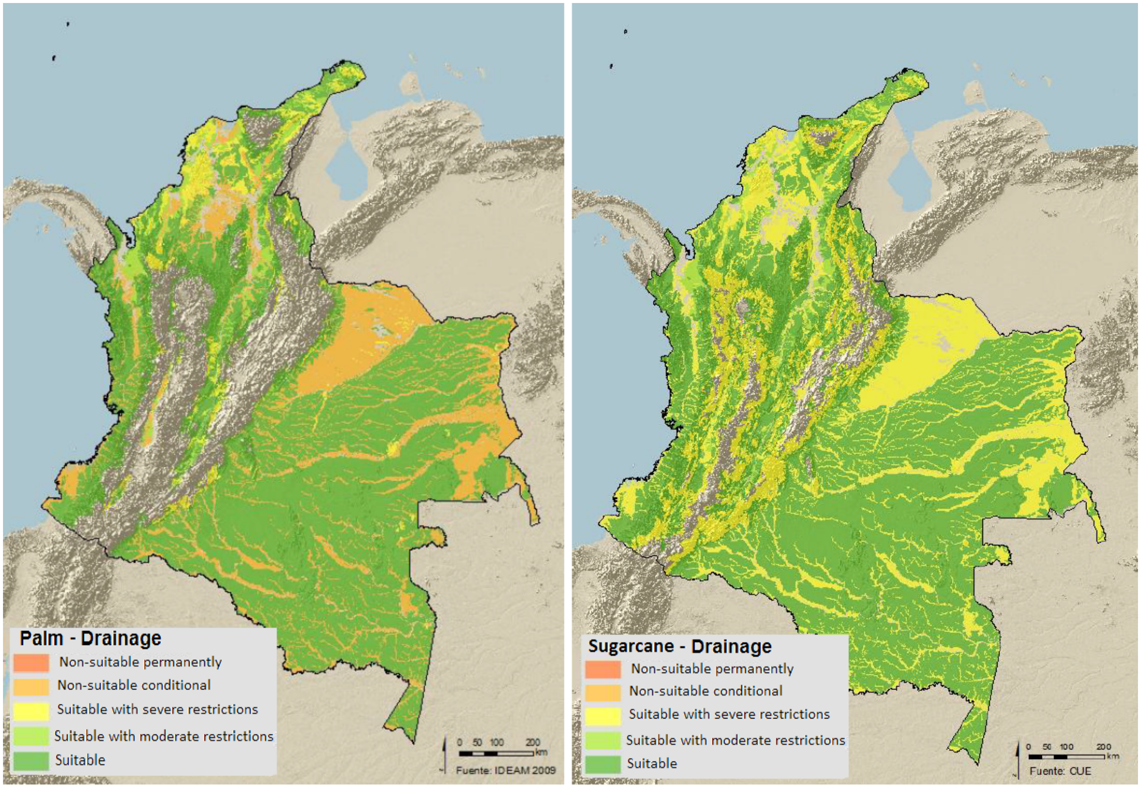
Natural drainage - Crop specific classification					
Attribute	**Variable**	**Palm oil**	**Value**	**Sugarcane**	**Value**
Drainage	Good or fairly good drainage	S1- Suitable	8	S1- Suitable	8
	Moderate drainage	S2- Suitable with moderate restriction	4	S2- Suitable with moderate restriction	4
	Excessive or bad drainage	S3-Suitable with severe restrictions	2	S3-Suitable with severe restrictions	2
	Marshy or very bad drainage	N1- non suitable conditional	1	S3-Suitable with severe restrictions	2

Source: Natural Drainage map from IDEAM, (IDEAM, 2009b)and Cenicaña 2011

Palm oil: Classification was suggested by CENIPALMA (IDEAM, 2009b). Importance of natural drainage is highlighted by Ogunkunle, where it is stated that soil that do not have good drainage properties are considered as non-suitable for palm oil cultivation (Ogunkunle, 1993).

Sugarcane: Employed classification was undertaken by experts in agriculture from CENICAÑA. Paiboonsank and DLD consider as highly suitable those soils that have good or very good drainage, moderately suitable those that have moderated drainage, and marginally suitable those that exhibit bad or very bad drainage properties (DLD, 1992; Paiboonsak et al., 2004).

Figure 98 Drainage suitability map



Palm oil crop (left), Sugarcane crop (right).

Source: IDEAM and CUE

Those areas that are suitable with severe restrictions in terms of drainage properties are near to bodies of water and in the base of mountain chains. (See figure above).

Despite all this, evolution of soils natural drainage based on maps of low resolution lead to generalization of patterns, and thus, big areas that seem to count on low suitability, could be, classified as suitable to a major extent. Therefore the scale of the map should be reduced in further studies in order to include in a better way those local heterogeneities.

7.3.2.6 Slope

Slope is an element of major importance in crop harvest and managing, allowing machinery activities or mechanized processes for land handling and feedstock transportation. Erosion problems become evident in lands that exhibit slopes that exceed 16°, which, in fact are accentuated by loss of natural cover. Data in terms of slopes do not change abruptly in short time spans, therefore up-to-date information, although desirable is not mandatory, to undertake a proper assessment. In this particular case data come from a digital model of elevation (USGS, 2012) and the classification has been provided by both CENICAÑA and CENIPALMA.

Table 85 Slope - Crop specific classification

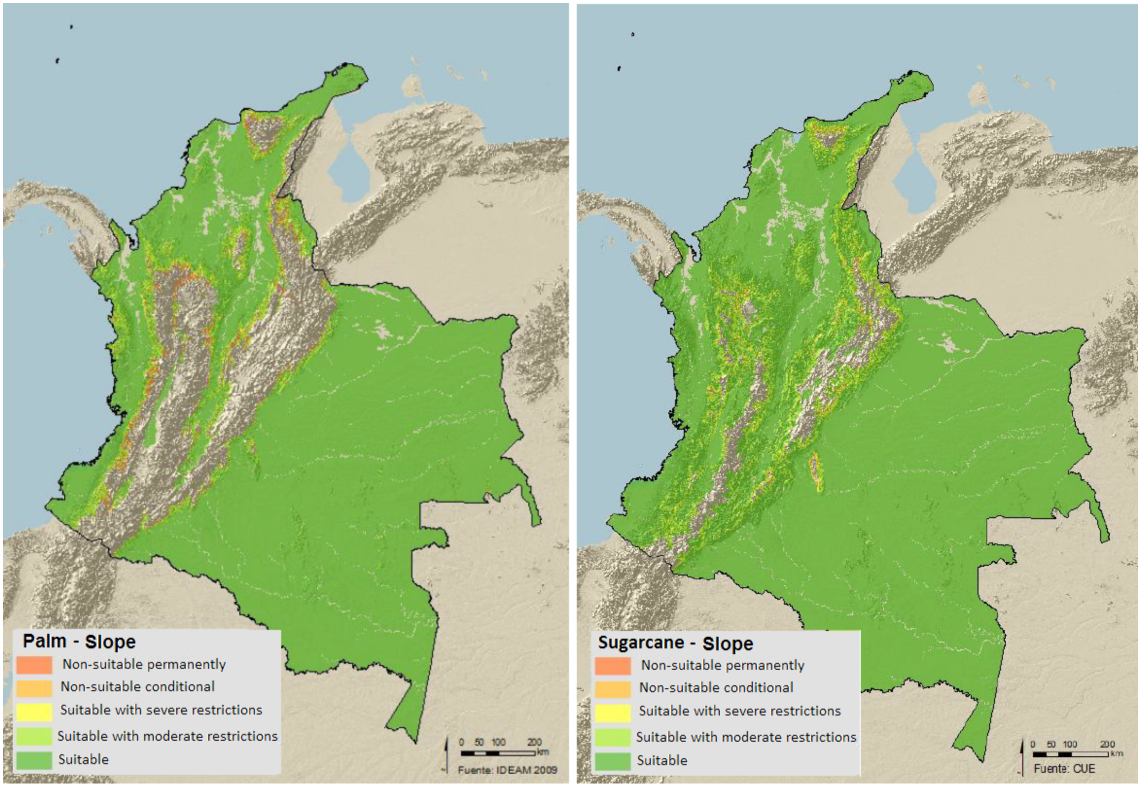
Slope - Crop specific classification					
Attribute	**Variable**	**Palm oil**	**Value**	**Sugarcane**	**Value**
Slope	0%-12%	S1- Suitable	8	S1- Suitable	8
	12%-25%	S2- Suitable with moderate restriction	4	S2- Suitable with moderate restriction	4
	25%-35%	S3-Suitable with severe restrictions	2	S3-Suitable with severe restrictions	2
	>35%	N2 - Non suitable in a permanent way	1	N2 - Non suitable in a permanent way	1

Source: Slope map from USGS, IDEAM, 2009b and Cenicaña 2011

Palm oil: Those assumptions presented in this information are consistent with the findings in the literature (Ogunkunle, 1993). In particular, it is considered that those terrains that present slopes superior to 30° are not suitable and those with slopes between 8° and 0° are perfect for palm oil cultivation.

Sugarcane: Based on the report presented by EMBRAPA, lands with slight slopes between 2° and 5° (this last value applies for those clayey lands), are especially suitable for sugarcane cultivation. Nevertheless, according to some studies these assumptions should be slightly more detailed (Kuppatawuttinan, 1998; Paiboonsak et al., 2004): all those lands with a slope over 12° are considered as not suitable, the ones that are between 5° and 12° are marginally suitable and between 2° and 5° are highly suitable.

Figure 99 Drainage suitability map



Palm oil crop (left), Sugarcane crop (right).

Source: IDEAM and CUE

Colombia is considered suitable for sugarcane and palm oil cultivation, except in some small spots along the Andean mountain chain. It is fundamental to bear in mind that this map is based on a digital elevation model that has an estimation of 1 kilometer above the earth's surface, so some small but still pronounced slopes are flattened.

7.3.3 Agronomic suitability

Different agronomic indicators were compiled regarding their ability to be controlled and modified. Variables that are hard to be modified (fixed key values) are flooding, erosion soil depth; whereas there are some others such as soil fertility and natural drainage (variable key values) that are susceptible to modification, through fertilization processes or water management (irrigation and drainage systems).

With the intention of adding agronomic factors for those fixed and variable items, it multiplied values that go from 0 to 8 for fertility and natural drainage, so if value for fertility is 2 while the value for natural drainage is 8, it results in 16 for variable key values. In the same way, a similar system is applied for those fixed key values, thus at the end the agronomic suitability is summarized on the table presented below. Mathematically, multiplication is a good choice for adding effects of different factors, because it implies that a profound lack of any of these characteristics cannot be compensated by the abundance of others, affecting general classification. Thus, for instance, a land with poor fertility, despite of having good numbers in drainage and erosion factors will be reported as non-suitable permanently or non-suitable under some conditions. For sugarcane and palm oil were used the same values (the ones suggested by IDEAM (IDEAM, 2009b)) and when it was required some assistance and therefore data was given by experts of CENIPALMA .

Table 86 Matrix to determine agronomic aptitude

Matrix to determine agronomic aptitude								
		Fertility and Natural Drainage						
		64	32	16	8	4	2	0
Flooding, erosion, soil depth	512	S1	S1	S1	S2	S2	N1	N2
	256	S2	S2	S2	S2	S3	N1	N2
	128	S3	S3	S3	S3	S3	N1	N2
	64	S3	S3	S3	S3	S3	N1	N2
	32	S3	S3	S3	S3	S3	N1	N2
	16	N1	N1	N1	N1	N1	N1	N2
	0	N2	N2	N2	N2	N2	N2	N2

Source: (IDEAM, 2009b)

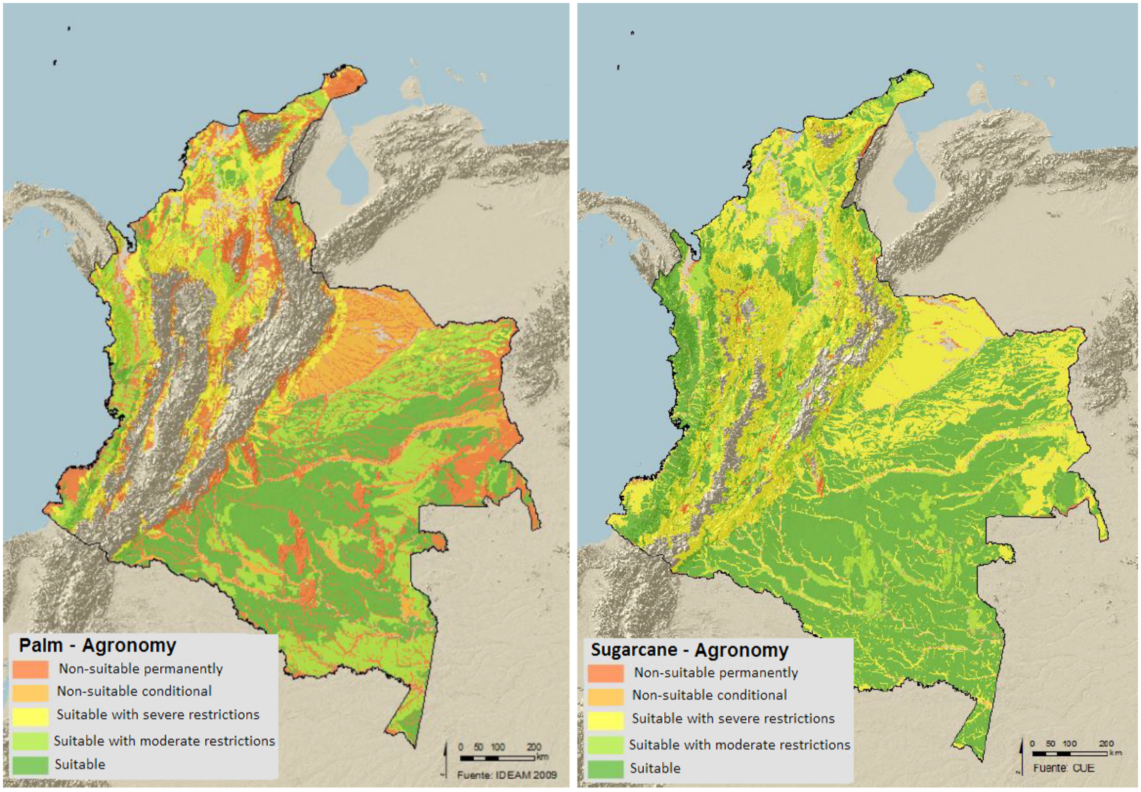
In addition, the slope effect was considered in the following matrix. As it is shown in the above figure, slope does not affect land suitability, given that it is a local effect, and those effects tend to disappear when the resolution of the employed maps improves. It is advised that a slight overestimation of suitability potential might emerge from this setback.

Table 87 Matrix to determine agronomic aptitude (including slope)

Matrix to determine agronomic aptitude (including slope)						
		Slope				
		0	1	2	4	8
Agronomic factors	0	N2	N2	N2	N2	N2
	1	N2	N1	N1	N1	N1
	2	N2	N1	S3	S3	S3
	4	N2	N1	S3	S2	S2
	8	N2	N1	S3	S2	S1

Source: (IDEAM, 2009b)

Figure 100 Agronomic suitability map



Source: CUE

In general agronomic suitability is lower for palm oil crops than the one exhibited for sugarcane crops, mainly due to the need of deep soil features.

7.3.4 Biophysical aptitude

The potential of biophysical expansion for palm oil and sugarcane is established when it contrasts agronomic suitability and climatic aptitude for each crop.

Table 88 Matrix to determine biophysical aptitude

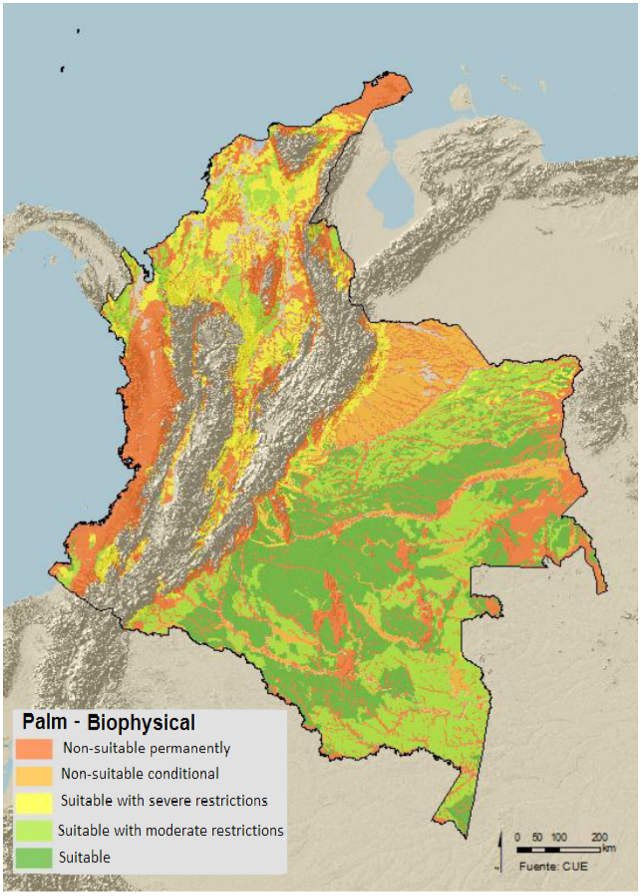
Matrix to determine biophysical aptitude						
		Climate				
		0	1	2	4	8
Agronomic factors	0	N2	N2	N2	N2	N2
	1	N2	N1	N1	N1	N1
	2	N2	N1	S3	S3	S3
	4	N2	N1	S3	S2	S2
	8	N2	N1	S3	S2	S1

Source: (IDEAM, 2009b)

7.3.4.1 Suitability map for palm oil

In general, great areas of Colombia are highly suitable for palm oil cultivation. Suitability is mainly limited for the high level of precipitation of the Pacific coast (up to 7000 mm/y) or by scarce rain in Guajira Peninsula (levels below 500 mm/y). Furthermore, some soils have inadequate conditions in terms of soil depth in the Eastern region just at the base of the Andean mountain chain, limiting the suitability for palm oil cultivation.

Figure 101 Biophysical factor suitability map for Palm oil crops.

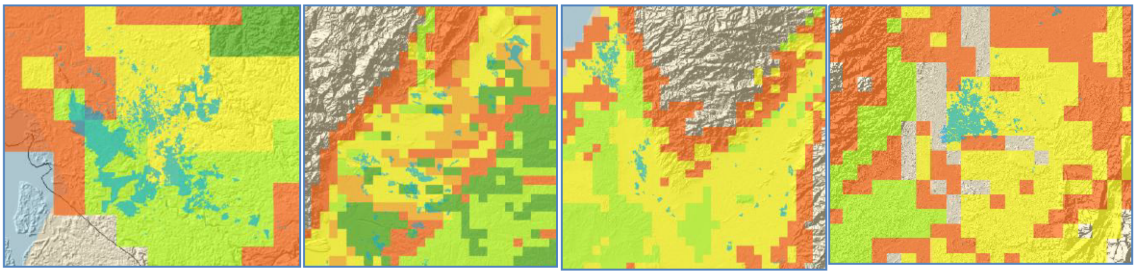


Source: CUE

The aptitude or suitability model was validated with the current area where crops are held in the south-western region (Department of Nariño), eastern region (Department of Meta), northern region (Departments of Magdalena and Cesar) and Central region (Department of Santander) and in fact it shows a relative similitude (see figure below). Nevertheless, different levels of detail between the suitability maps (1:500.000) and cultivated areas (less than 5km resolution) lead to conclude that some of the crops are established in some non-suitable lands. However, this exercise must be taken into account as a mere approximation and general guideline for detecting potential areas of expansion, although the level of detail is not big enough for setting individual territorial planning.

Figure 102. Detailed biophysical suitability map

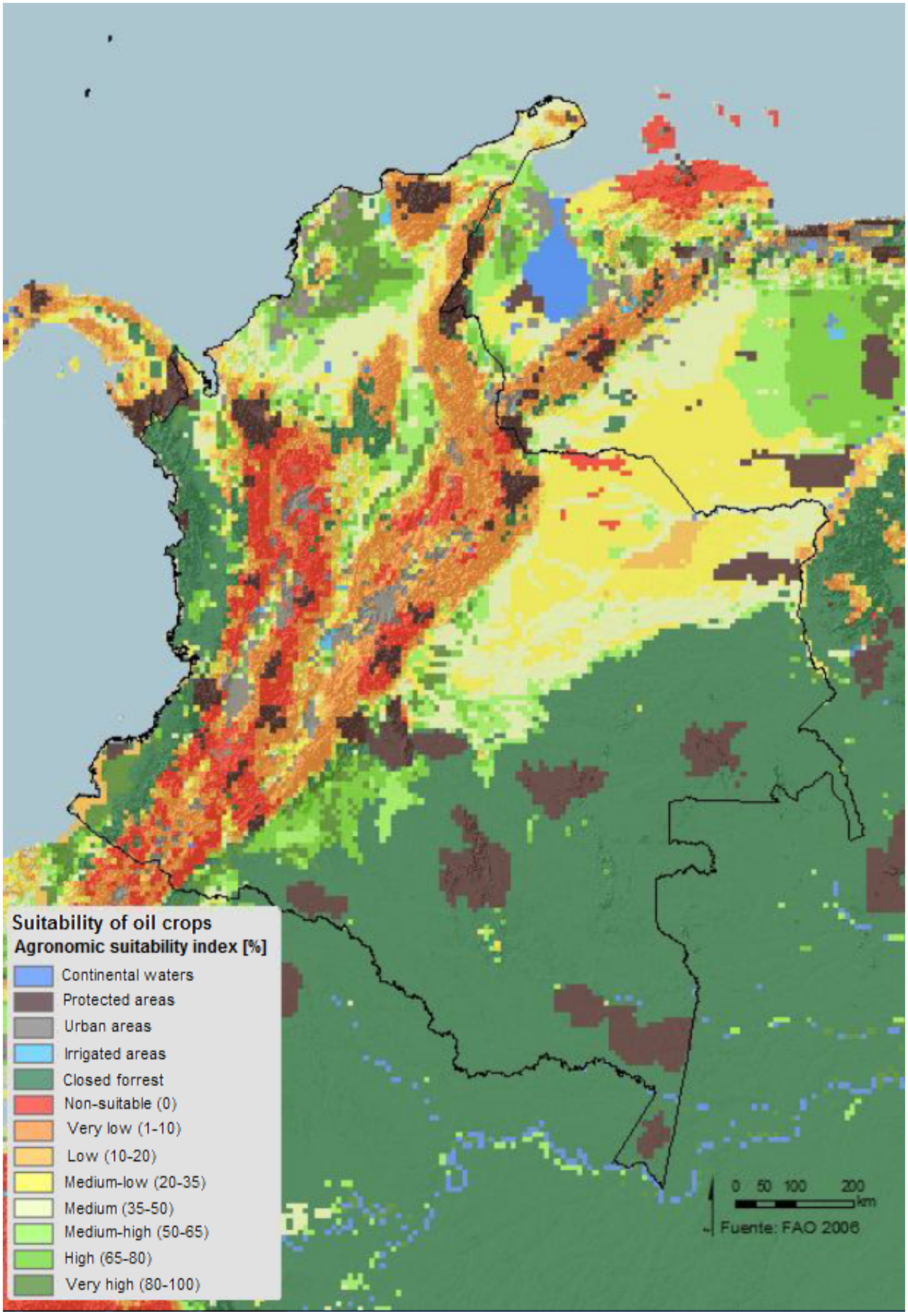
Note: (every pixel:5km x 5km) Every pixel has been zoomed in the current palm oil crops areas (noted in blue) in Nariño, Meta (2), Magdalena y Cesar (3) y Santander (4).



Comparing the suitability map with the model of suitability suggested by FAO (see figure below), it can be observed that in general suitability patterns are quite similar (FAO and IIASA, 2007). The information for the maps elaborated by FAO is a set of climate parameters (thermal climate, growth of plant time span and degree of climatic variability), characteristics of soil (depth, fertility, drainage, texture), slope and land use (excluded natural forest and protected areas). As a consequence similar patterns applied, which lead to analogous patterns but with the presence of some slight discrepancies. For instance, in the North of the pacific coast (except for Department of Nariño) is considered as non-suitable by the study carried out by IDEAM (IDEAM, 2009a) due to high precipitations, while the study presented by FAO classified as potentially apt.

In addition, a detailed spatial study on sustainability of different crops shows similar suitability patterns for palm oil in Antioquia (potential around Caucasia and along the Magdalena River in the border with the Department of Santander) (Alfonso Buitrago, Correa Roldán, & Palacios Botero, 2007).

Figure 103 FAO suitability map for palm oil crops



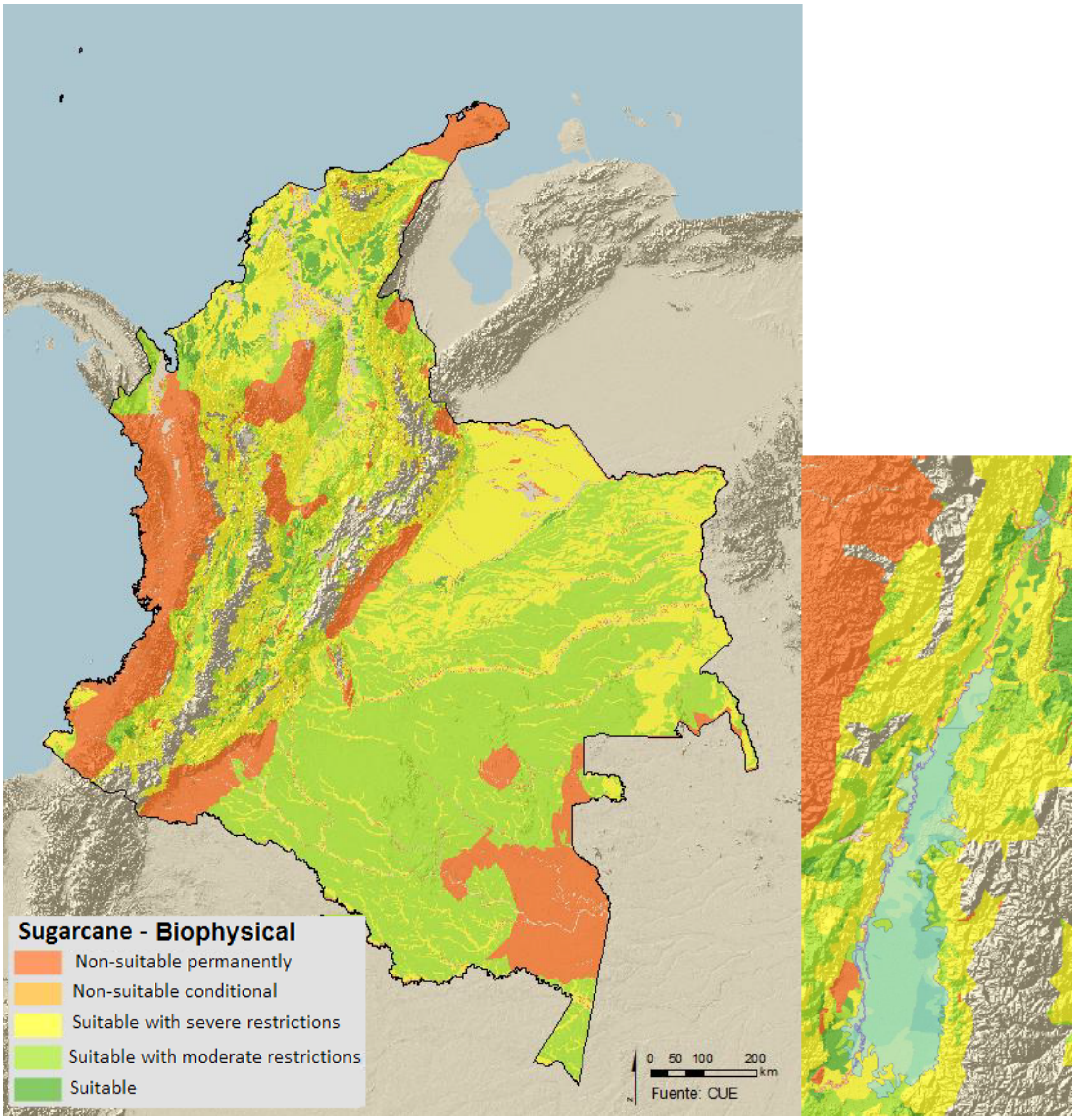
Source: (FAO and IIASA, 2007)

In general the most suitable areas were identified in the eastern region of Colombia regarding biophysical conditions (Departments of Meta, Guaviare y Caquetá), in the northern region (Department of Magdalena, nearby to Panamanian border) and in the inter-Andean valleys (Department of Santander and the northern zone of Antioquia). The largest areas, suitable for palm oil cultivation, though, are located in the eastern region of Colombia. Nevertheless, high impact on biodiversity and substantial carbon emissions that emerge from turning wild forest into energy crops constrain to a great extent potential expansion in these areas. These effects are discussed further down.

7.3.4.2 Suitability map for sugarcane crops

In a general sense, big extensions of land in Colombia are suitable for sugarcane cultivation. However, again, just like it the case of palm oil, extreme (high) levels of annual precipitation in the Pacific coast and the Amazon region narrow down expansion potential.

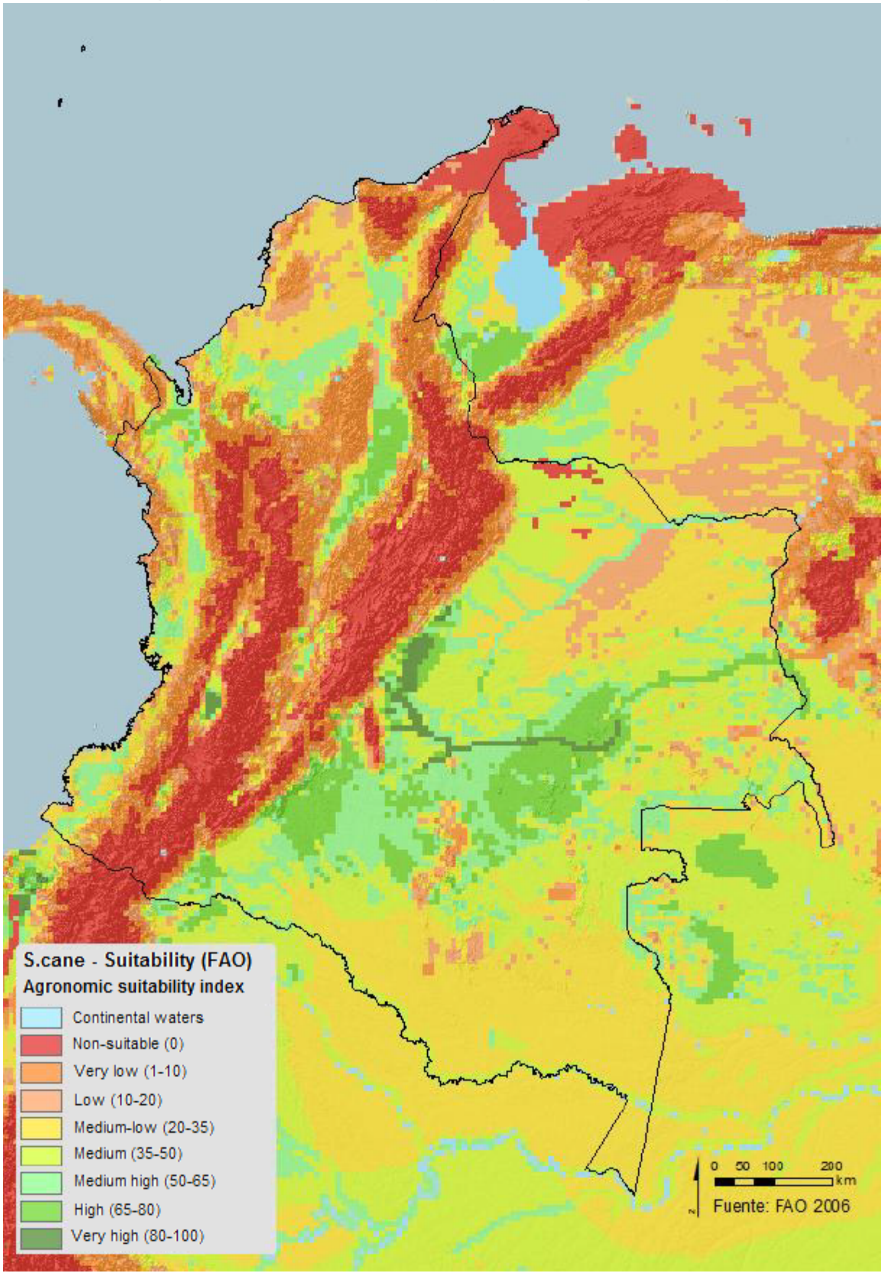
Figure 104 Biophysical factor suitability map for Sugarcane



Biophysical factor suitability map for Sugarcane crops (left).Detailed zoom in of the Cauca River Valley (blue: current sugarcane crops) (right).

When the model is compared with the areas that are currently under production of sugarcane, it is observed that a big portion of the geographic valley of Cauca River are considered as suitable and moderately suitable, and some other minor areas as suitable with severe restrictions.

Figure 105 FAO suitability map for sugarcane crops



Source: (FAO and IIASA, 2007)

By comparing this map of suitability for sugarcane crops with the one presented by FAO (figure above), it is observed that general patterns are emulated, notwithstanding some subtle differences: Due to high a precipitation factor in the Pacific region, that particular region was ruled out of this study as a suitable area under any circumstances; although it was included in the FAO report as an area of mild suitability. Moreover, big extensions located in the Departments of Magdalena and Cesar were included as suitable in the study, whereas the FAO study considered them as lands with only mild suitability. On the other hand, the map of suitability presented by FAO shows less suitability for those areas in the south of Colombia. This fact could suggest a mistake in the use of parameters in the present study (e.g. relative humidity), therefore, as a way to exemplify, the Amazon region was not excluded for biophysical parameters. Nevertheless, when social and environmental criteria are taken into consideration some of these controversial areas are removed in terms of a holistic suitability for sugarcane cultivation.

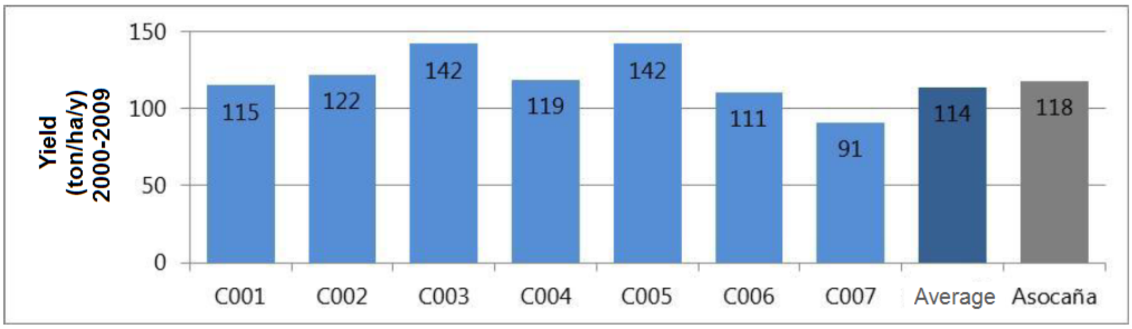
7.3.5 Potential productivity

The yield of the harvest is highly dependent on soil conditions, genetic characteristic of the seed material, and managing agricultural practices. Due to local differences, it is impossible to establish as precise a potential yield for all Colombian territory. It is especially hard to relate biophysical factors to crop yield, due to the fact that most factors are capable of being manipulated by agricultural practices (irrigation, protection against floods, shadow cover, fertilizations, etc.). Nevertheless, the approach used in this study is trying to establish a yield map more generally indicating the typical ranges of productivity that are used in the map of GHG's emissions. Therefore the categories of suitability are linked with the values of productivity. The correlation between suitability and productivity was done based on values from the literature and field data from the studied spots.

7.3.5.1 Productivity of the sugarcane

Maximum productivity is based on real numbers from the geographic valley of Cauca River. Below is shown different yields for the farms in the sample (tons per hectare per year). Under optimal conditions the average production is 120 tons /h/y. Mild productivity (suitability class 2) is near to 90 tons /h/y.

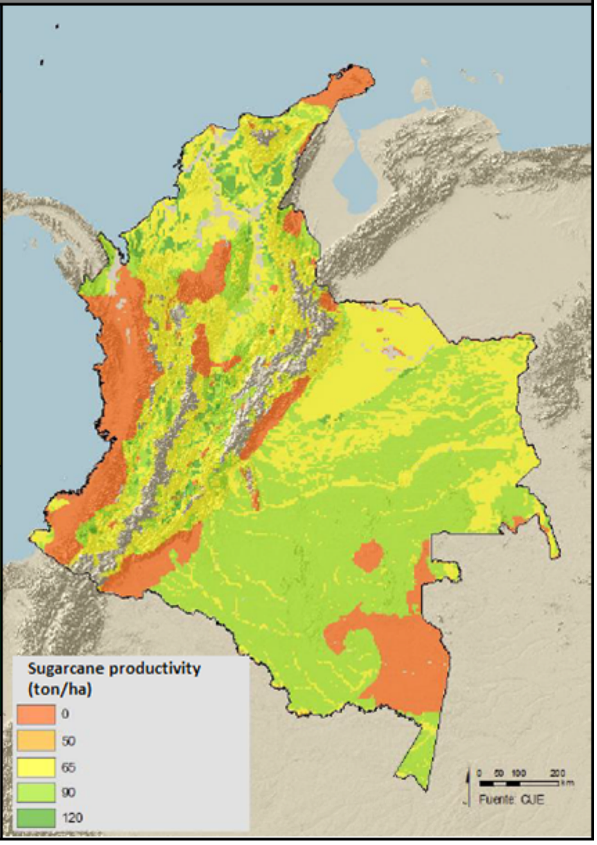
Figure 106. Annual yields of sugarcane spotted in the sampled sites



Yields for the less suitable zones have been evaluated based on the crops statistics presented by FAO (FAOSTAT, 2010). For zones in the category with non-suitable conditional, it was assumed a potential productivity of 50 tons /h/y and 65 tons /h/y for suitable land with severe restrictions.

Table 89 Sugarcane: annual yield assumed per every type of suitability

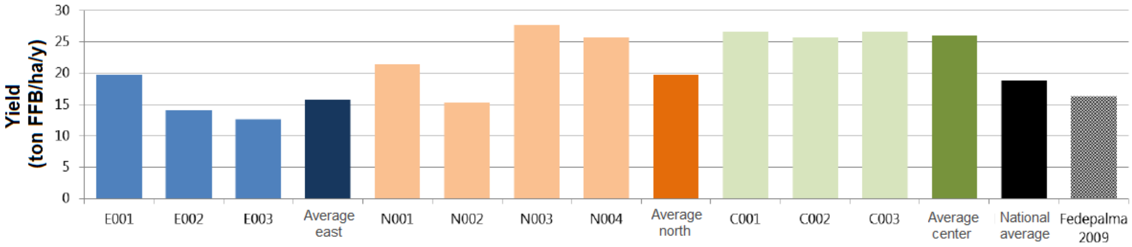
Sugarcane: annual yield assumed per every type of aptitude (suitability). Tons of sugarcane per ha	
Aptitude	**Productivity (ton/ha)**
N2 - Non suitable in a apermanent way	0
N1 - Non suitable conditional	50
S3-Suitable with severe restrictions	65
S2- Suitable with moderate restrictions	90
S1- Suitable	120
>2500 m	excluded



7.3.5.2 Productivity in oil palm

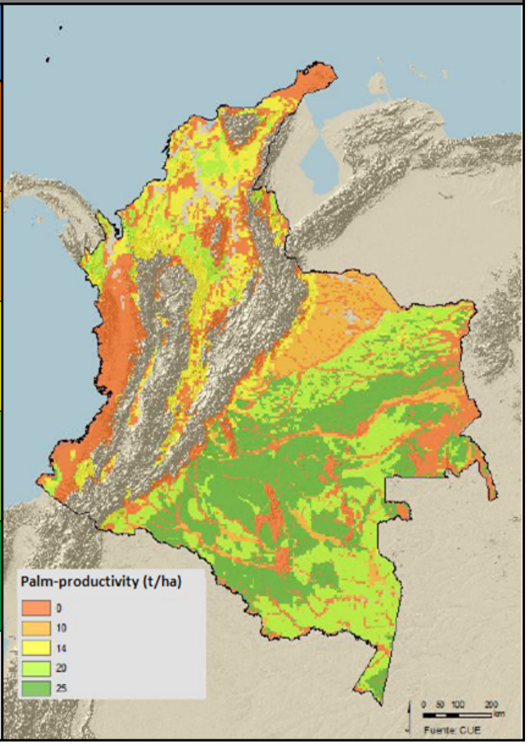
Maximum productivity is based on real yields that have been collected during field trips. In the figure below is presented yields from the farms that belong to the sample (assessed in tons /h/y). Under optimal conditions, average yield is close to 25 tons of bunches of fresh fruit per h/y. Moderate yields (i.e. those that have suitability class 2) are close to 20 tons/ h/y).

Figure 107 Annual yields of Palm Oil in Colombia. (E) East (N) North (Center).



Yields for the less suitable zones have been evaluated based on crops statistics presented by FAO (FAOSTAT, 2010). It has been assumed marginal yields of 10 tons of fresh fruit for the category labeled as non-suitable conditional, 14 tons /h/y for the category ‘suitable with severe restrictions’.

Table 90 Palm oil yield assumed per every type of altitude

Palm oil: annual yield assumed per every type of aptitude (suitability). Tons of FFB per ha		
Aptitude	**Productivity (ton/ha)**	
N2 - Non suitable in a apermanent way	0	
N1 - Non suitable conditional	10	
S3-Suitable with severe restrictions	14	
S2- Suitable with moderate restrictions	20	
S1- Suitable	25	
>1000 m	excluded	

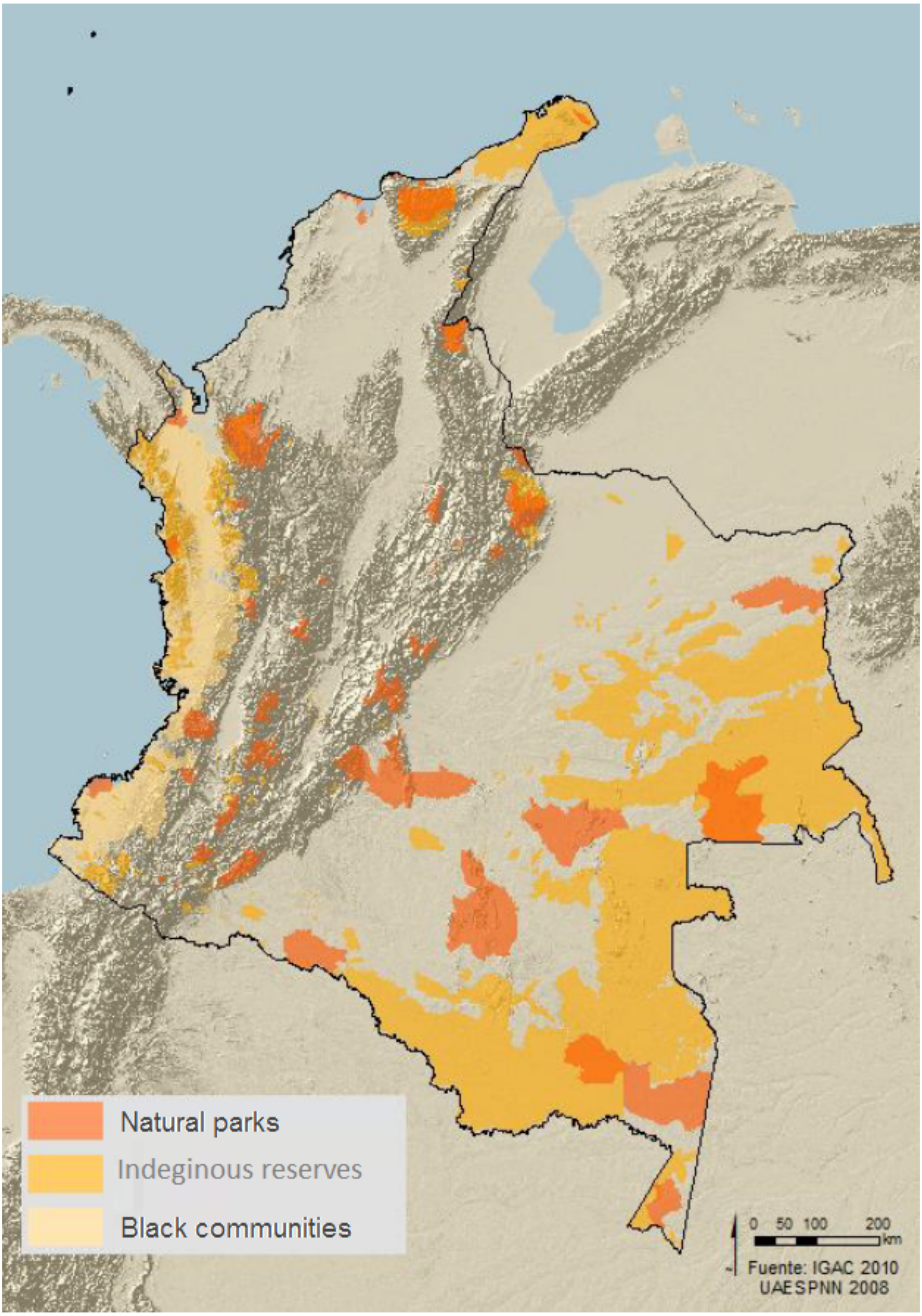
7.4 Legal restrictions

In order to determine the expansion potential for bioenergy crops those areas that are legally protected (natural areas, indigenous reservoirs, and collective titles of black communities) were excluded. Natural parks are marked with permanent constraints (Parques Nacionales Naturales de Colombia, 2011), while indigenous reserves and collective titles of black communities exhibit conditional limitations (IGAC, 2010). These limitations make reference to two key aspects:

1. these territories belonging to a communal proprietorship; therefore they cannot be sold, leased or transferred to a private initiative
2. Biofuels projects that are considered to be implemented within these areas can be set in motion only under leadership and approval of the affected communities.

Below, it is possible to see natural parks, indigenous reservoirs, and collective titles of black communities that constitute a constraint for a potential expansion of bioenergy crops. These limitations exclude big areas of the Pacific coast, the Amazon region and Guajira Peninsula, to be considered as suitable for biofuel feedstock crops establishment.

Figure 108 Map of legal restrictions

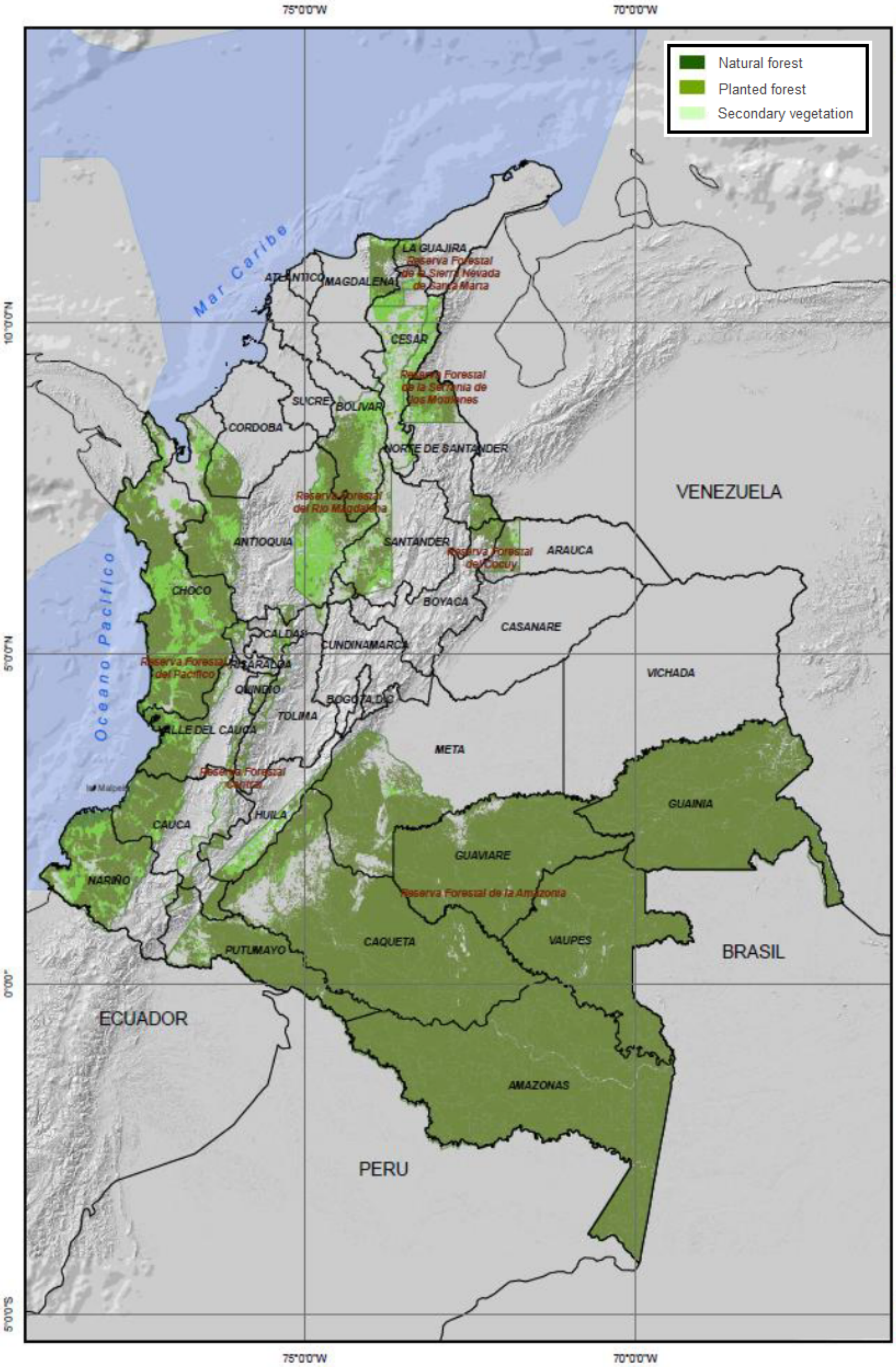


Grey areas do not represent any restriction.

On the other hand, those forest lands that are protected by law 2 of 1959 are restricting potential expansion of sugarcane and palm oil through legal mechanisms (Congreso de Colombia, 1959). All forest areas are excluded later on, not only to comply with legal criteria, but also to avoid biodiversity loss and diminishment of hydrologic services that are provided by forest systems.

Figure 109 Forest ecosystems protected by the law

law of the Forest Reserve Zones (Law 2 of 1959).



Source: (IDEAM, 2007)

7.5 Ecologic limitations

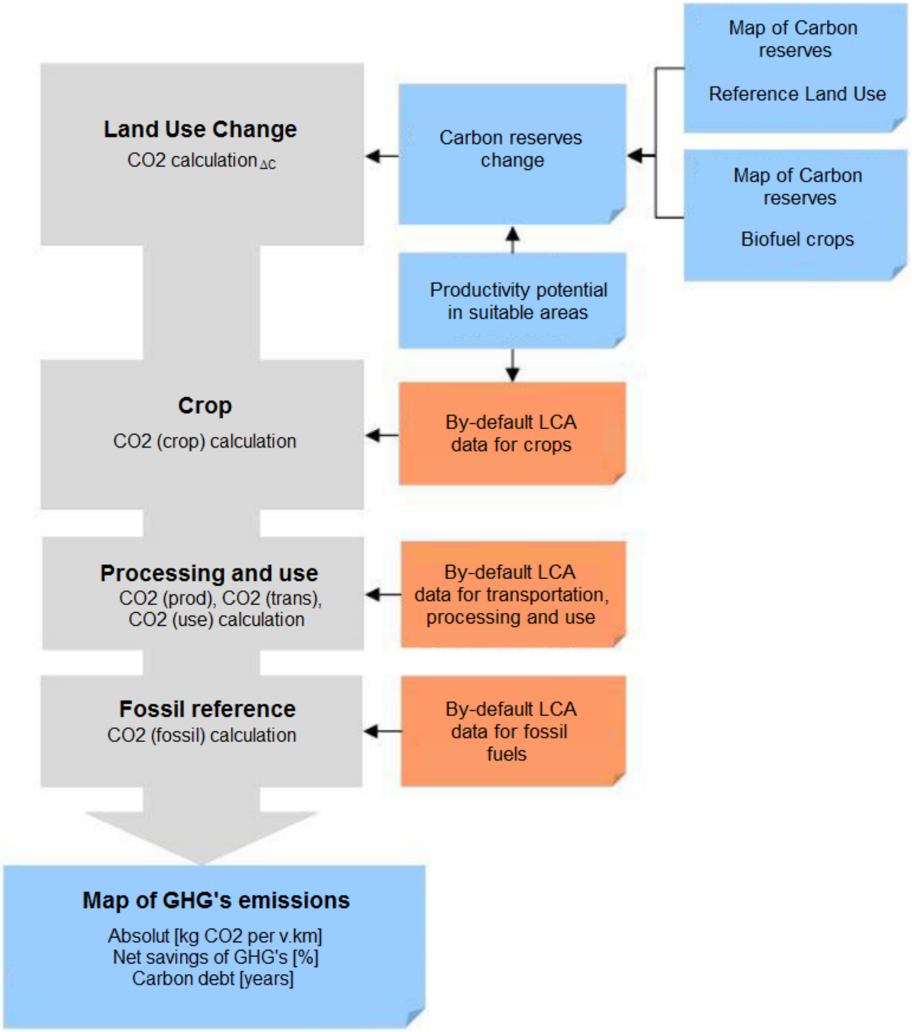
In a former section, it was determined potential areas of suitability for biofuels crops taking into the account biophysical factors. In this section biophysical areas are even more restricted by use of environmental criteria, such as carbon emissions, water shortages and biodiversity.

7.5.1 Greenhouse gases (GHG's) emissions

Current studies on GHG's show the importance of considering land use change (LUC) regarding environmental performance of biomass-based fuels. According to Fargione et. al. the LUC generated by biofuels production might cause a "carbon debt" by the release of great amounts of CO2 that is trapped underneath the surface soil layer and that has been stored for years. According to these authors, if palm oil plantations are established in a natural forest, it would take up to 400 years to offset the carbon debt created by this bioenergy project. Even more, if sugarcane plantations were established in an old savannah it would take close to 17 years to settle such carbon debt (Fargione et al., 2008).

In this study a calculation of a carbon debt is drawn for potential plantations of sugarcane and palm oil. In fact a regional LCA is implemented for every grid in Colombia (5km x 5km) and based on the GHG's balance obtained the carbon debt.

Figure 110 Concept for modeling a GHG's emissions map.



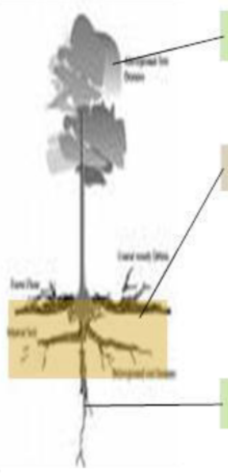
The first step is to calculate the amount of GHG's emissions related to LUC. Later, a biomass map is established, and a map that depicts carbon contained in soil for reference in Colombia. Additionally biomass and carbon in soil reserves were calculated for potential land where potential bioenergy feedstock crops can be established. Finally potential LUC effects were evaluated for eligible areas destined for biofuel production initiatives. Maps of potential productivity are used for expressing the change of carbon reserves as kg of CO2 for every kg of feedstock for biofuels (instead of kg per hectare). In agricultural stages, as well as processing and usage stages of biofuels it employed values given by default for GHG's emissions. Finally, it calculated the carbon debt and the net benefit if fossil fuels are changed for biofuels. A general overview is illustrated in the figure above.

7.5.1.1 Carbon emissions due to LUC

This section analyses carbon emissions that emerge as a consequence of land use changes (LUC). Reserves of carbon within the soil are determined by the carbon content in the biomass and the organic carbon that is embedded in the fertile layer of the soil (first 30cm).

Figure 111 Soil carbon reserves

Above-ground biomass, Soil Organic Carbon and Below-ground biomass.



Above-ground biomass (AGB)

All living biomass aboveground including stem, shoots, branches, bark, seeds and foliage.

Soil Organic Carbon (SOC)

It includes all organic matter in mineral and organic soils (including peat moss) given a specific depth selected by a particular country and applied consistently through time series. Thin living roots (with a lesser diameter than the one suggested for the below-ground biomass) are mixed up with the soil organic matter , thus, it is not possible to distinguish one from the other empirically.

Below-ground biomass (BGB)

It is represented by all living biomass of living roots. Fine roots with a diameter less than 2 mm are regularly excluded, given that these are not able to be distinguised from the soil organic matter empriricaIly.

Biomass embedded in plant store a substantial quantity of carbon at ground level and below ground level in several ecosystems. Above Ground level Biomass (AGB) associated with annual herbaceous and perennial plants is fairly low, while the AGB that is related to woody plants can accumulate a vast amount of carbon (up to hundreds of tons per hectare) throughout its lifespan. Thin and thick roots are probably the main component of Below Ground level Biomass (BGB), which can be important to both herbaceous and woody systems. When ecosystems change from a humid climate to a dry one, plants distribute an increasing proportion of biomass below ground level.

Total carbon reserve [tC/ha] = carbon of above and below ground level biomass [tC/ha] + Organic carbon of soil [tC/ha]

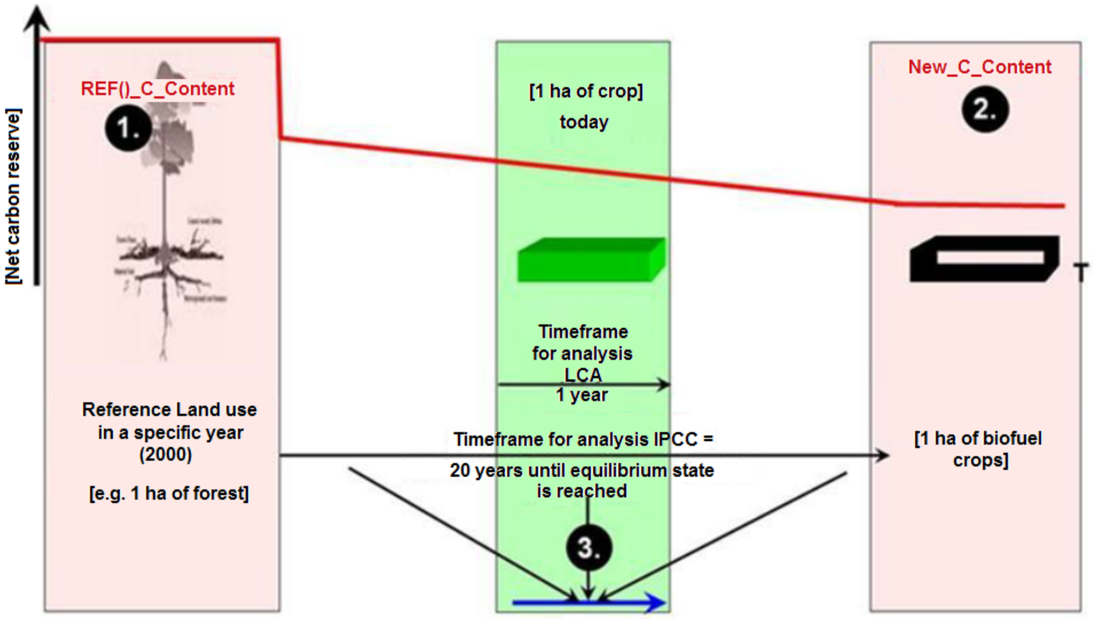
Assessment of carbon emissions is based in the following assumptions:

- The assessment accounts for the direct land use changes (LUC) and do not include the indirect land use changes (ILUC).
- Reference year (for data availability is 2000)
- Change in the carbon reserves are assessed in a period of 20 years (IPCC/EU standard)
- It was assessed biomass above ground level (i.e. plants), below ground level (i.e. roots) and carbon embedded in the ground in the years 0 and 20.

- Data sources for carbon reserves come from regional studies (IPCC Level 2/3) or if there is no available data the default value is given by (IPCC level 1).

Basically this means, that carbon reserves for soil in 2000 (step 1) is compared with carbon reserves for biofuel crops (step 2). It calculates the difference in carbon reserves for 20 years as an average change in the reserve of carbon per year.

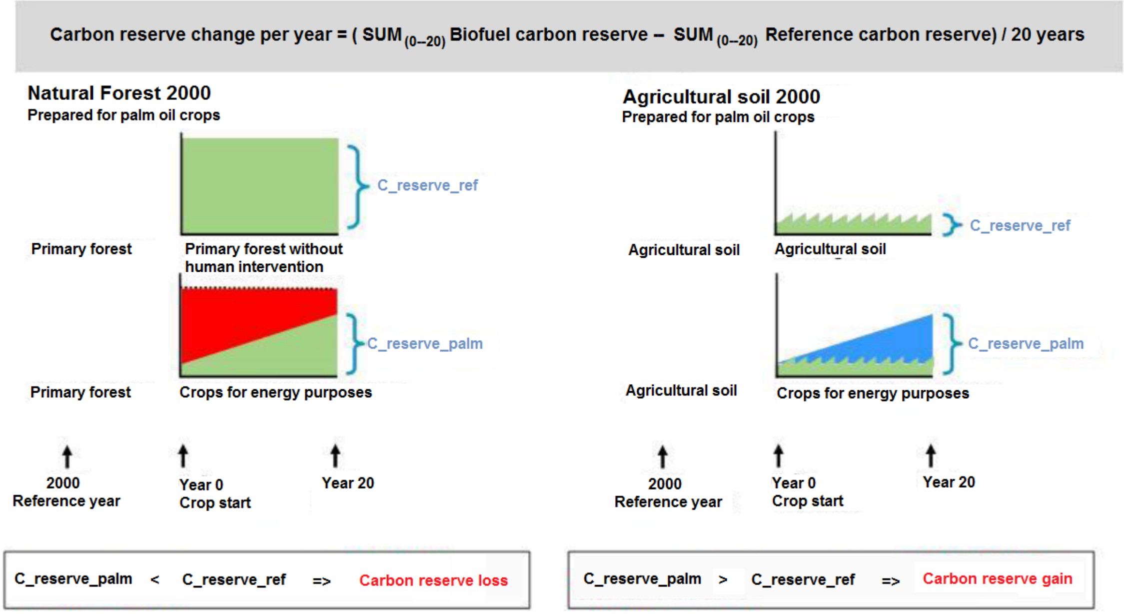
Figure 112 Assessing model for calculating GHG's emissions due to LUC



The following figure shows an example of a palm oil cultivation in a natural forest and agricultural soil.

Figure 113 LUC from natural forest and agricultural land biofuel crops (palm)

LUC from natural forest to palm oil cultivation (left), and from agricultural land (non-energy purposes) to biofuel crops (right).



The red area indicates carbon loss and the blue area represents the increase in carbon reserve. The following section describes the change in AGB and BGB and change in organic carbon in the soil. As a way of a summary, it also calculates total carbon change and carbon debt.

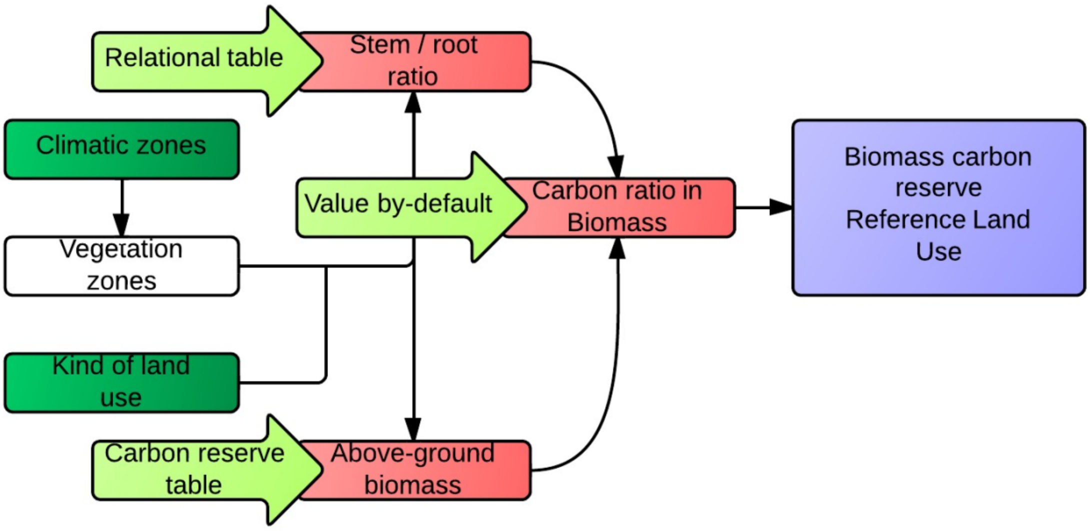
Carbon change in biomass

With the purpose of evaluating the change of carbon in biomass, it assessed the reserve of above and below ground level biomass for land use for the reference year (2000) and the potential of bioenergy crops for biofuel projects after 20 years. Further down are described the methodologies that were employed and presents corresponding maps.

Reference land use – Carbon change in Biomass

Below is defined a flow chart of those processes that are employed to identify and quantify carbon reserve of biomass for the reference land use (2000).

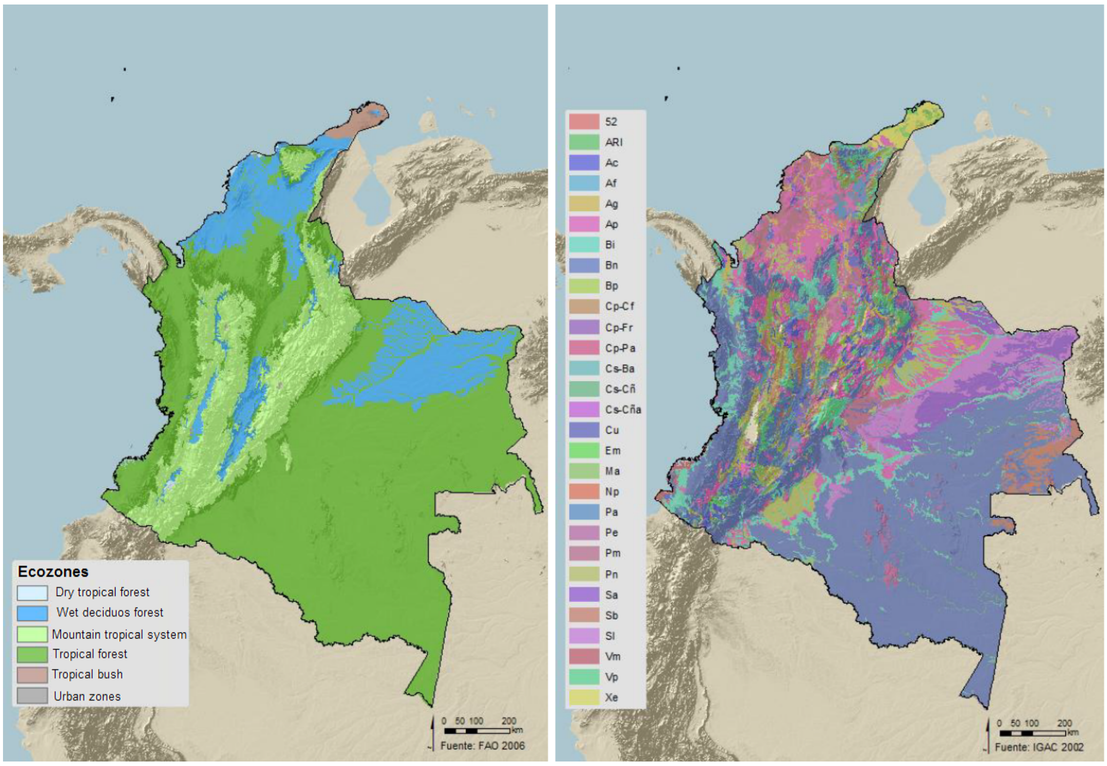
Figure 114 Process to evaluate biomass carbon reserve for the reference use soil.



Current land use map was created based on the different types of land use and vegetation zones (zones of life or green coverage). The soil coverage map from IGAC in Colombia acknowledges 29 different kinds of soil coverage (see map below). This study was focused on the gap between 1990 – 2000 (IGAC and CORPOICA, 2002). It created a detailed map with vegetation zones in Colombian territory, as it was addressed by the guidelines fixed by the IPCC (IPCC, 2006), creating new climatic zones (eco-zones) in Colombia.

Figure 115 Map of reclassification of eco-zones and Map of land use

Map of reclassification of eco-zones by vegetation type and Map of land use defined by FAO and IPCC (left) and Map of land use (IGAC)



Source: CUE

Most land in Colombia is classified in these categories as follows:

- tropical forest (735,133 km2),
- wet forest caecilian (184,771 km2)
- and tropical mountain system (207,296 km2).

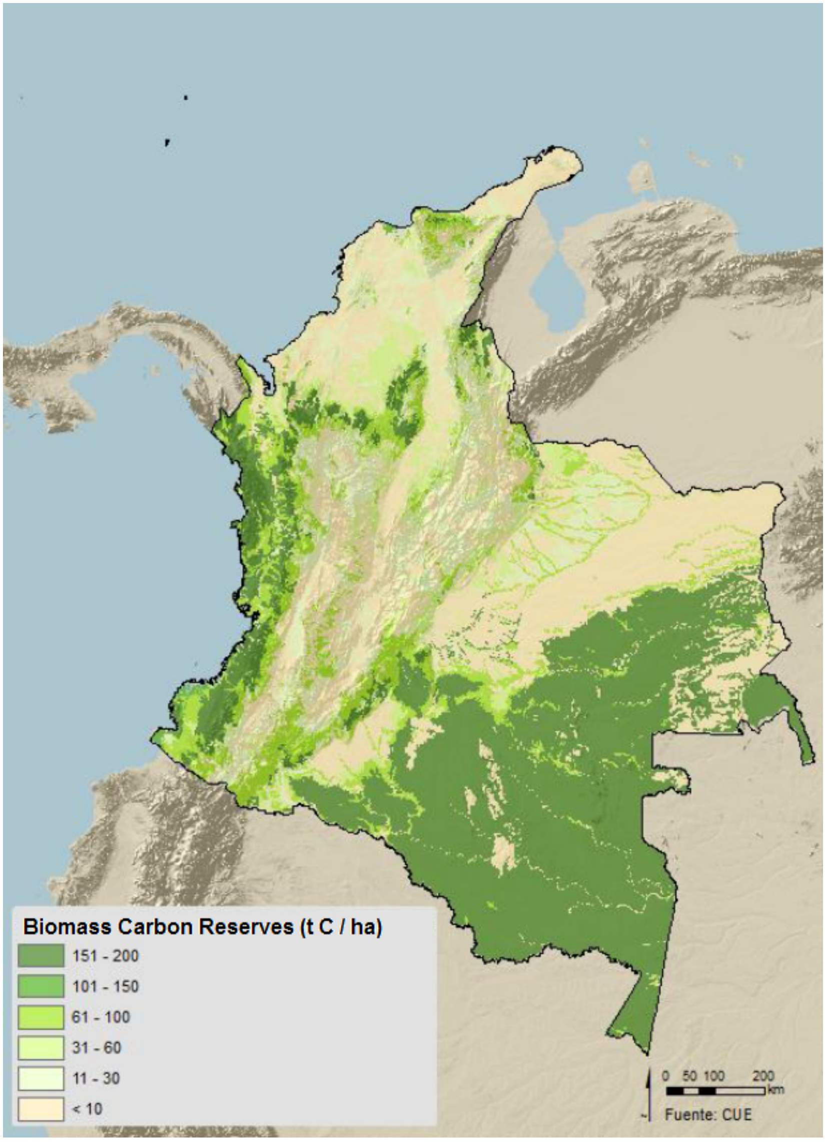
A limited quantity of land is located in tropical bushes (9,637 km2) and tropical dry forest (1,978 km2).

Combination of land uses and vegetation zones draw 94 carbon zones. Their superficial areas (km2) are defined in appendix 16.

For each one of the 94 combinations of AGB and BGB biomass were taken values provided for IPCC. If the values given by the IPCC are not available, some regional estimations from similar vegetation zones are used instead.

Below ground level biomass (BGB) is calculated as AGB times the ratio between stem and root (RS-R). Biomass' carbon content is calculated by multiplying the content of dry matter times the carbon fractionation (CF). The typical CF of dry biomass is assumed as 0.47 in tropical systems. Maps of AGB and BGB are presented here.

Figure 116 Total carbon biomass of the reference land use (in tons of carbon per ha)

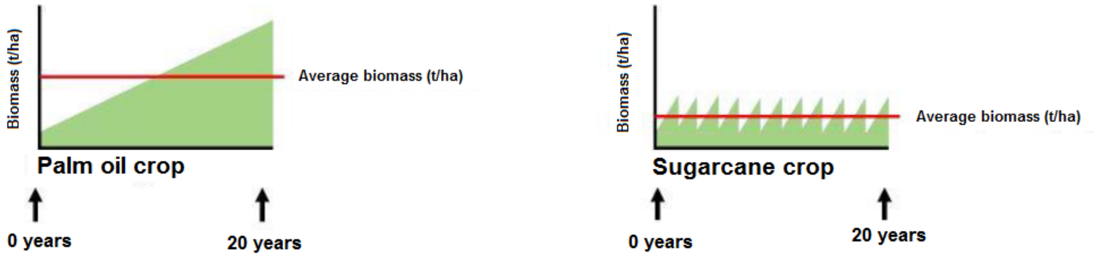


Source: CUE

Carbon reserves for biofuel feedstock cultivation

The typical growth of biomass and CF (kg C / kg biomass) must be quantified in a period of 20 years for sugarcane and palm oil.

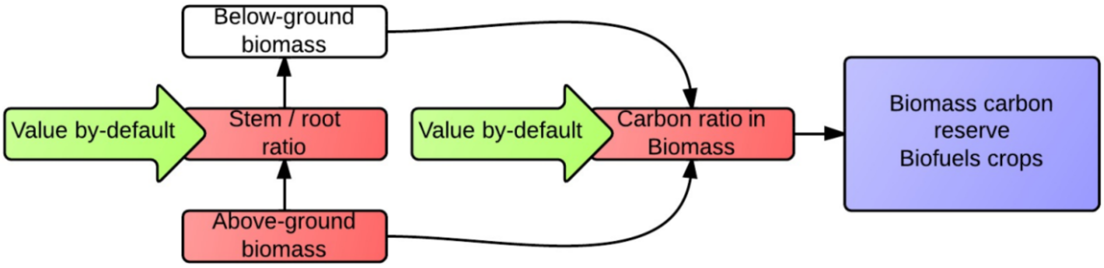
Figure 117 Cumulated biomass of palm oil (left) and sugarcane (right).



Red line indicates the average biomass accumulated in a period of 20 years.

As is illustrated below, values for reserve of superficial biomass, RS-R and CF were established from those reference default values found in the literature. Values used for sugarcane and palm oil are described below:

Figure 118 Process to evaluate biomass carbon reserve for the crops for bioenergy



Plantation of oil palms

The following table describes the AGB and BGB of palm oil plantation in Indonesia in different ages (Vlek, Denich , Martius, Rodgers, & Giesen, 2005).

Table 91 Distribution of the carbon reserves above and below ground for Palm Oil

Distribution of the carbon reserves above and below ground for Palm Oil in Sumatra, Indonesia					
System		Belowground		Above ground biomass	Below ground/ total (%)
		Soil	Biomass (Mg/ha)		
Imperata cylindrica		137,6	2,9	3	97,9
Palm oil	3 year-old	161,2	5,4	11,2	93,3
	10 year-old	482,2	10,4	38,9	92,1
	20 year-old	155	16,6	48,6	71,7
	30 year-old	232,4	21,6	62,8	75,3

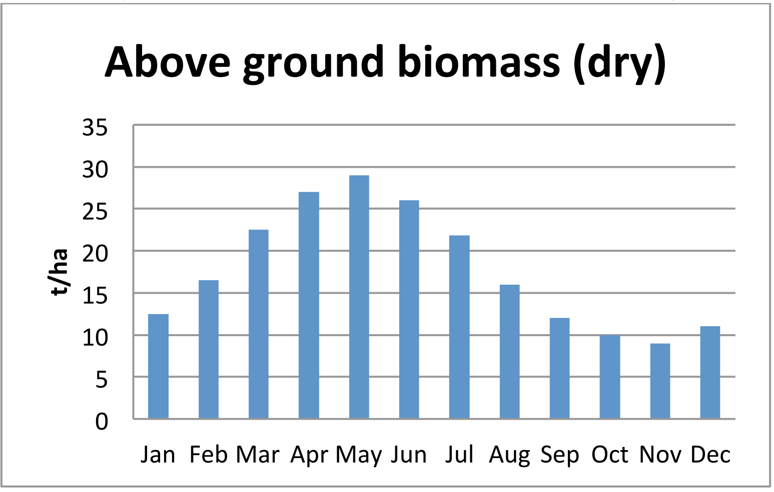
Source: (Vlek et al., 2005)

In order to verify if the estimations of biomass of Southeast Asia can be applied in Latin America, it referred to another study implemented in Costa Rica, that actually quantified 25 tons of carbon per hectare in an palm oil plantation that was 7 years old (Subía Loayza & Cueva Moya, 2005). This last estimation averages out the estimated AGB for Indonesia for plantations with ages between 3 and 10 years (that is, 93 tons of dry matter per ton and the BGB is 13.5 tons of Carbon per hectare, which draws a RS-R =0.3), assuming a rotation of 25 years.

Plantation of sugarcane

The development of simulated plant (model CS) for AGB of sugarcane in Brazil varies from 28.7 tons per hectare (starting in May - the harvesting season) to 9.1 tons per hectare (ending in November) with an average of 17.5 tons per hectare (I.C. Macedo, 2010).

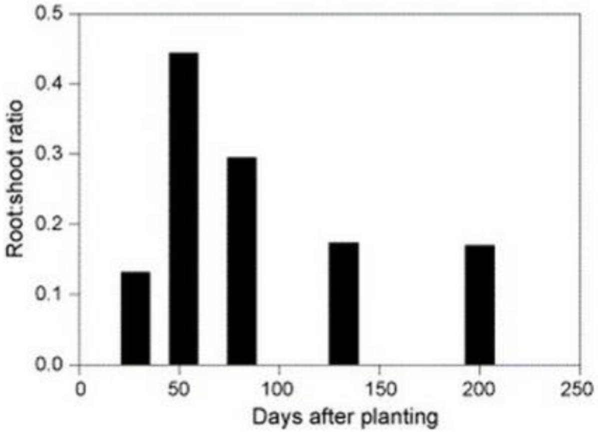
Figure 119 Development of a simulated plant for the AGB of sugarcane in Brazil



Source: (I.C. Macedo, 2010)

In the work of Smith (J. P. Smith, Lawn, & Nable, 1999) it assessed the relationship of stem-roots for sugarcane sowed in a flower pot and found that such ratio fell right after having achieved a peak value of 0.42 kg/kg 50 days after having been planted (I.C. Macedo, 2010). Therefore it assumes that AGB is approximately 17.5 tons of dry matter per hectare, and the average RS-R it is assumed as 0.25.

Figure 120 Ratio Stem-root (based on dry weight) for sugarcane planted in pot.



Source: (I.C. Macedo, 2010)

Changes in the carbon reserves of biomass due to land transformation

The effect of the LUC in AGB and BGB is calculated as the difference between the carbon reserve of the biofuel feedstock (in this case sugarcane and palm oil) and the carbon reserve that is above and below ground before the LUC takes place (in 2000).

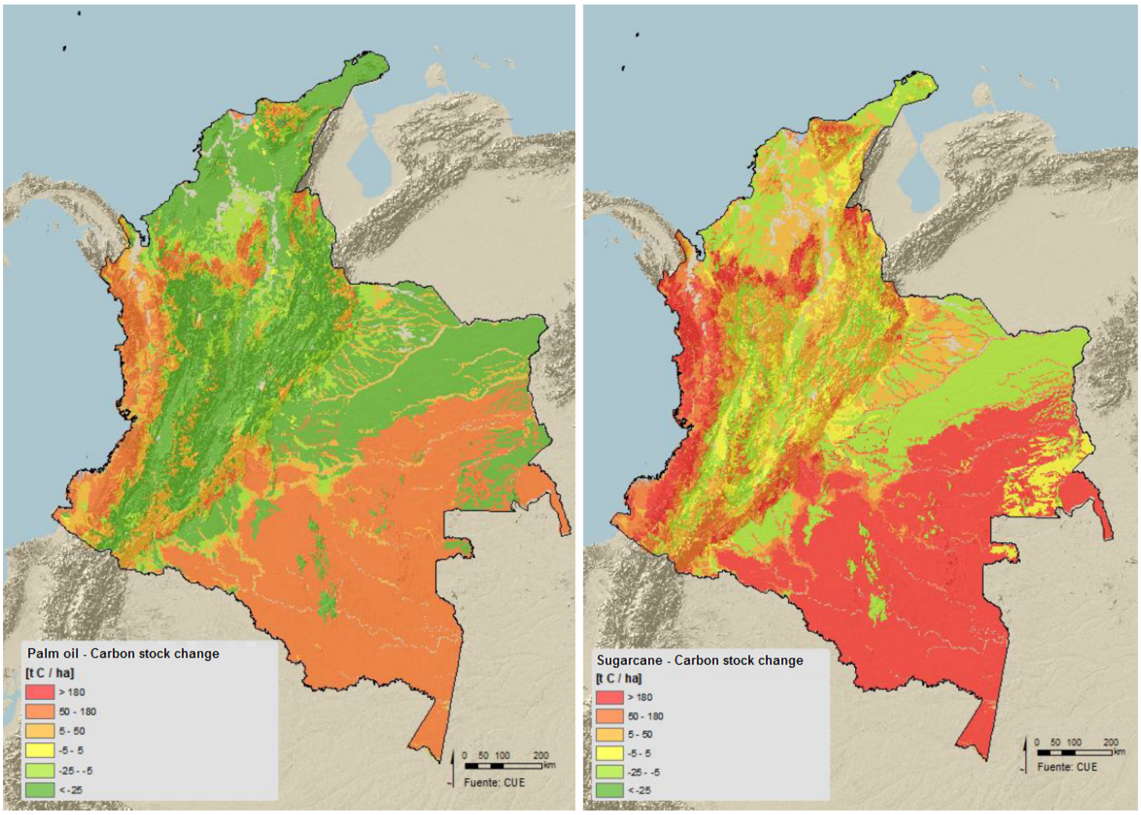
$$AGB_{t1} = (AGB + BGB)_{Biofuels} - (AGB + BGB)_{Initial}$$

AGB_{t1}= Above-ground biomass after the land use change (t C per Ha)

$(AGB + BGB)_{Biofuels}$ = Above-ground biomass for biofuel feedstocks (t C per Ha)

$(AGB + BGB)_{Initial}$= Above-ground biomass for the reference soil (t C per Ha)

Figure 121 Potential change in the biomass reserves



If land is employed for palm oil cultivation (left) and for sugarcane cultivation (right). Assessed in tons of carbon per hectare.

Soil organic carbon

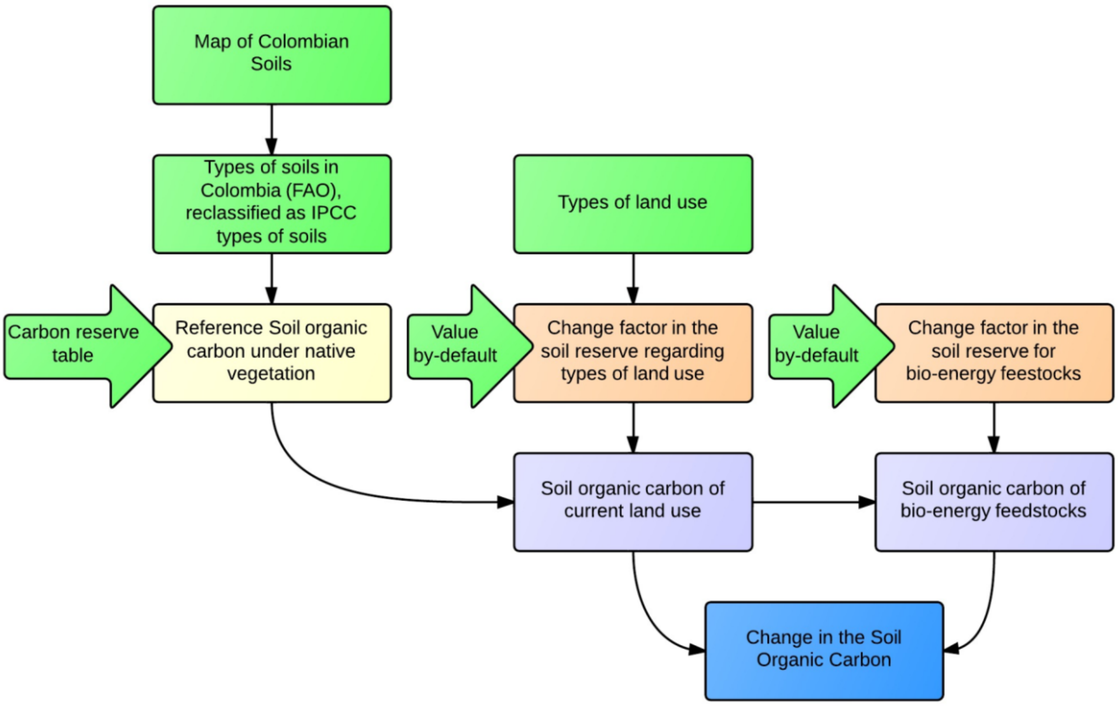
Despite the fact that both types of carbon (organic and inorganic) are found in the ground, land handling and use have a great impact on reserves of soil organic carbon (SOC). Lands of mineral type are, most of the time, classified as moderate to good in terms of drainage and are predominant in almost all ecosystems (with exception of wetlands) and generally they account with a relatively low amount of organic matter (this is, between 0 and 15% of organic matter). Organic soils (mainly peat and manure) have a minimum of 12 to 20% of organic matter per unit of mass and are developed specifically under insufficient drainage conditions in wetlands, where substantial amounts of organic matter accumulates as the time passes. Stored carbon in organic soils will decompose easily when soil conditions turn aerobic after soil drainage.

A great deal of the inputs for SOC come from fallen leaves that are accumulated in the surface layer of soil, therefore organic matter tends to be concentrated in the superior part of land horizon, with almost half of SOC in the first 30 cm in the upper layer. Organic carbon contained in this profile is generally the one that presented major chemical decomposition, physical erosion and the one that faces major exposure to natural and anthropogenic shocks.

The upper layer (between 0 and 30 cm) includes the soils that are directly related to interaction with the atmosphere, and these soils are more sensitive to environmental changes and LUC.

Reference condition for SOC is under the category of native land (which means non-degraded land, land under native vegetation without human interventions or improving actions), which is used for assessing the relative effect of LUC and reserve quantity of SOC (implying, for instance, the relative difference in carbon storage under the reference condition and any other land use, like food crop cultivation). Reference reserves of soil organic carbon were drawn through the association of FAO land classification and the types of soil that are given by default by the IPCC, through rules of pedotransfer functions, as described in Batjes (Batjes, 2010).

Figure 122 Assessment method for the change in Soil organic carbon



Source: Adapted from (Batjes, 2010)

For the geologic data for Colombia it used as primary source a set of unified land properties developed for Latin America, using a land and terrain data base with a scale 1:5,000,000 (ISRIC-WSI, 2005) and land auxiliary profiles that belong to the data base WISE. The main land was described and characterized, using 1660 surveys of land profiles, selected by experts in land at a national level. The pedotransfer functions that were used (proposed by Batjes 2010), report to the units of land of SOTERLAC the proportion of land classes by default from the IPCC (IPCC, 2006).

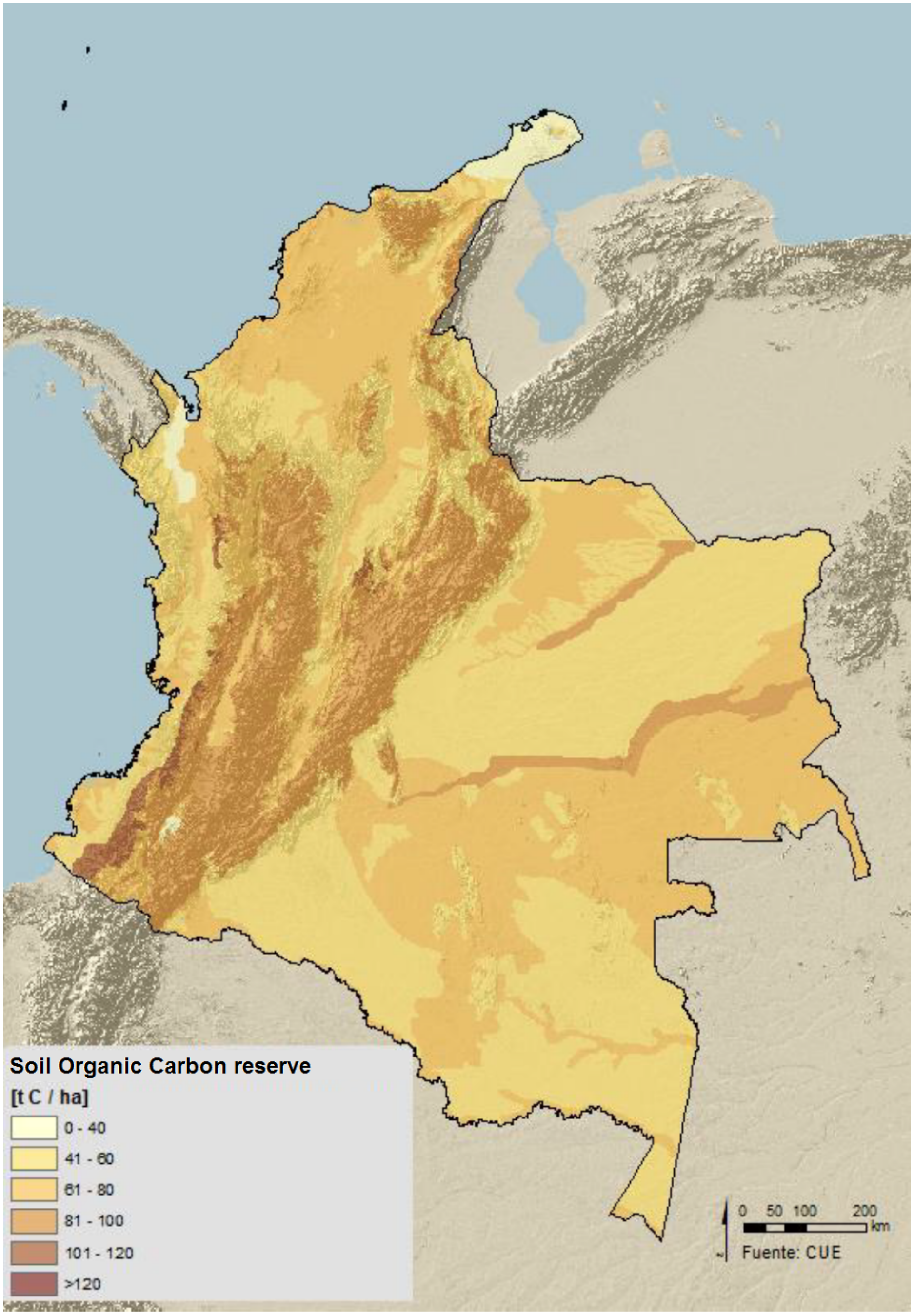
The size of SOC reserve is influenced by activities of LUC, just like conversion of pasture lands and wood lands into food crop cultivation lands, which can loose between 20% and 40% of the original SOC in mineral soils. Regarding land use, a variety of agricultural managing practices might have a significant impact in SOC storage as well, particularly in crops and pasture lands. The LUC and managing activities can influence SOC, by changing erosion rates in a predetermined way, creating a subsequent loss of carbon; a portion of eroded carbon comes back to the atmosphere as CO2, whereas the remaining fraction is stored in other locations.

Hence, with the intention of calculating the current SOC reserve in Colombian soil (SOC0), the reference reserve of SOC (SOCref) is multiplied by the change factor in reserve according to the guidelines given by de IPCC (IPCC, 2006). The same approximation was employed to calculate the reserve of carbon in the soil if the land is used for energy crops (SOCT).

Reference Soil organic carbon (SOCref)

Estimation of the SOCref is classified in carbon per hectares and it is presented below as a function of the proportion of the types of land from IPCC and the maps of vegetation zones of Colombia, previously examined.

Figure 123 Map of carbon reserve of a reference natural system



Source: CUE

The content of SOC in Colombia varies between 0 and 130 tons per hectare approximately, for the first 30cm depth of ground. A small fraction of organic soils is found in wetland areas that are relatively small located in the northern region of Colombia, which were classified as non-suitable for the LUC criteria proposed in this study.

Soil organic carbon of current land use

The SOC depends mainly on the natural characteristics of land, characteristics of crop and agricultural management. Firstly, it is required to determine SOC for the year 2000 (SOC_0). For natural ecosystems the SOC_0 is equal to SOC_{ref}, however for the land that is used for crop purposes (either food or energy) the SOC_{ref} changes due to crop management. The SOC_0 for the existent categories of land use is estimated by multiplying SOC_{Ref} reserves times change relative factors in land carbon reserves. These factors are widely defined and they are broken down as follows:

1. Land use factor (LUF), which represents changes in carbon reserves associated with the type of land.
2. Management factor (MF), which reflects specific key practices for a particular sector of land use (that make reference to the kind of farming or tilling routines employed on the land)
3. Intake factor (IF), which embodies the level of carbon that is contained by the soil.

Based on that, Soil organic carbon can be represented as follows:

$$SOC_0 = SOC_{REF_{c,s,i}} * LUF_{c,s,i} * MF_{c,s,i} * IF_{c,s,i}$$

SOC_0 =Organic carbon reserve in the last year of the timespan, (ton of carbon per ha).

$SOC_{REF_{c,s,i}}$ = Organic carbon reserve in the soil of reference, (ton of carbon per ha).

$LUF_{c,s,i}$ =Change factor in reserve due to land use systems, or subsystems for a particular kind of land, (no assessment unit).

$MF_{c,s,i}$ = Change factor in reserve based on the management system of land, (no assessment unit).

$IF_{c,s,i}$ = Change factor in reserve based on the intake of organic matter (no assessment unit).

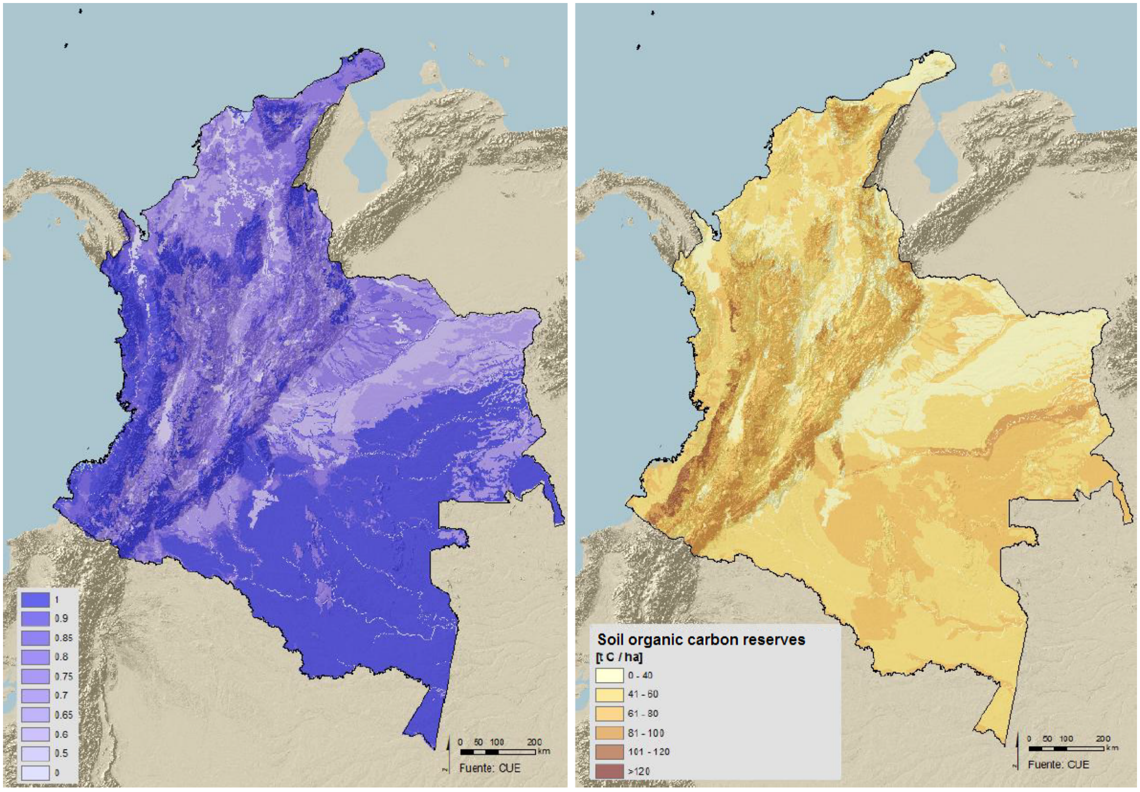
c = Climatic zones

s = type of soil

i = set of management system applied.

Change relative factors in reserves (LUF, MF, and IF) take values from 0 to 1 and the values of each type of soil are given in appendix 16. Values for SOC_0 are calculated based on the change relative factors in reserves and the value of SOC_{ref} (see figure below).

Figure 124 Relative Change factors of reserves (left) and SOC0 for Colombia



Source: CUE

Difference between the map of SOC_{ref} and SOC_0 is only for areas that are currently under cultivation (areas where the reserves relative change factor is not equal to 1, see figure above).

Reserves of soil organic carbon (SOC) for biomass-based fuels

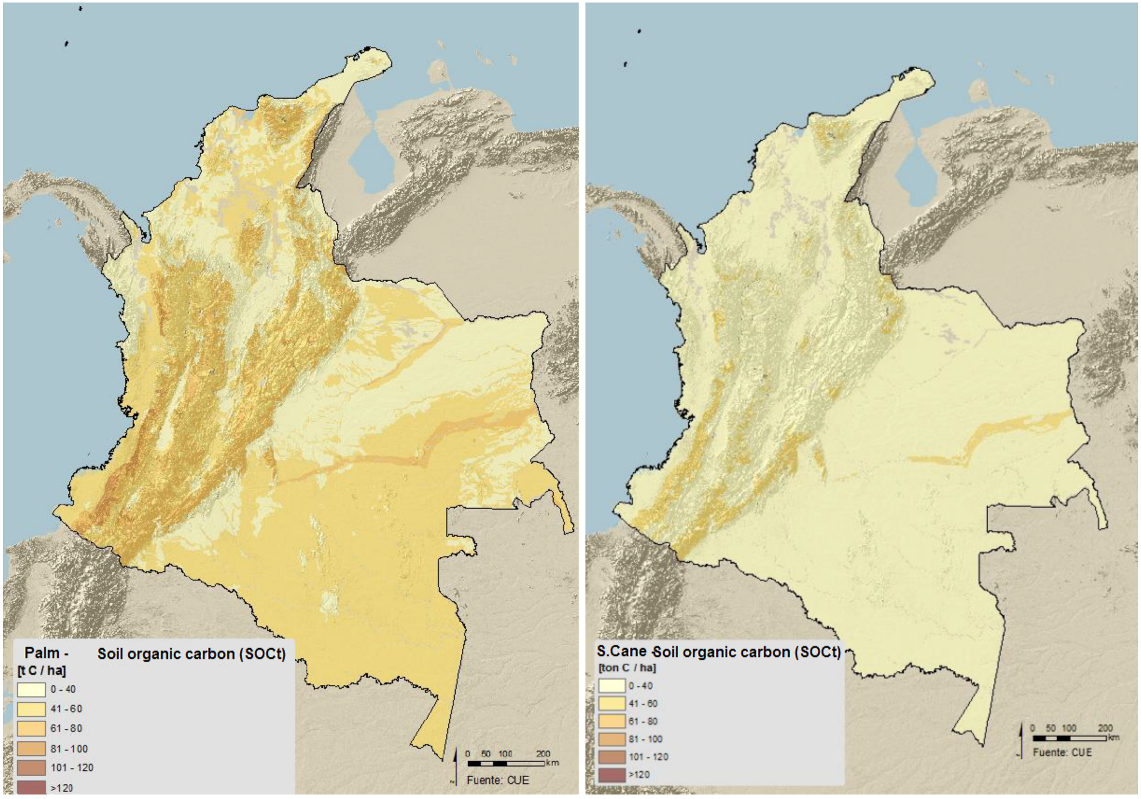
With the purpose of calculating related emissions with change of SOC, it models the influence of SOC when feedstocks for biofuels are cultivated. Accordingly, it is assumed that the change in a natural area or prairies for energy crops turn in a SOC reduction. This SOC is calculated based on the SOC before the land use change and (SOC0 that is equal to SOCref) times the factors of relative change in the reserves for sugarcane and palm oil.

Factor of relative change of reserves in those crops cultivated in the long run in wet climates (i.e. sugarcane) is approximately 0.5 (IPCC, 2006).

For perennial crops, the factor of relative change in reserves is equal to 1 regarding the guidelines provided by the IPCC. Factor equal to 1 is supported on the assumption that crop management does not lead to soil erosion, when it changes native vegetation. Nevertheless, that situation is not always accurate for tree plantations. In fact, observation of 100 different samples of study show a reduction up to 30% in the average of soil carbon content when forest land are turned into crop plantations (Germer & Sauerborn, 2008). Therefore a factor of 0.8 is much more realistic and used in this study instead of the generic values propose by the IPCC.

If food cultivation land (or any other agricultural purpose) is turned into sugarcane or palm oil the change factor is assumed as 1, leading to zero changes in SOC.

Figure 125 SOCt after land use change to palm (left) and sugarcane (right).



Change in the reserve of soil organic carbon

The GHG's emissions related with SOC change due to the introduction of biofuel feedstocks are calculated as the difference of SOC of the previous land uses ($SOC_{0,i}$) and after 20 years of biofuel cultivation (SOC_t).

$$\Delta C_{soil} = \sum_{i} \frac{[SOC_{0,i} - SOC_t]}{T}$$

ΔC_{soil}: Annual change in carbon reserves in mineral and organic soils (tons of carbon per hectare)

SOC_t: Reserve of soil organic carbon at the end of the inventory period (tons of carbon per hectare)

SOC_0: Reserve of soil organic carbon at the beginning of the inventory period (tons of carbon per hectare)

i: Type of soil

T: It is the time dependence of those factors of change in the reserve. This span is the time period by default for the transition between the equilibrium of SOC values.

The following figure illustrates the change in SOC for palm oil and in the next one the change in SOC for sugarcane.

Depending on the type of land, if sugarcane plantations are established, up to 55 tons of carbon are emitted. These soils are rich in organic carbon content, and generally located in the nearby of rivers and mountain chains. Palm oil cultivation has a lesser effect in the change of SOC, hence the maximum quantity of carbon emitted is 22 tons per hectare.

Figure 126 SOC Change after turning the reference soil into palm oil crops (assessed in tons of C per ha).

Source: CUE

Figure 127 SOC Change after turning the reference soil into sugarcane crops (Assessed in tons of C per ha).

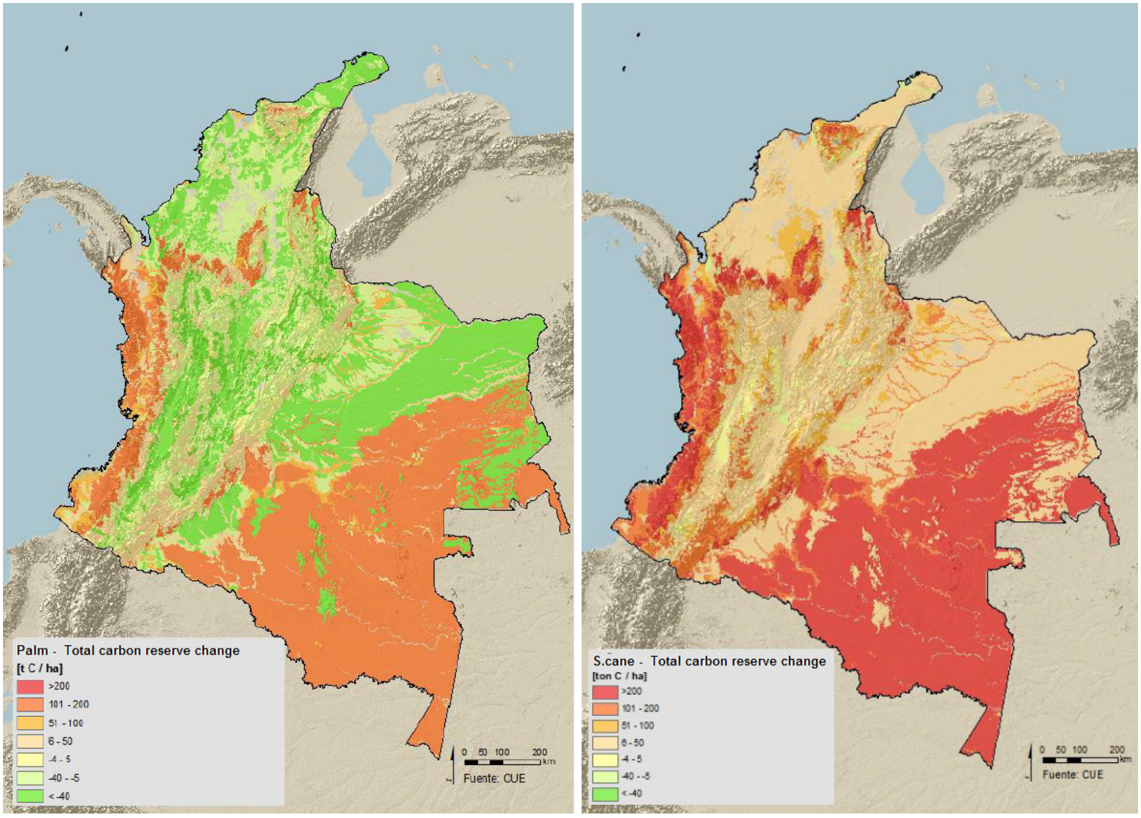
Change in the total reserve of carbon by account of land use change (LUC)

Total emissions due to LUC are calculated by using AGB, BGB and SOC. Values for sugarcane and palm oil are presented below. Given than palm plantations have a carbon reserve relatively high, just the conversion of areas that formerly were high in carbon content (typically natural forest) would create carbon emissions (depicted in red). Green areas represent areas where the carbon reserve would be increased if palm oil were cultivated. This is the normal case for non-forest land in the eastern region, north zone and also land that has been already used in the Andean valleys.

Due to the fact that the average carbon reserve for sugarcane is relatively low, just a few areas in the Andean valleys present an increment in the carbon reserve.

Generally, not only carbon embedded in biomass is dominant. The type of soil also determines total emissions of carbon due to the LUC. This is the case for organic land that stores high content of carbon.

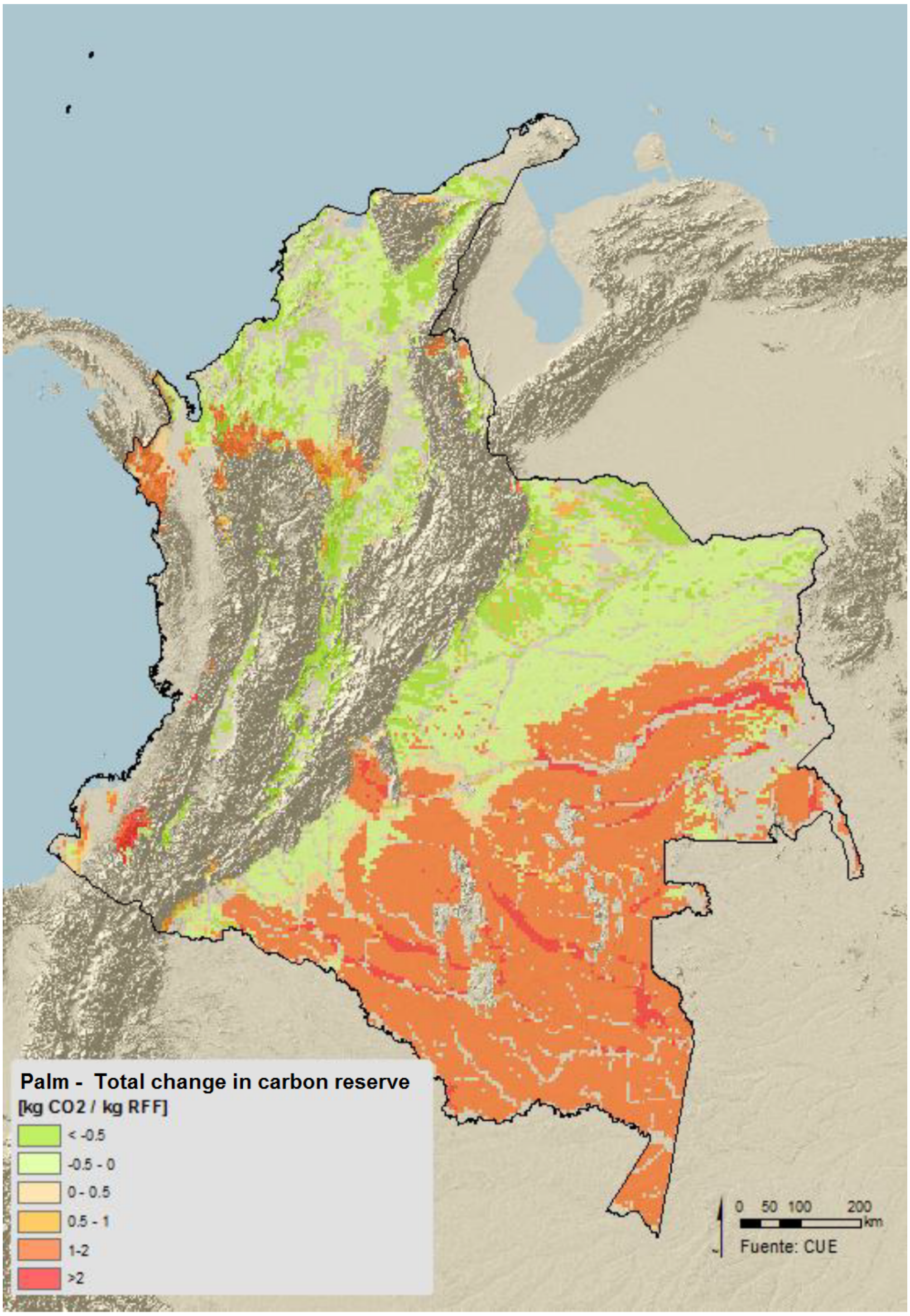
Figure 128 Change in the carbon reserve due to LUC from current use



Change to palm oil production (left), and sugarcane production (right) .

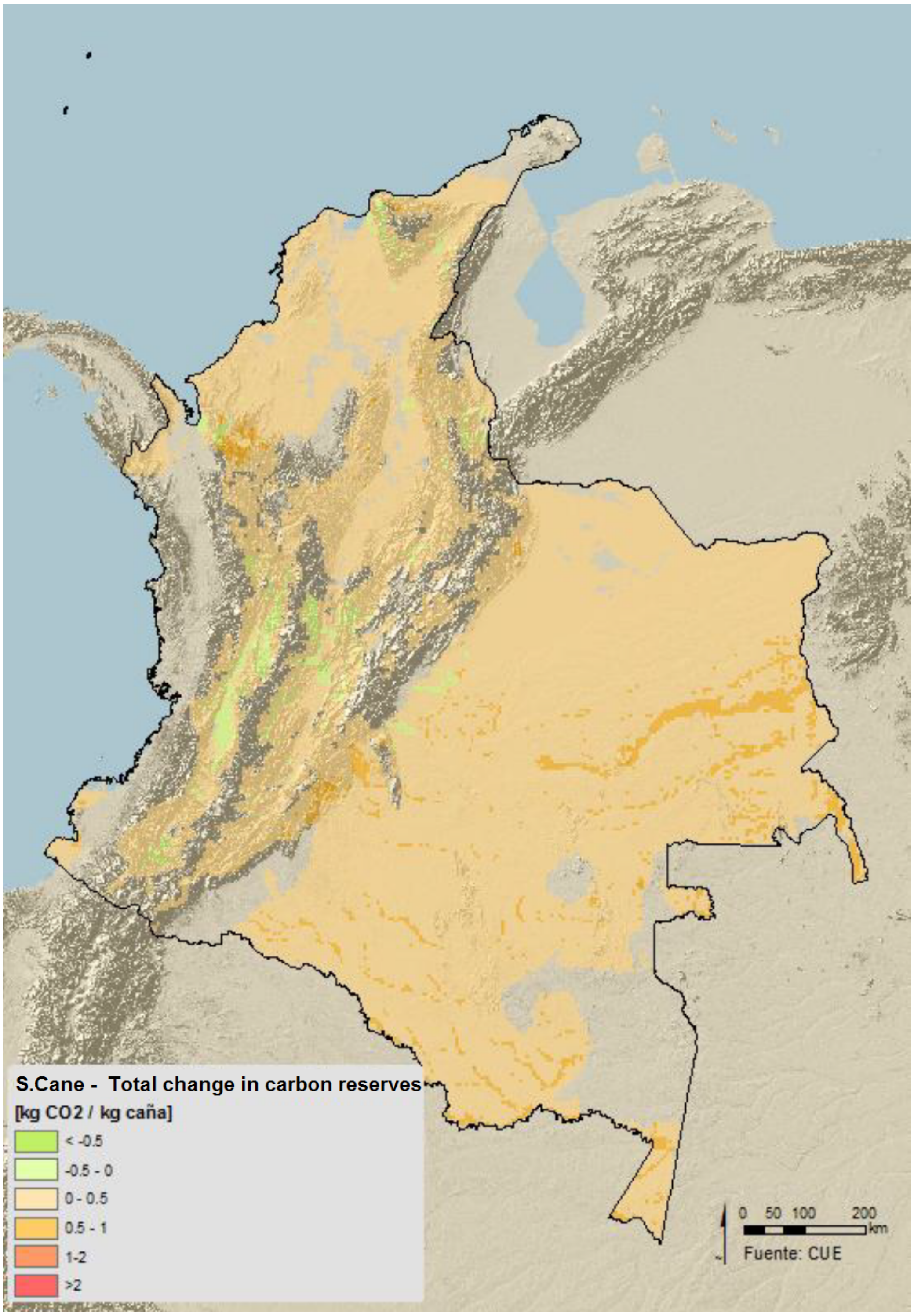
Notwithstanding, not all these lands are suitable for cultivation. With the purpose of including the biophysical aptitude for biofuels feedstock cultivation, the amount of GHG's emissions per kg of biomass harvested is calculated (sugarcane and bunches of fresh fruit of palm oil).

Figure 129 Change in carbon reserve due to current land use change to palm oil crops *(tons of CO2 per kg of FFB).*



Source: CUE

Figure 130 Change in carbon reserve due to current land use change to sugarcane crops
(tons of CO2 per kg of FFB).



7.5.1.2 Relating greenhouse gases (GHG's) emissions of specific locations to the default result of the life cycle assessment (LCA)

In the following step, carbon emissions by region due to LUC are related to results from LCA, in order to calculate the net benefit of the impact of using biofuels instead of fossil fuels. Therefore, the values given by default were added up (in Kg CO_2 per vehicle km) for crop material transportation (included infrastructure), processing and usage, and emissions of GHG's of reference fossil fuels was subtracted (see equation).

$$CO_{2em} = \frac{CO_{non-LUC} \times ref\_prod}{loc\_prod} + CO_{2\Delta C} + CO_{2prod} + CO_{2trans} + CO_{2use} - CO_{2fos}$$

CO_{2em}: Net emissions of CO_2

$CO_{non-LUC}$: Emission during crop stage without LUC

$CO_{2\Delta C}$: Emissions of change in carbon reserves (SIG)

CO_{2prod}: Emissions during production stage (fixed value)

CO_{2trans}: Emissions during transportation stage including infrastructure (fixed value)

CO_{2use}: Emissions during use stage (fixed value)

CO_{2fos}: Emissions of the fossil fuel reference (fixed value)

ref_prod: Reference productivity. Calculation LCA (fixed value)

loc_prod: Local productivity of crop (SIG)

Land use change: maps presented in the previous two figures for sugarcane and palm oil correspondingly were used. Values (kg of CO_2 per unit of harvested biomass) are multiplied by the conversion factor listed in the following table with the purpose of calculating GHG's emission for driven kilometers. Conversion factor itself is based on the result of the LCA (taking into the account efficiencies and distributions).

Crop: Besides LUC, crop impact depends vastly on the climatic characteristics and soil characteristics, genetic material and agricultural management of biofuel crops. The current impact of biofuel crop is based on the values defined in the LCA. Within this study of the crop impact, is in turn undertaken by region, based on the crop yield in a specific spot.

Processing: for the processing stage, the values found in the LCA were used, taking into the account that processing of biofuels is relatively simple and there are few differences in technologies.

Transportation: for biomass transportation and biofuels different types of vehicles and transportation distances previously established were estimated. These estimations are based on field data used for the LCA study. Nevertheless, section 7.5.1.4 shows sensibility to transportation purposes.

Use and reference fossil fuel: For biofuel use and reference fossil fuel (substitution) values defined by LAC are employed.

Table 92 By-default values for the GIS calculation

By-default values for the GIS calculation			
Stage of the life cycle	**Unit**	**Palm oil**	**Sugarcane**
Infrastructure	Kg CO2eq / vehicle.km	0,026	0,025
Crop	Kg CO2eq / vehicle.km	0,02	0,02
Productivity	ton/ha	18,78	113,53
Conversion factor	Kg of biomass / vehicle.km	0,21	1,05
Processing	Kg CO2eq / vehicle.km	0,06	0,01
Transport	Kg CO2eq / vehicle.km	0,001	0,006
Use	Kg CO2eq / vehicle.km	0,0017	0,0056
Total	**Kg CO2eq / vehicle.km**	**0,11**	**0,06**
Diesel substitution	Kg CO2eq / vehicle.km	0,19	
Gasoline substitution	Kg CO2eq / vehicle.km		0,23

Source: CUE

Figure 131 Relative GHG's emissions for palm oil-based biodiesel

Savings are represented in green whereas emissions in red.

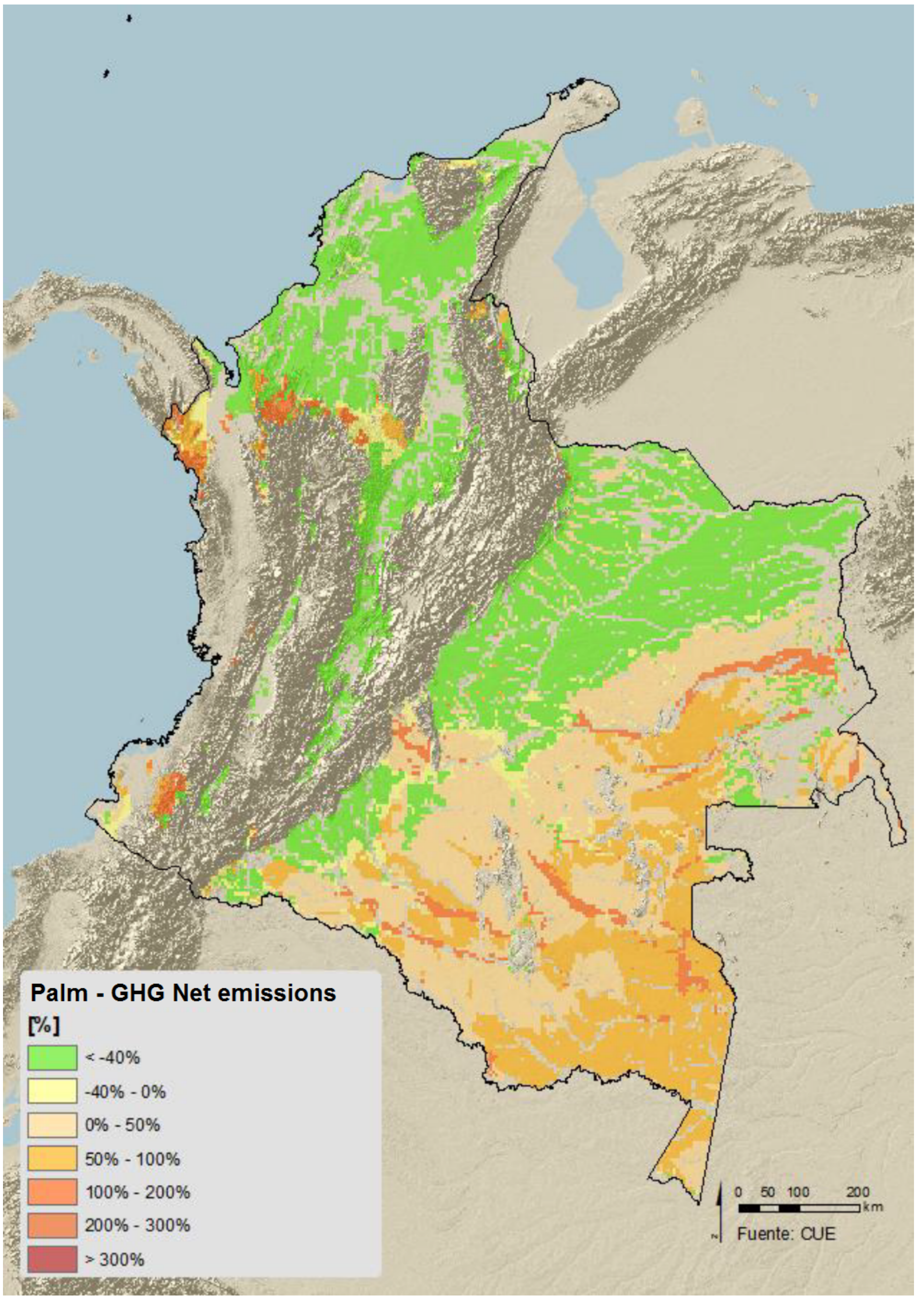
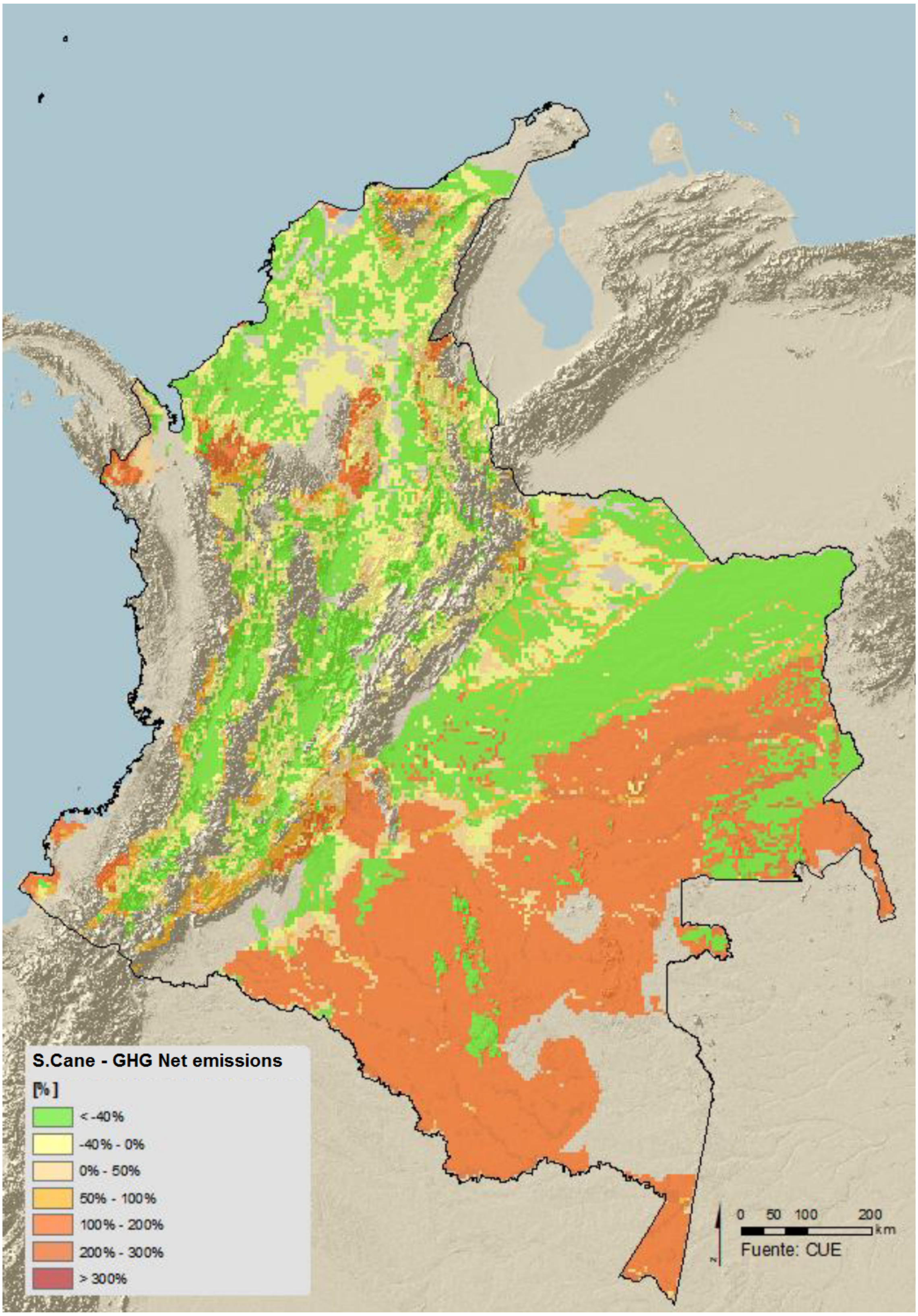


Figure 132 Relative GHG's emissions for sugarcane-based ethanol

Savings are represented in green whereas emissions in red.



As it shows in the last 2 figures, potential carbon savings are achieved in the northern region of Colombia, in the inter-Andean Valleys and the Llanos region. As soon natural areas are turned into crops the carbon balance becomes negative.

7.5.1.3 Carbon debt by region for biofuels in Colombia

LUC in most cases creates carbon emissions. The quantity of CO2 that is released in the first 20 years of this process is called soil conversion "carbon debt" (Fargione et al., 2008). As the time passes, biofuels from converted soils can offset this carbon debt, if its production and combustion have net emissions below emissions of the LCA that belong to fossil fuels that are being substituted. Below is shown the duration of restoring carbon debt, expressed in years.

$$CD = \frac{CO_{2\Delta C\_LUC}}{CO_{2crop\_no\_LUC} + CO_{2prod} + CO_{2trans} + CO_{2use} + CO_{2fos} \times \alpha \times produc}$$

CD = carbons debt [years]

$CO_{2\Delta C\_LUC}$ = CO_2 emissions of the carbon reserve change due to LUC (layer GIS) [kgCO_2/ha]

$CO_{2crop\_no\_LUC}$ = CO_2 emissions in the cultivation stage without LUC [kgCO_2/v.km]

CO_{2prod} = (fixed value) [kgCO_2/v.km]

CO_{2trans} = (fixed value) [kgCO_2/v.km]

CO_{2use} = (fixed value) [kgCO_2/v.km]

CO_{2fos} = (fixed value) [kgCO_2/v.km]

$\alpha \times produc$ = Conversion productivity factor [v.km/ t feedstock]

As is shown in the figure below, sugarcane expansion to almost all areas of Colombia creates a carbon debt. Particularly in the Amazon region, in river basins and in the base of the Andean mountain chain, it is possible to observe big carbon debts between 60 and 130 years. Due to the great carbon reserves of palm oil plantations, carbon debt in this case exhibits a less pronounced trend in comparison with sugarcane experience, going up to 70 years (in the Amazonas region and in the bases of the Andean mountain chain).

Figure 133 Carbon debt of palm oil-based biodiesel produced in Colombia [years].

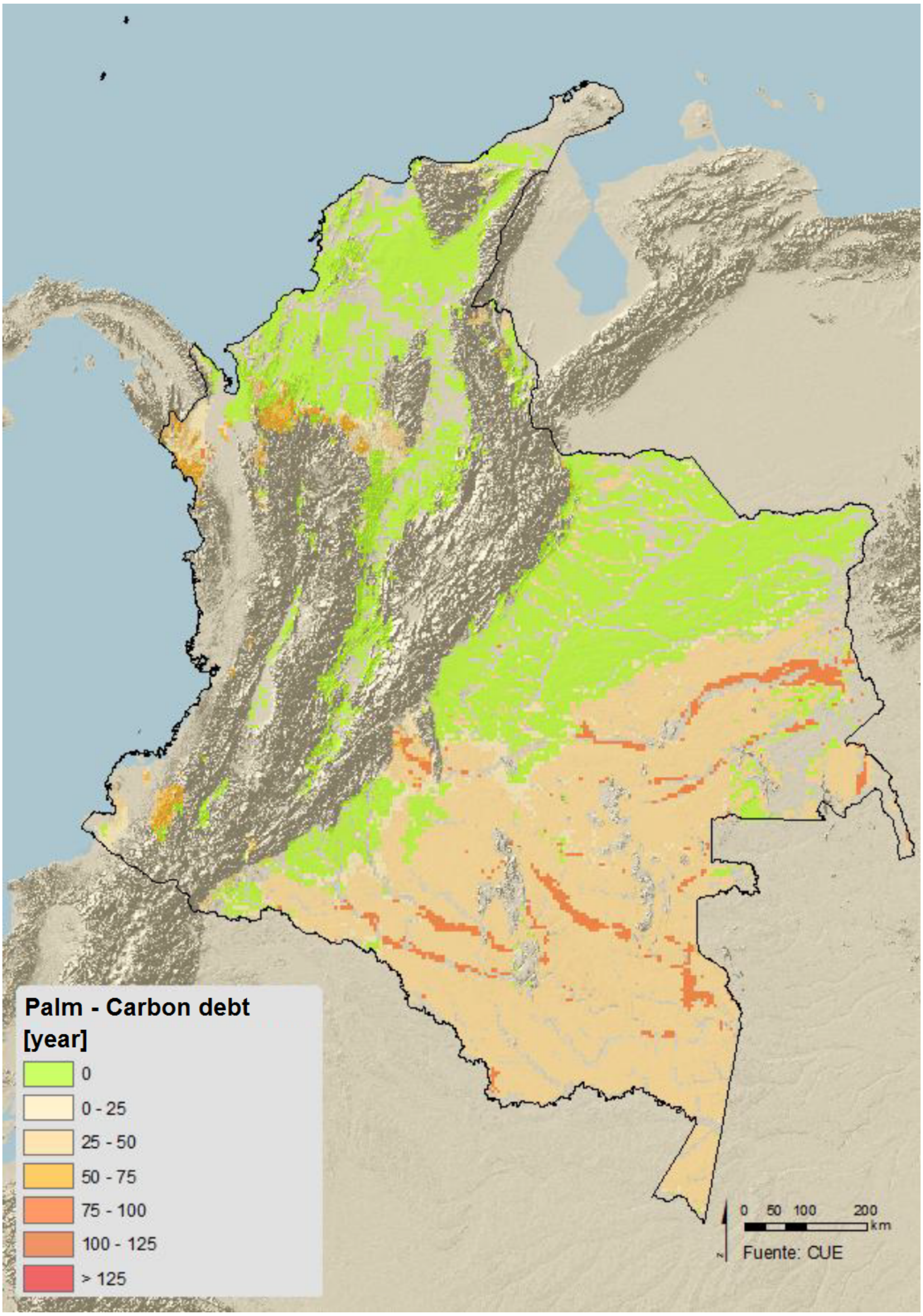
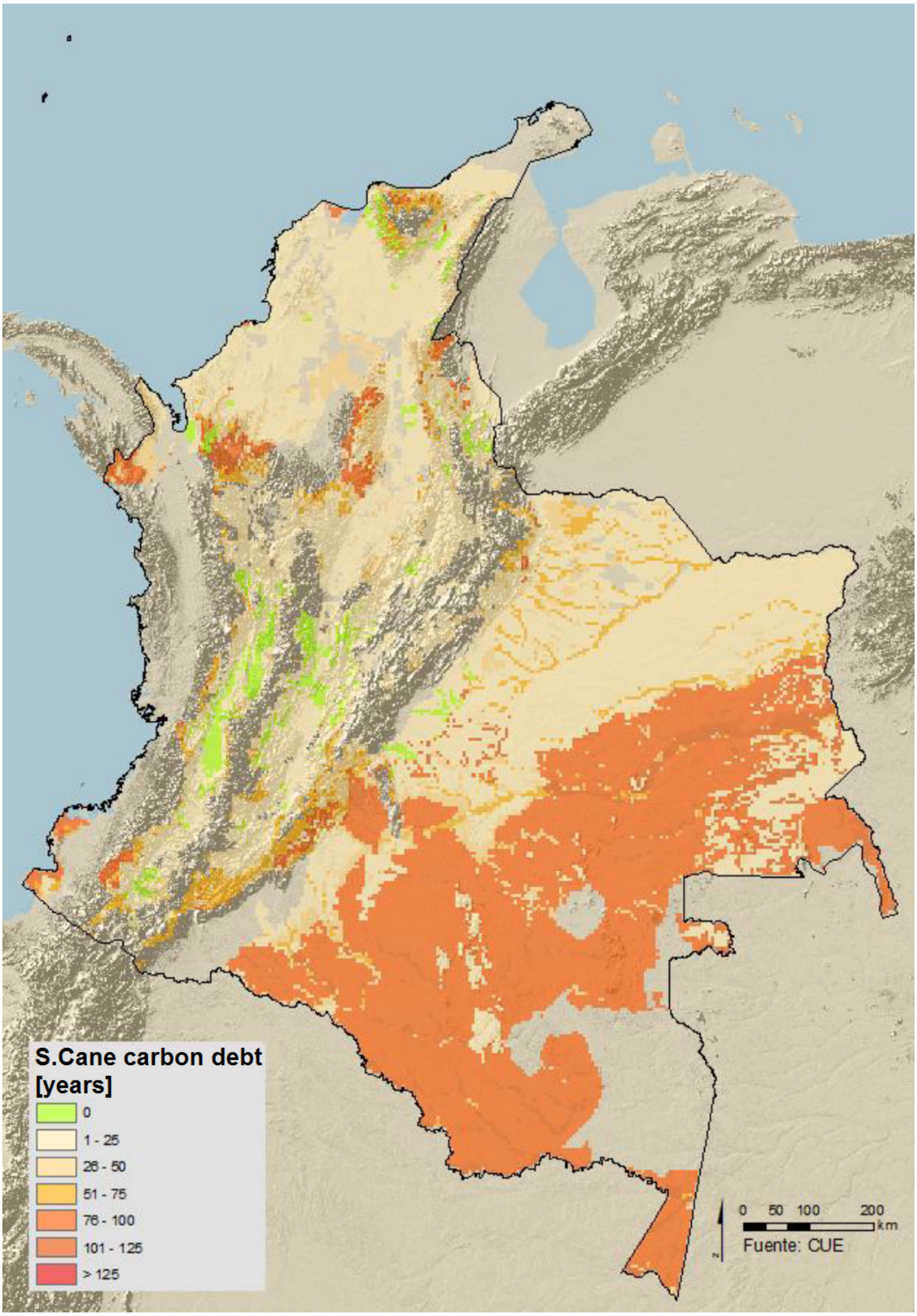


Figure 134 Carbon debt of sugarcane-based ethanol produced in Colombia [years].



7.5.1.4 Sensitivity for transportation distances

Former calculations, mentioned above, were drawn based on average transportation distances. For economic reasons, driven distances from feedstock crops to processing plants do not exceed 100 km. Therefore, if a new plantation is created, it is required to install a new plant if there is no plant at a reasonable distance. Based on such estimation, distances were 'defined distances' as considered in former calculations (using real transport distances).

However, in order to show sensitivity of transportation as a whole, distances from agricultural field to not only to biofuel processing plants but also to retailer fuel service stations in Bogotá were calculated.

The first step consisted in mapping all the existent and planned processing plants for sugar production or oil extraction. Afterwards a grid of 5km x 5km was set on the Colombian map in order to calculate the distance from crops to the nearest plant. With the purpose to correct the difference between the aerial scale assessment and the actual terrestrial assessment it assumed a correction factor of 1.3.

Transportation distances data from biofuel production plants to blending stations in Bogota were taken from real data on the road. Distances were calculated with a network analysis tool from ArcGis. As a standard vehicle it was assumed a truck of 32 tons, which releases 0.185 kg of CO2 per ton-km (tkm).

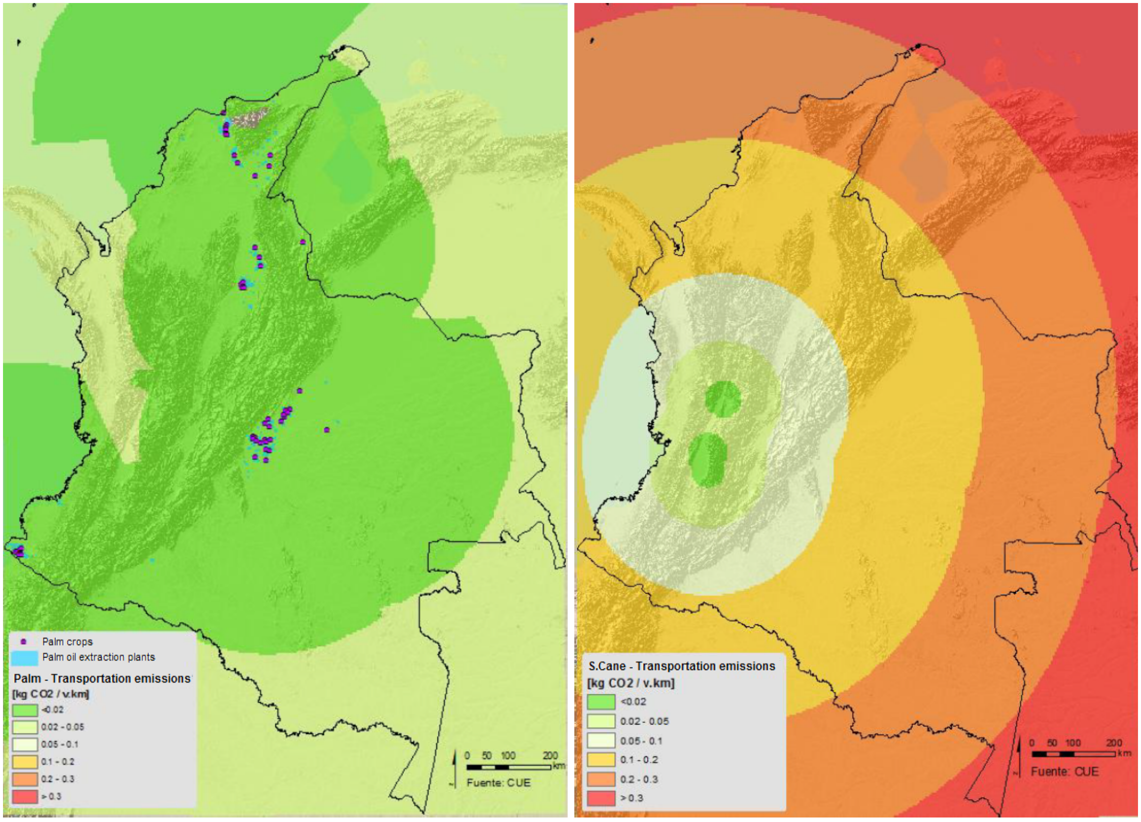
Transport distance is multiplied times the quantity of biofuels that are required to operate a vehicle during a kilometer (biofuel ton/driven kilometer). Values are obtained from the LCA and the units of assessment are tkm per vehicle driven kilometer, noted here as v.km.

Figure below are related GHG's (kg CO2 eq) with the transportation of feedstock, and sugarcane-based ethanol and palm-based methyl ester. For instance, for sugarcane, long distances feedstock transportation are linked to more GHG's emissions (more than 0.4 kg of CO2/v.km, when a Renault Logan in Bogota is driven), which exceeds GHG's emissions released by fossil fuels (0.23 kg CO2 eq / v.km). Therefore in feedstock transportation process only (without including those emissions related to crop, processing and use) creates much more GHG's emissions that fossil fuels, if transportation distance is long.

For palm-based biodiesel, the feedstock transportation effect is not as dominant as in the case of sugar cane. This is mainly due to the fact that in the palm case there is a lower amount of raw material to be transported (0.2 kg of fresh fruit/v.km) in comparison to ethanol which demands (1.6 kg of sugarcane/v.km).

In general terms, it is possible to conclude that transportation distances to processing plants are crucial in the net savings of GHG's, in particular for the case of sugarcane-based ethanol. Hence, if new plantations are established, it is desirable to set processing plants located at a reasonable distance, not only for cost optimization, but also to reduce environmental impact.

Figure 135 Kg of CO2 emitted per vehicle per km.



On the left side is the palm oil biodiesel case, and in the right sugarcane. This situation is based on the assumption that biofuels are only produced in currently existing plants.

7.5.2 Water shortage

Each year 3.8 trillion tons of fresh water is extracted for human consumption. Near to 70% of all extracted water is related to some extent with agriculture sector. In Colombia the demand for this resource is also significant (IDEAM, 2010), and despite the abundance of water in this nation, water scarcity in some particular regions is at the core of growing issues. Water shortage can be expressed as the relationship between supply and demand required for human development and for different ecologic life-supporting activities. It can be expressed using the scarcity index.

The IDEAM presented a national water study in which is shown the relationships between water supply and demand. This study uses a map of hydric stress on a scale of 1:500,000.

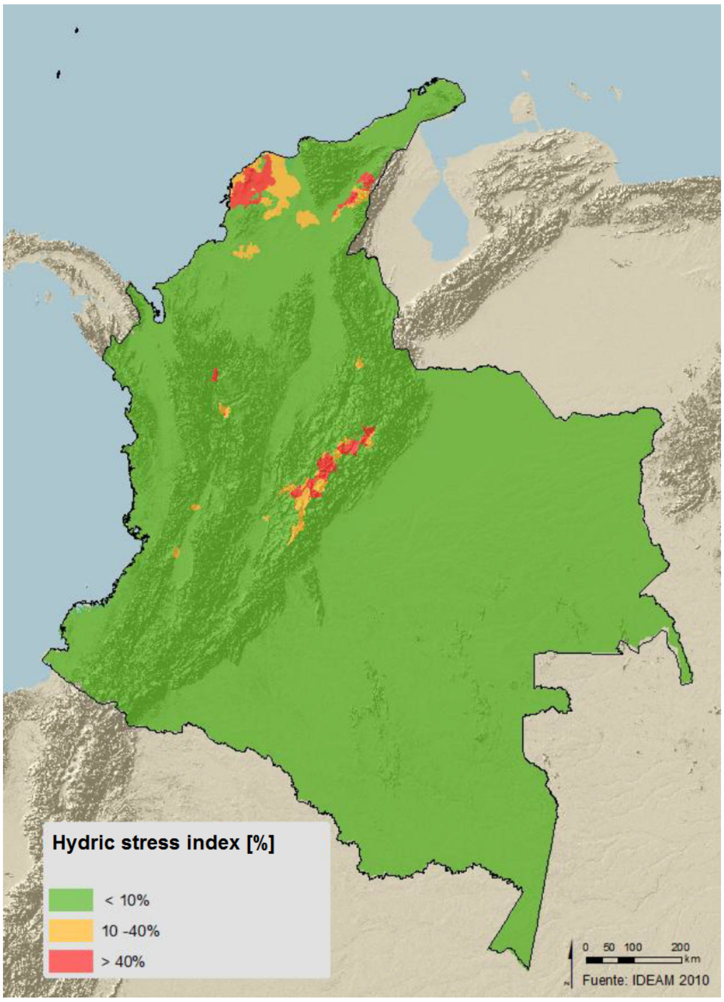
Table 93 Classification of hydric stress

Classification of hydric stress		
Restriction degree	**Value**	**Description**
Total restriction	> 40%	Municipalities with high levels of hydric stress
Severe restriction	10%-40%	Municipalities with levels of hydric stress from mild to low, which may experience severe limitations for socio-economic development
Without restrictions	< 10%	Municipalities with low levels of hydric stress. It is not foreseen a shortage of available water that might limit agricultural development

Source: Adapted from Mora, Arcila-Burgos et al 2009

As is illustrated below in most areas in the Caribbean coast close to Cartagena de Indias, similar to big cities in the Andean region, there is a high percentage of hydric stress. This is mostly formed by the relatively high demand of water in urban areas.

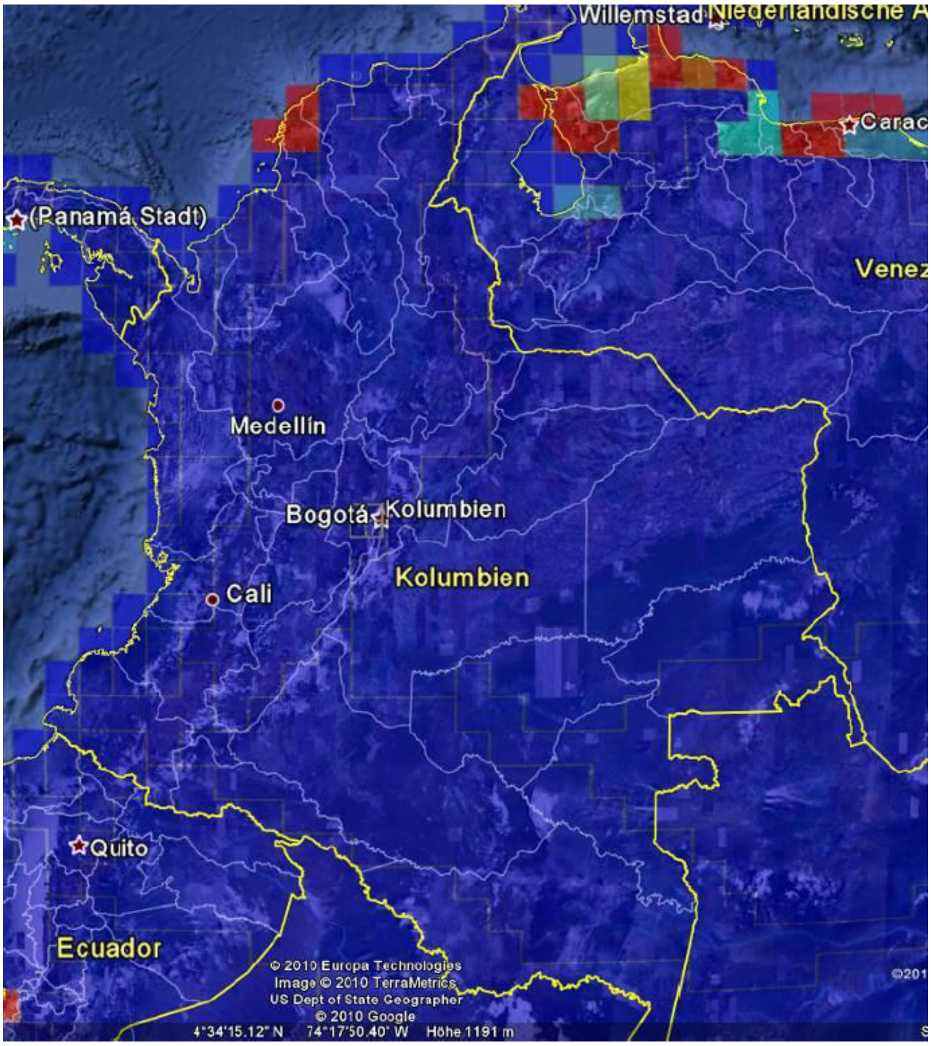
Figure 136 Hydric stress in Colombia



Source: (IDEAM, 2009b)

Results are fairly consistent with other studies that report, in lesser detail, water stress in the Caribbean region (Pfister, Koehler, & Hellweg, 2009).

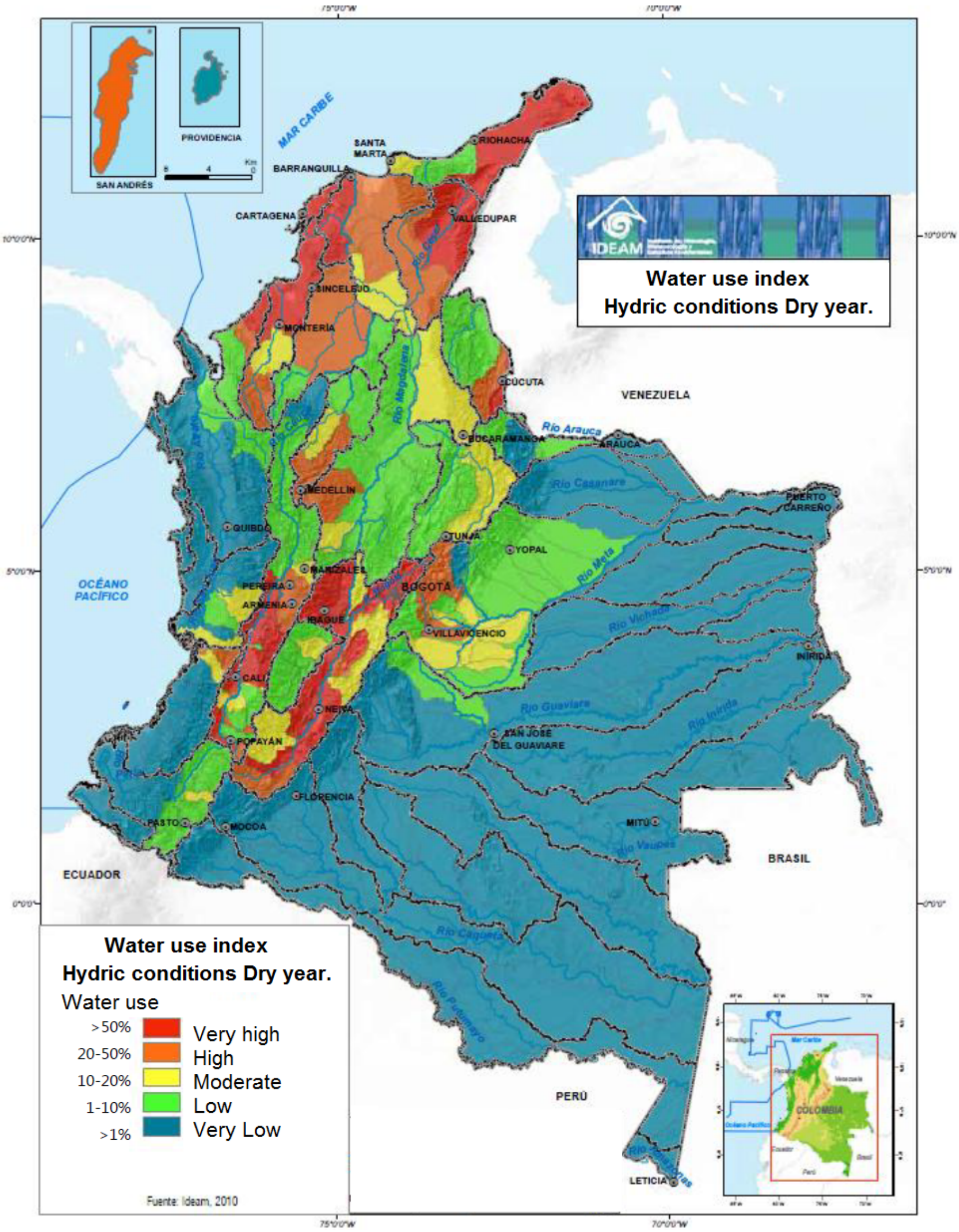
Figure 137 Comparative Hydric stress Map for Colombia



Source : (Pfister et al., 2009)

In general, hydric stress is influenced by the size and style of population, climate variations, pollution, and unsustainable management, among others. Therefore, hydric stress can be a regional phenomenon that changes over time. Reduced water supply in dry years increases hydric stress. In recent years, particularly in the Northern zone and in areas with intense agricultural activity, just like the region where most of sugarcane is produced, nearby Cali, might exhibit high levels of hydric stress.

Figure 138 Water use index in Colombia for a dry year.



Source: (IDEAM, 2010)

7.5.3 Biodiversity

There are different biodiversity indicators for Colombia, such as the ones presented in the study of palm oil found in Mora et.al (2009). Some indicators, like specific ecosystem or habitat fragmentation, are quite theoretical and cannot be used directly to evaluate energy crop expansion, due to the fact that impact depends completely on the expansion factor (spread parcels or great areas of monoculture practices).

That is why it was decided to use a priority conservation areas map from *Sistema Nacional de Areas Protegidas* –SINAP- (National System for Protected Areas) (Corzo et al., 2008). This map is a good foundation to discuss expansion of energy crops, because it puts together a variety of information about ecosystems and classes, indicating the amount of disturbed area, which could be related with the potential expansion area for different regions.

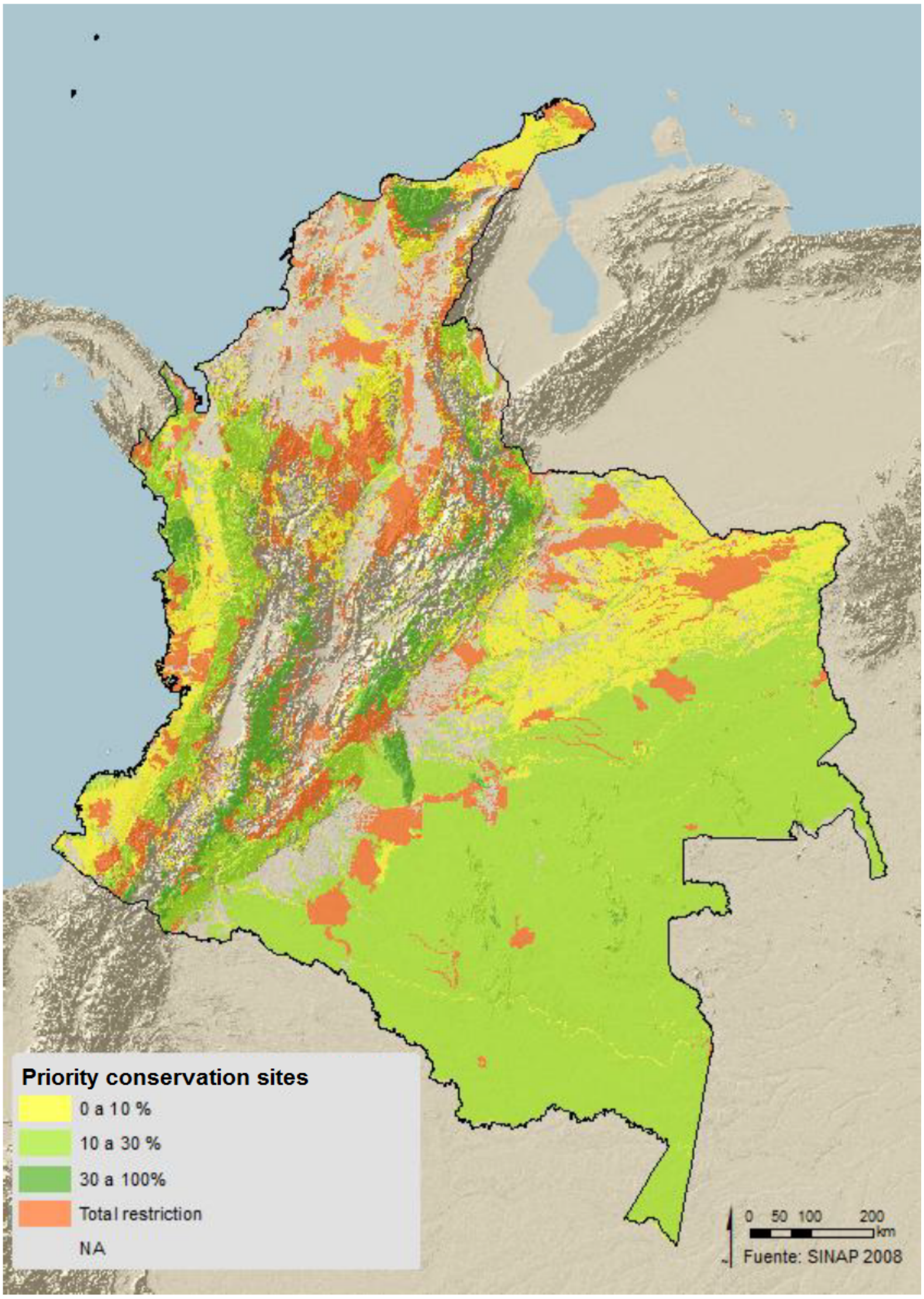
Table 94 Restriction levels for areas of priority preservation according to SINAP

Restriction levels for areas of priority preservation according to SINAP		
Level of restriction	**No-preserved areas (%)**	**Description**
Total restriction	0%	Priority conservation areas according to SINAP
Severe restrictions	0%-10%	High value ecosystem with less than 10% disturbed land
Moderate restrictions	10%-30%	In accordance with ecologists, 30% of the non-conservation areas, is the maximum area to preserve unique natural characteristics of the ecosystem
Without restrictions (unknown)	30%-100%	Areas with low value ecosystems, given the predominance of disruptions

The figure below shows spatial distribution of preservation or conservation areas in Colombia. Priority conservation areas are widely distributed through Colombian territory. There are strong restrictions on the wet forest in the Pacific coast, central region along the shore of the Magdalena River, Guajira peninsula and the Oronoco basin.

It is remarkable, the status of high conservancy that has been gained by La Guajira region and some spots in the Orinoco basin. In both cases a potential expansion in these areas could be interesting in regards to the carbon reserves presence, and they would be ideal from GHG's emissions, however, they have restrictions from other nature.

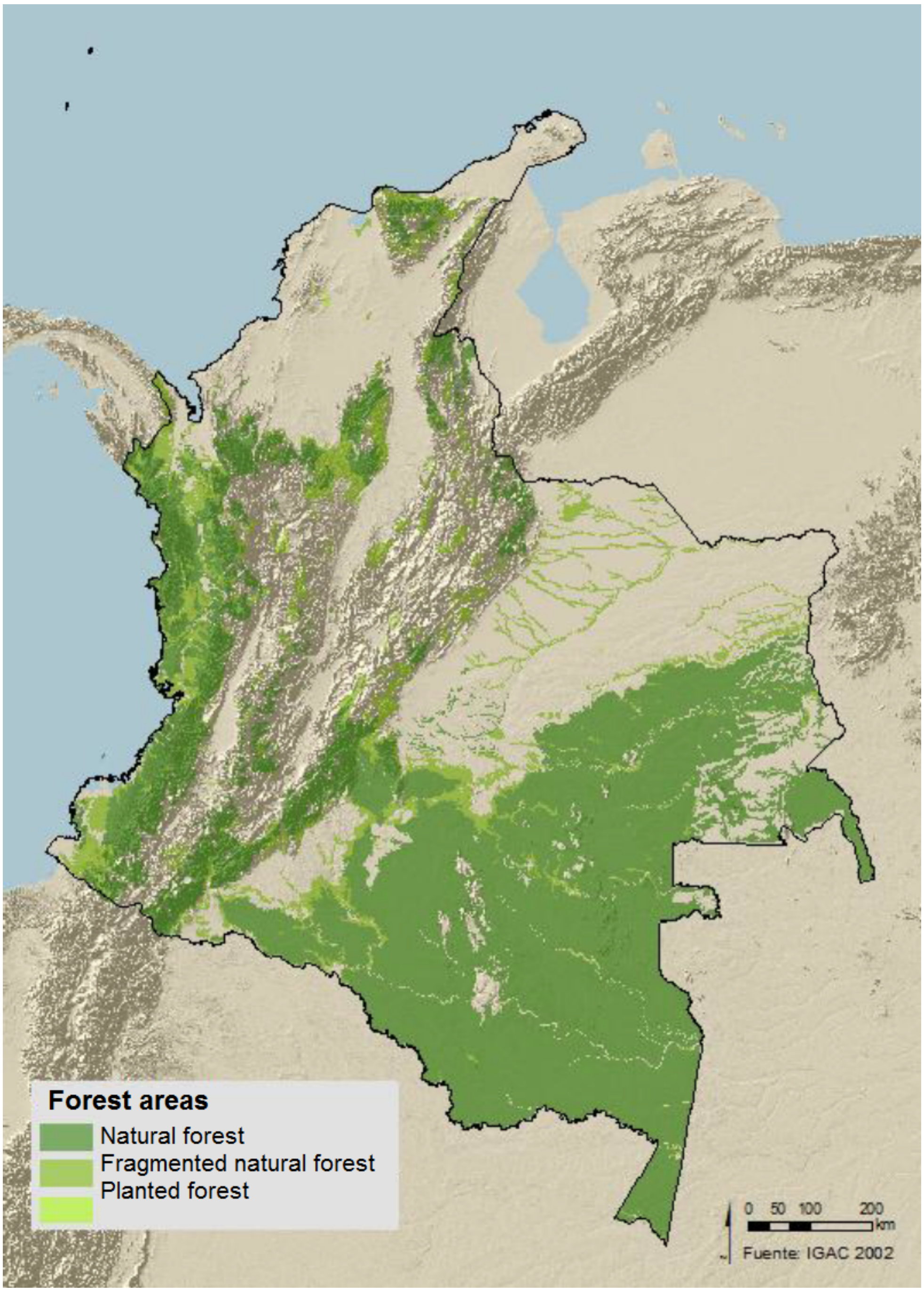
Figure 139 Priority conservation areas according to SINAP guidelines



Source: (Corzo et al., 2008)

In addition to priority conservation areas defined by the SINAP, other factors influence the impact on biodiversity. Biodiversity is particularly high in natural forest, hence they are left out as suitable land for bioenergy crops. Another reason to do so is that, in fact, forest lands are protected by law and environmental regulation make any possible intervention as non-sustainable, including the establishment the agro-industrial crops. Furthermore, deforested lands are fragile and might be vulnerable to erosion.

Figure 140 Colombian forest areas.



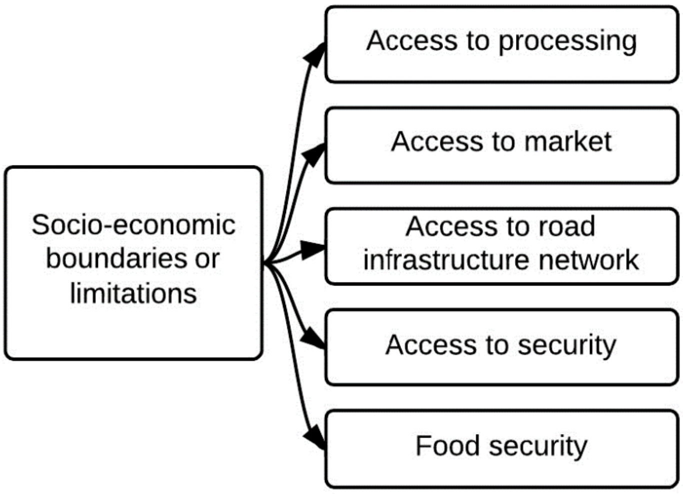
Source: (IGAC, 2003)

7.6 Socio-economic criteria

Socio-economic aspects of biofuel production are very important in order to secure the feasibility of bioenergy expansion. Nonetheless, direct and indirect potential impacts are specific of each area and are not easy to evaluate. For that reason, assessment of potential expansion areas should include a socio-economic study at a local level.

In this study, only a limited amount of socio-economic factors that affect the biofuel value chain are discussed. Information used is based on the existing literature, and it includes access to existing infrastructure, roads, markets, safety and food security.

Figure 141 Summary of the socio-economic factor taken into consideration

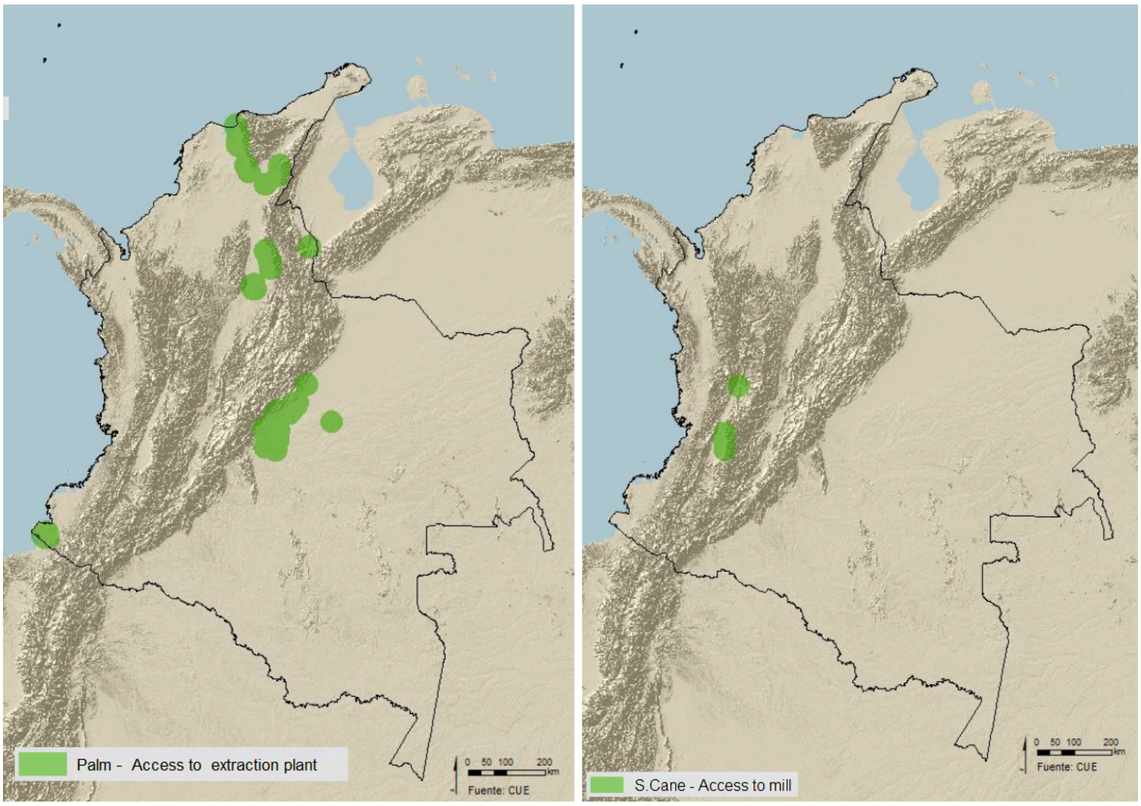


It is noteworthy that employees indicators used in this study are mainly taken from the IDEAM report (IDEAM, 2009c), and they simplify in a general way local socio-economic reality. Moreover, these indicators can change rapidly through time, which suggest a constant evaluation is required.

7.6.1 Access to processing facilities

Ideally, bioenergy feedstocks are cultivated close to an already existent processing plant, to make use of its services, and also to gain acceptance of crop introduction in the population that inhabit the nearby area. In the next map are presented those areas that are 30km away from a processing unit of palm oil or sugarcane. Nonetheless, it was not considered access quality, meaning, general road conditions, like slope, paving treatment, etc.

Figure 142 Access to processing facilities.



Palm oil on the left side. Sugarcane on the right side. Distance considered: 30 km.

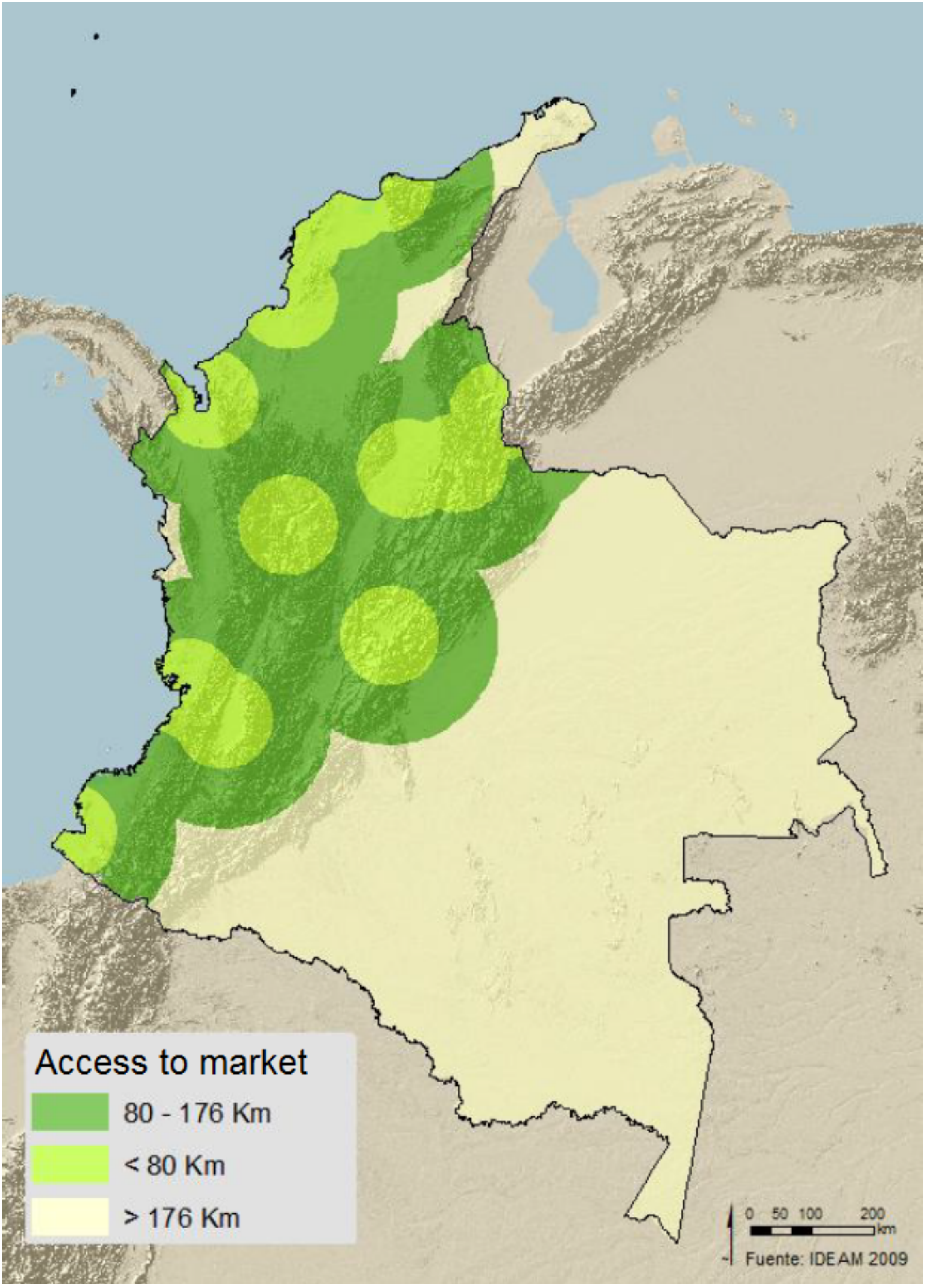
7.6.2 Access to markets

Feedstock cultivation for biofuel production is, in general, much more competitive if processing facilities are located close to main markets. Thus, locations within short transportation range (less 154km) to mid-range (between 154km and 337km) to the main markets or export ports are economically preferred over locations that are established within larger transportation ranges.

Assessment is based on aerial distance and transportation cost from cells in the grid on the map that were mentioned earlier, from where production areas are located, to market places. Even though, aerial distances where taken into account – instead of real distances/cost of transportation – it is possible to create approximate indicators about more suitable areas in economic terms.

Distances less than 80km are indicated in light green; whereas mid-range distances (80km to 176km) are indicated in dark green.

Figure 143 Access to markets



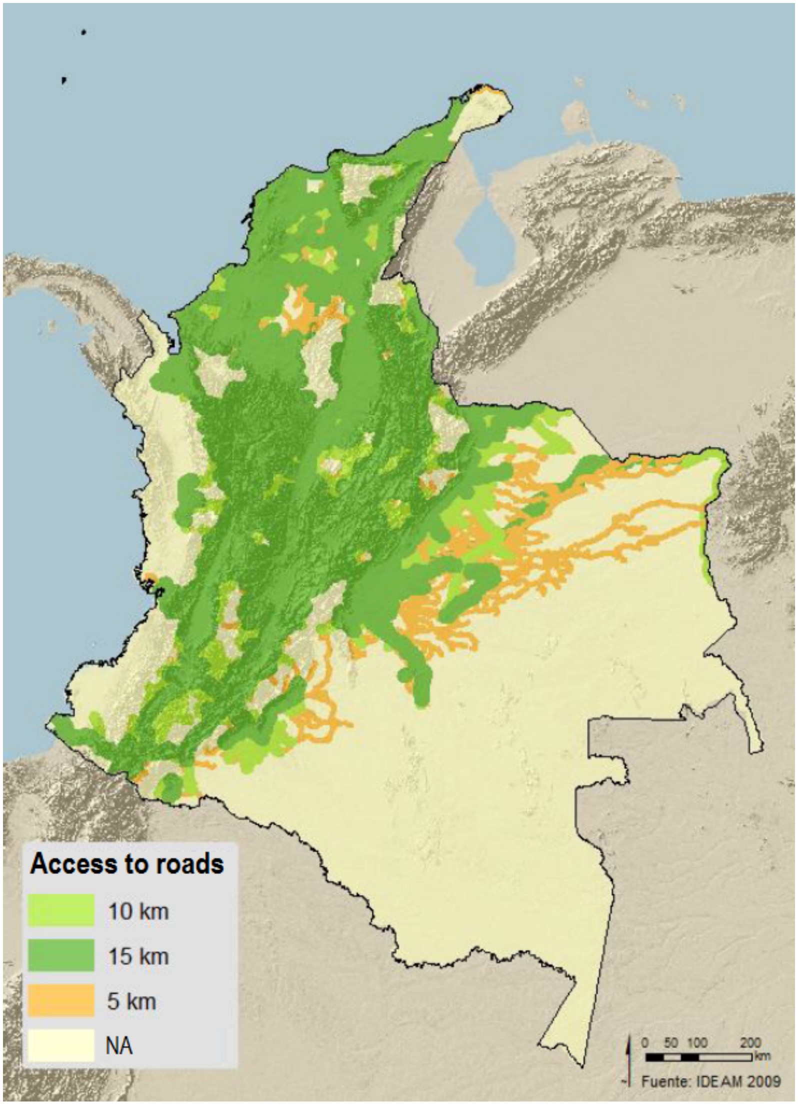
Source: (IDEAM, 2009c)

7.6.3 Access to road network

Those areas close to roads and rivers (suitable for fluvial transportation) have economic benefits, due to better transportation conditions. In this case the maps employed were the road network map provided by IGAC and the river map extracted from the Ministry of Transport (IGAC, 2005; Ospina, 2008). Classification was implemented based on the IDEAM guidelines (IDEAM, 2009a); thus, it selected an absorption distance of 15km for main roads (regardless if they are paved or unpaved roads, but that have at least 2 lanes available all year long, i.e. terrestrial condition 1 and 2) and also main rivers (with permanent navigation, i.e. fluvial condition 1). For seasonal rivers and narrow paved roads, which are open for traffic all year long, an absorption distance of 10km was selected (terrestrial 3 and 4, and fluvial 2). For unpaved roads that are only accessible during a dry season the absorption or buffer distance is 5km (terrestrial 5).

The following map provides a broad approximation of the accessibility for transport infrastructure, while further studies will have the task of updating the terrestrial and fluvial network and they should consider more detailed the quality and current state of roads (including seasonal closing of roads).

Figure 144 Access to main terrestrial roads and rivers.



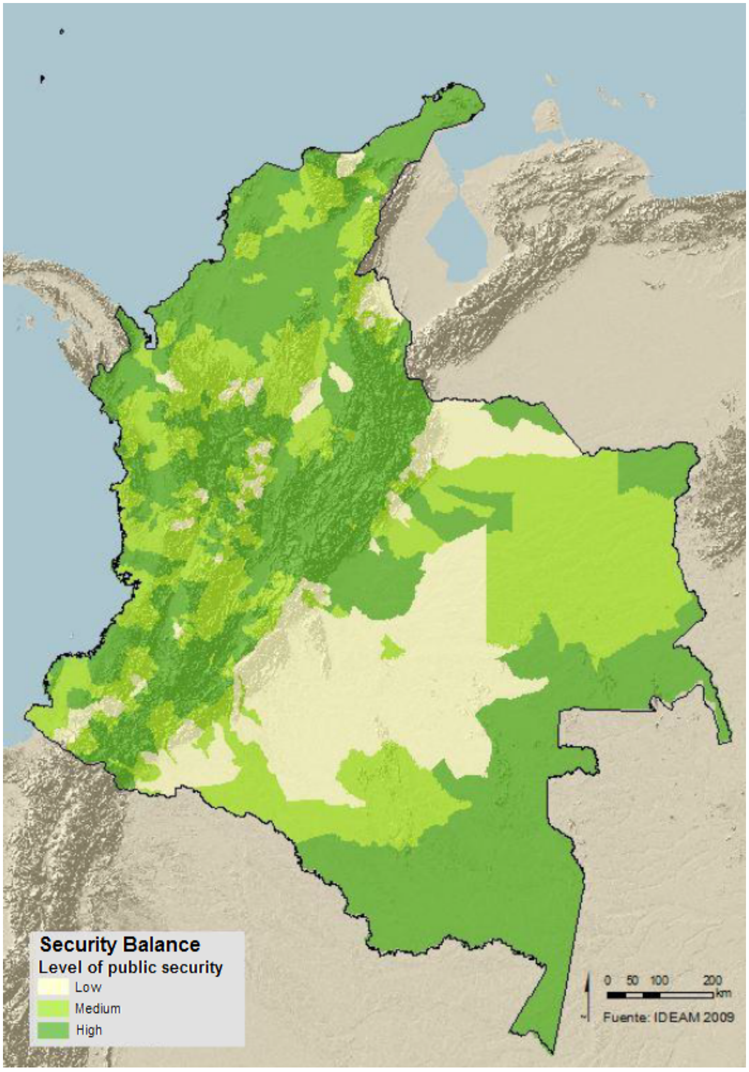
Source: (IDEAM, 2009c)

Existing crops for palm oil and sugarcane production are located in areas that have good access, and are relatively close to markets (as shown before). Transportation distances in the eastern region of Colombia are either quite long or the road infrastructure is completely deficient. This aspect reduces to a great extent competitiveness of remote areas for biofuel production, given the disincentive that such a situation represents for potential investors. Nevertheless, in the mid or long-term biofuel transportation via pipe infrastructure, the establishment of alternative markets, or an improved road network should change the ongoing situation.

7.6.4 Safety

Also important, is the safety of a particular area when the selection of a potential location for bioenergy initiatives is at stake. Map of security accounts for the number or murdered people, armed robbery episodes, and forced displacement of population. This data come from the Observatory of Human Rights, and the Office of International Human Right of the Vice-presidency. For more information and a description on the methodology of the map itself see the IDEAM report (IDEAM, 2009b).

Figure 145 Map of public security risk in Colombia



Source: (IDEAM, 2009c)

Areas with historic complications regarding national security are located in the Orinoco region, particularly in the departments of Meta, Arauca and Vichada. Territories of some municipalities in North Santander, northern region of Antioquia and Putumayo are also classified as zones with limited security conditions. Notwithstanding, indicators just provide an approximate insight based on the historical violent incidents; so, if a new production location is planned, it may be required to evaluate security conditions in that particular area.

7.6.5 Food security

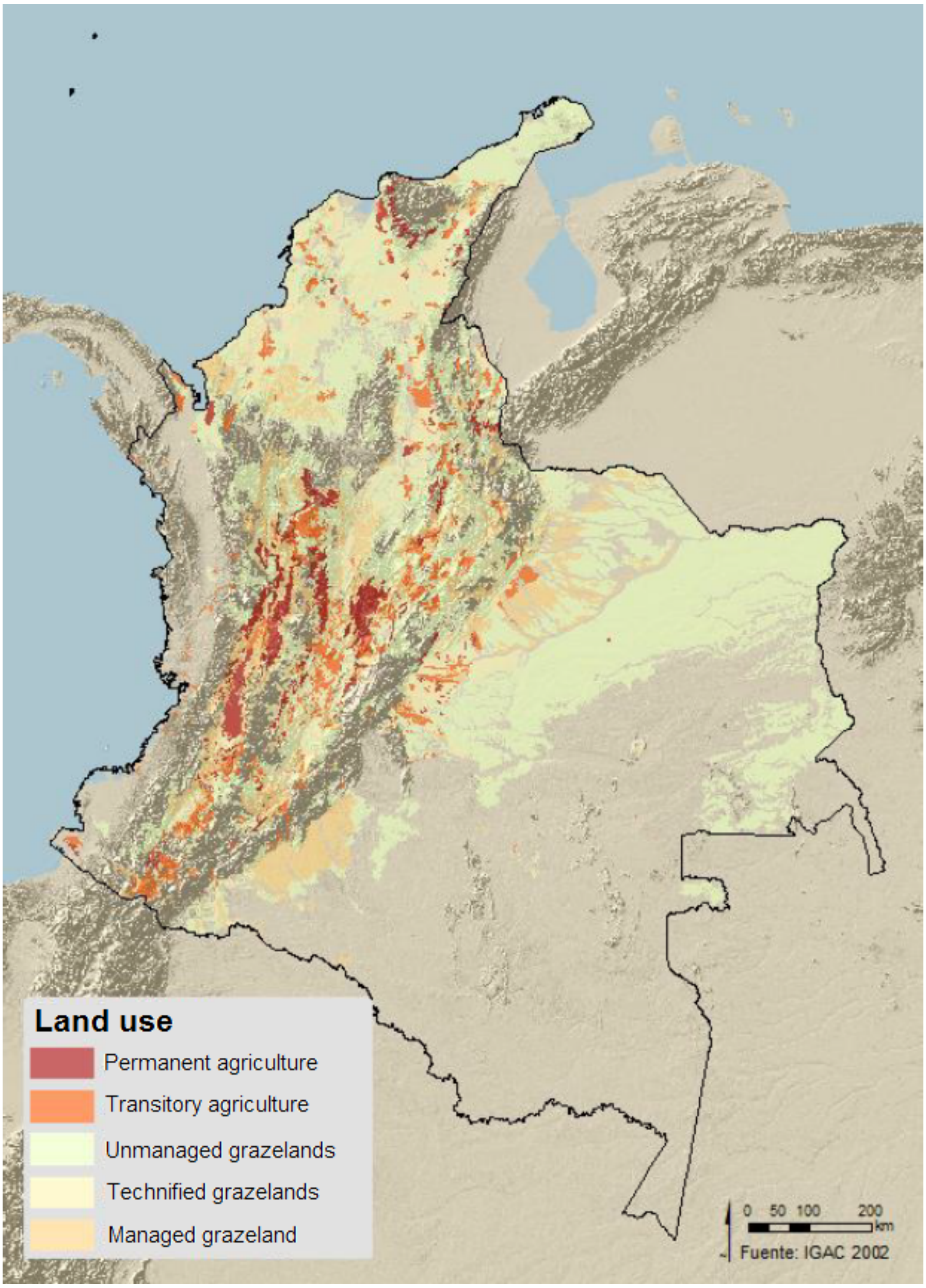
If energy crop expansion takes place in agricultural areas a displacement effect is started. These effects of displacement are significant, if food crops such as maize are eliminated or moved out to other regions, causing disbalance in the population acces to food (Johnson & Rosillo-Calle, 2007).

Effects can be reduced, if extensive activities are replaced, such as cattle grazing. Effects can be offset totally if agricultural soils are recovered through intensification (i.e. using grazing land but with more livestock heads/ area) in the same place, while feedstock for biofuel production takes place.

The map below, shows the agricultural production in Colombia. This figure is differentiated by very intensive agricultural practices and extensive practices in rural areas. The figure provides an overview of the potential expansion that might take place with limited effects or without indirect effects.

This map does not take into the account the quality of agriculture (so it could be some areas have relatively low agricultural production). However, a detailed land management plan is required in order to avoid unfavorable displacement impacts. This requires a profound and specific study on the potential impact in food security or indirect effects. Furthermore, it only excluded agricultural land, so for grazing land similar effects can be developed, and therefore a more detailed analysis should be implemented in such regard.

Figure 146 Map of current agricultural production



Source: (IGAC and CORPOICA, 2002)

7.7 Discussion and final remarks

The aim of this whole section was to point out areas with expansion potential for palm oil and sugarcane crops, taking into account biophysical, legal, environmental and socio-economic factors. The main scientific contribution of this particular study is the establishment of carbon reserves and GHG's maps that were neither available nor documented in the past.

The knowledge base built so far, on the areas of potential and sustainable expansion is relevant for strategic decision-making process at national level and indicates interest areas where more and deeper research is required.

Work scale in these maps is 1:500,000, and for calculation a grid that uses cells of 5km X 5km was used. such resolution is enough to identify general patterns at national level. Nonetheless, results suggest that it is not recommended for planning of local or individual biofuel initiatives.

Below will be discussed biophysical adaptation in combination with environmental and economic aspects for potential expansion of palm oil and sugarcane crops. Initially national parks were excluded where cultivation is completely restricted. Territories of black communities and indigenous reservations are considered as not suitable for commercial biofuel initiatives exploitation.

With the purpose of complying with adaptation criteria from the Board of Renewable Energy (EC, 2009), those produced biofuels must save at least 40% of GHG's emissions in comparison to fossil reference (GHG's net savings). Later, there were excluded from the suitability map, the hotspots of biodiversity (priority conservation areas and natural forest lands). Natural tropical forests are usually guardians of high levels of biodiversity, and they are also important for preservation of the hydrological cycle. In addition, deforested areas of land are very fragile, hence, for those reasons forest land were excluded from the land that is considered suitable for biofuel crop expansion. Furthermore, land for agricultural purposes was excluded from potential areas for bioenergy feedstock cultivation, in order to avoid potential interference with food production and indirect effects of LUC. Lastly, those areas that do not have connection to road infrastructure were not included, mostly regions of Amazonas and Vichada, given that economic production competitiveness in remote and isolated areas is compromised. It is important to highlight, however, that the establishment of new infrastructure in these areas might support the potential development of these regions and it would cause a change in the classification.

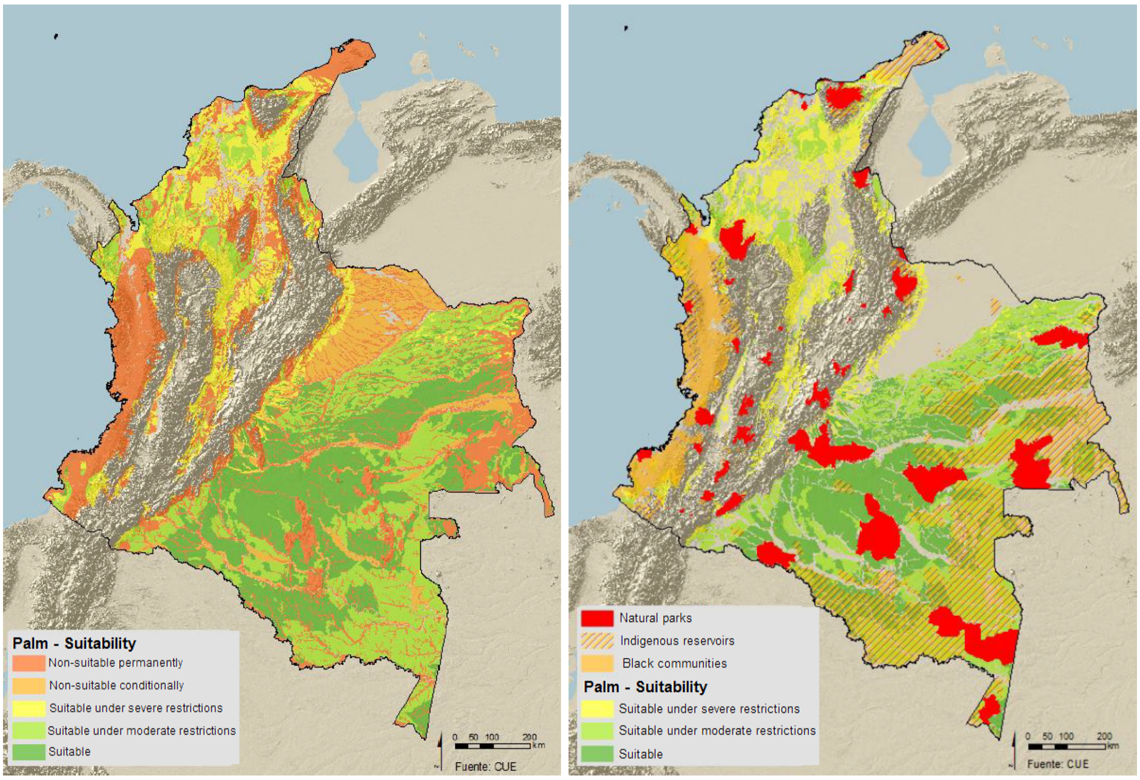
There are, of course, some other factors that influence suitability and sustainability of those crops for biofuel production (such as economic factors, temporary or seasonal issues, among others). Some of these factors were discussed when suitability maps were presented.

7.7.1 Palm oil

Due to climate and agronomic conditions big areas of Colombia are suitable for palm oil cultivation. Nevertheless, in those regions where precipitations levels are extreme, just like in the case on the Pacific Coast with frequent rainy seasons, and La Guajira peninsula with rain shortages, are considered as not suitable. Besides this, other areas are protected by some regulations (indigenous reserves and collective titles for black communities), which constrains palm oil expansion. There are some issues with lands located in the base of Andean mountain chain (particularly department of Casanare) that limits suitability for palm oil cultivation. Nevertheless, some of these areas can be ruled out not by agronomic conditions but by the scale of resolution (5km x 5km) requiring a more detailed local evaluation in order to improve the estimation of suitable land.

Figure 147 Palm oil suitability (1)

Biophysical suitability (left), overlapped with legal limitations (right).



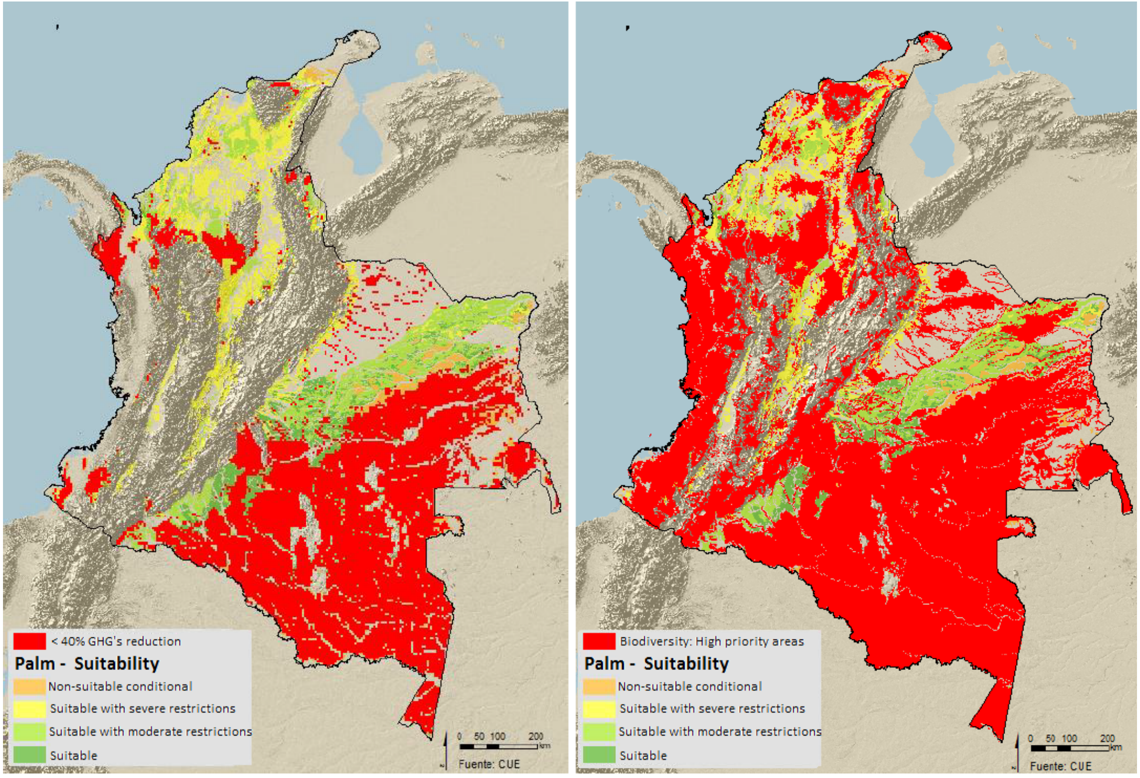
Source: CUE

Likewise, those areas where palm oil crops do not reduce significantly GHG's in comparison with fossil fuels use are excluded (GHG net emission savings less than 40%). This means that basically all areas with a carbon reserve in biomass relatively high, and those with elevated organic carbon reserves are left out (that covers large areas of natural wet forest lands of the southeastern territory and the Pacific coast). Suitable lands for palm oil cultivation in terms of GHG's net savings are located in Andean valleys, the eastern zone (non-forest area) and Northern zone of Colombia.

Suitable land for palm oil cultivation without compromising vulnerable and high biodiversity areas is determined by the exclusion of protected natural parks (former figure on the left side) and hotspots of biodiversity including forestall areas (following, on the right side). Vast areas of Colombia are excluded in terms of biodiversity, particularly natural ecosystems and with low use.

Figure 148 Palm oil suitability (2)

Excluding non-suitable areas regarding soil and climate conditions and protected areas, overlapped with protected areas and areas with less than 40% GHG's savings.

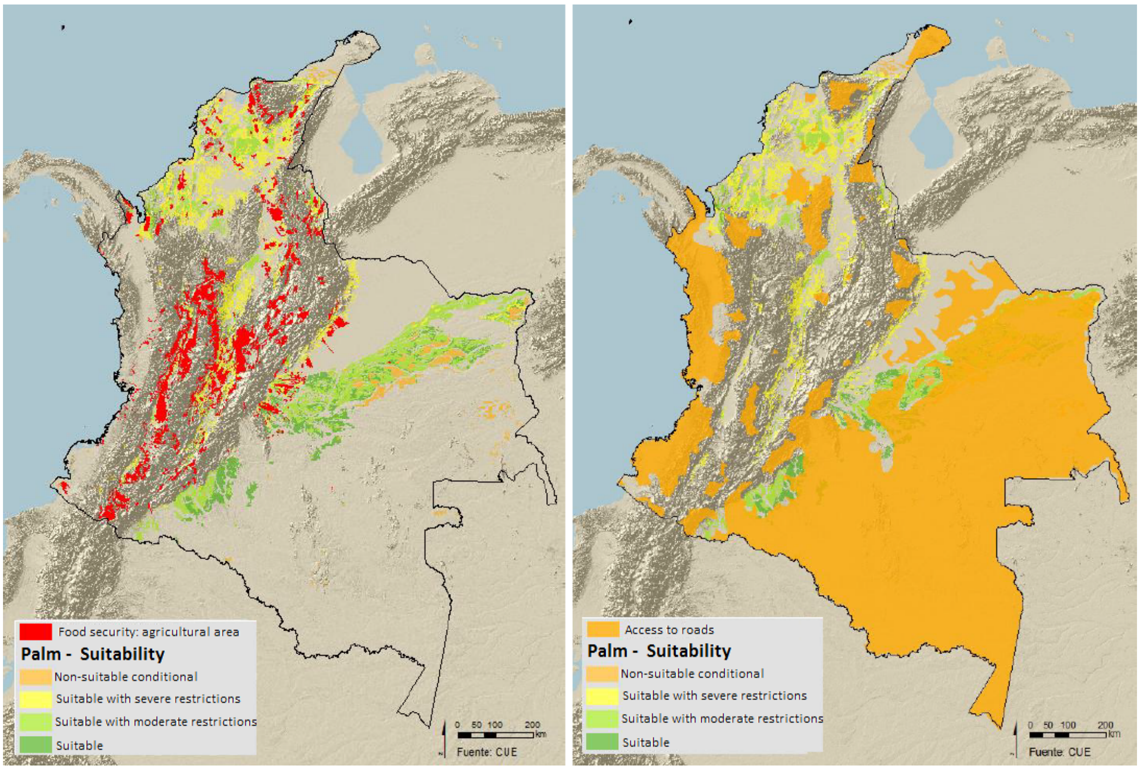


On the left side of the figure above, soil that is used currently for intensive agriculture is excluded, which is located mainly in mountain valleys. In this step, those current palm oil plantation that have been established recently were excluded, mainly in the southwest (Nariño), east (Meta), North (Magdalena and Cesar), and Central region (Santander). This action makes sense if it is understood that here is supposed to define expansion potential. In addition, the fact of turning grazing land into potential biofuel crops might cause an indirect pressure on the natural system and before creating an establishment, it must be evaluated locally for all its potential indirect effects.

Competitiveness of crops located far from the road network, processing facilities and existing markets is limited; therefore these areas were classifies as "non-suitable condition" in the suitability map. Areas along Pacific coast, amazon region and areas on the eastern side of Colombia are remote.

Figure 149 Palm oil suitability (3)

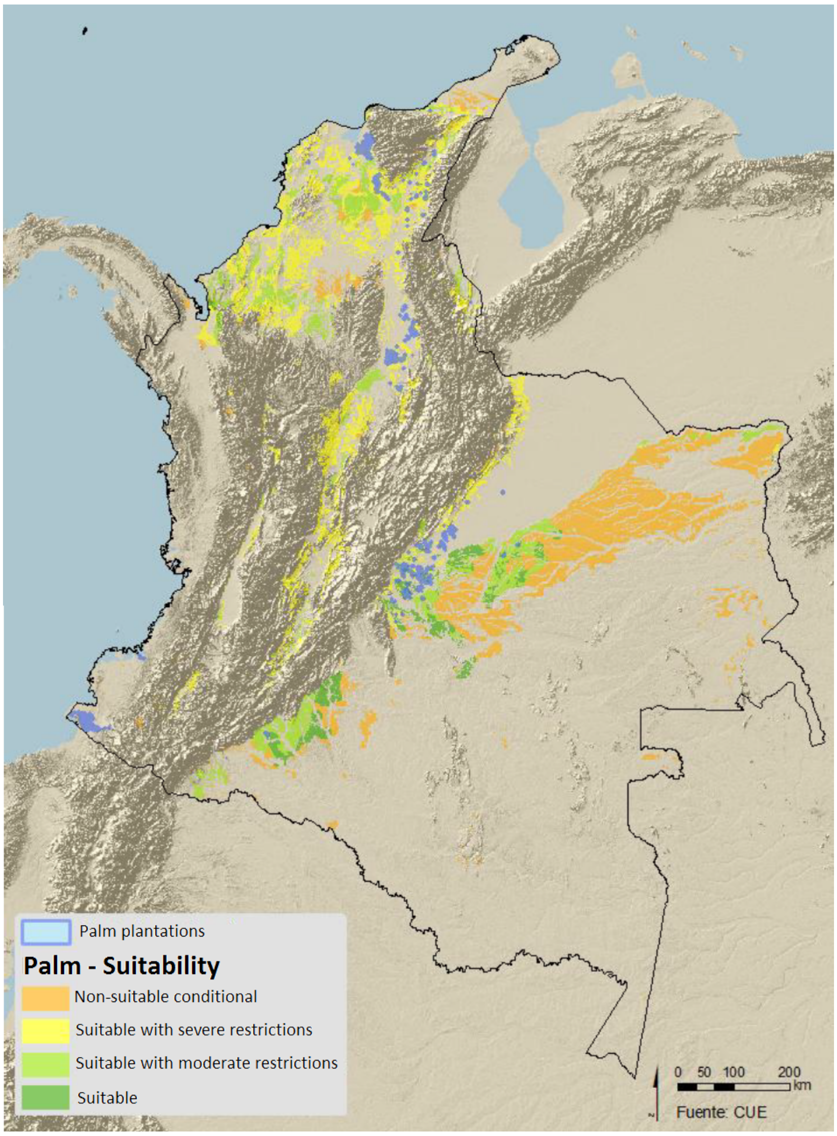
Excluding non-suitable areas regarding biophysical conditions, areas with less than 40% GHG's savings, biodiversity hotspots, overlapped with a map of agricultural zones (left) and areas with access to road infrastructure (right).



Finally, sustainable expansion area for palm oil crop is reduced to the northern section of the Llanos (on the eastern side of Colombia), central areas in the Andean Valleys, non-forest land in the eastern zone and small spots in the south-western area of Colombia.

Figure 150 Palm oil suitability (4)

Excluding protected areas and non-suitable areas in biophysical terms, areas with less than 40% GHG's savings, biodiversity hotspots, agricultural areas and limited access areas.



In total 1000,000 hectares were identified as highly suitable for palm oil cultivation and near to 2,900,000 hectares as moderately suitable. The larger area for the highly suitable zones is located in the base of the Eastern branch of the Colombian Andean mountain chain, in the departments of Caquetá and Meta (see figure below).

Both regions have already proven to be suitable for palm oil cultivation, predominantly in Meta, vast parcels have been employed for this particular crop. Nevertheless, there is a potential risk in the department of Caquetá, and it refers to a possible pressure on adjacent areas with a presence of wet forest land. With the purpose of preventing indirect LUC by the expansion of biofuel feedstock production it must be analyzed critically for suitability. In addition, there is a need for research on land planning and management in order to evaluate these potential effects.

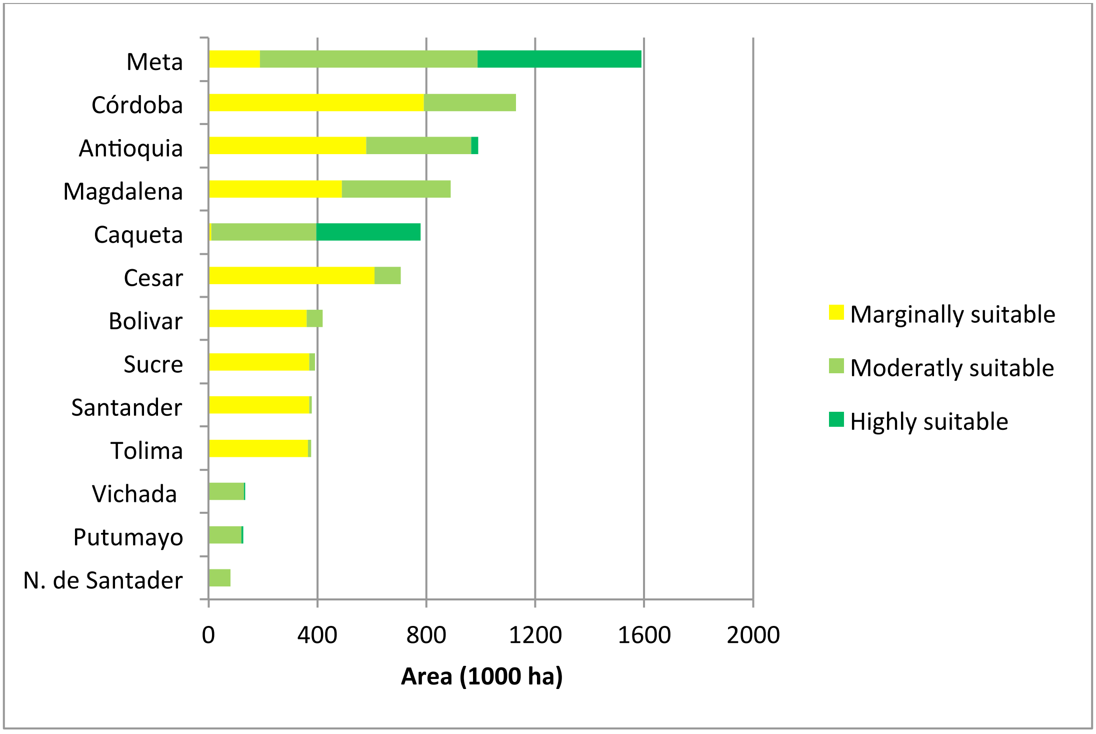
There is another area that exhibits high suitability conditions for palm oil tree cultivation, located along the shore of Magdalena River (in the departments of Antioquia, Santander and Bolívar) and especially close to the river mouth in the Department of Magdalena (in the western side of the Sierra Nevada de Santa Marta). Also, some parts of Cesar located along the Cesar River are suitable for palm cultivation.

The department of Cordoba and northern region of Antioquia are moderately suitable and suitable with severe restrictions for palm oil cultivation. The warning for these areas is similar to the one that was mentioned earlier. Land planning and land management are required to evaluate to what extent the implementation of bioenergy crops is appropriate without compromising soil characteristics.

Suitable land for palm oil cultivation suggested by the IDEAM study drew an area of 6,000,000 hectares, which is, as a matter of fact, less than the one pointed out in this study (9,354,000 ha). A plausible explanation for the difference between the two is the nature of the employed parameters (making special stress on the socio-economic factors). Nonetheless, the IDEAM study also categorized as suitable (with the highest potential) for palm oil cultivation the departments of Meta, Caquetá, Antioquia, Córdoba and Magdalena, which, in effect, coincided with the statements of this study. Considering highly and moderately suitable areas, that accounted for 4,001,000 hectares in total, match with 3,500,000 hectares suitable shown in the Ministry of Agriculture's report (Fernández Acosta, 2009). In comparison with this study, the report given by the Ministry indicates the highest potential for palm oil cultivation focused in Meta basin.

Figure 151 Zones with different suitability for palm oil plantations in Colombia (1)

(Highly, moderately and marginally suitable)

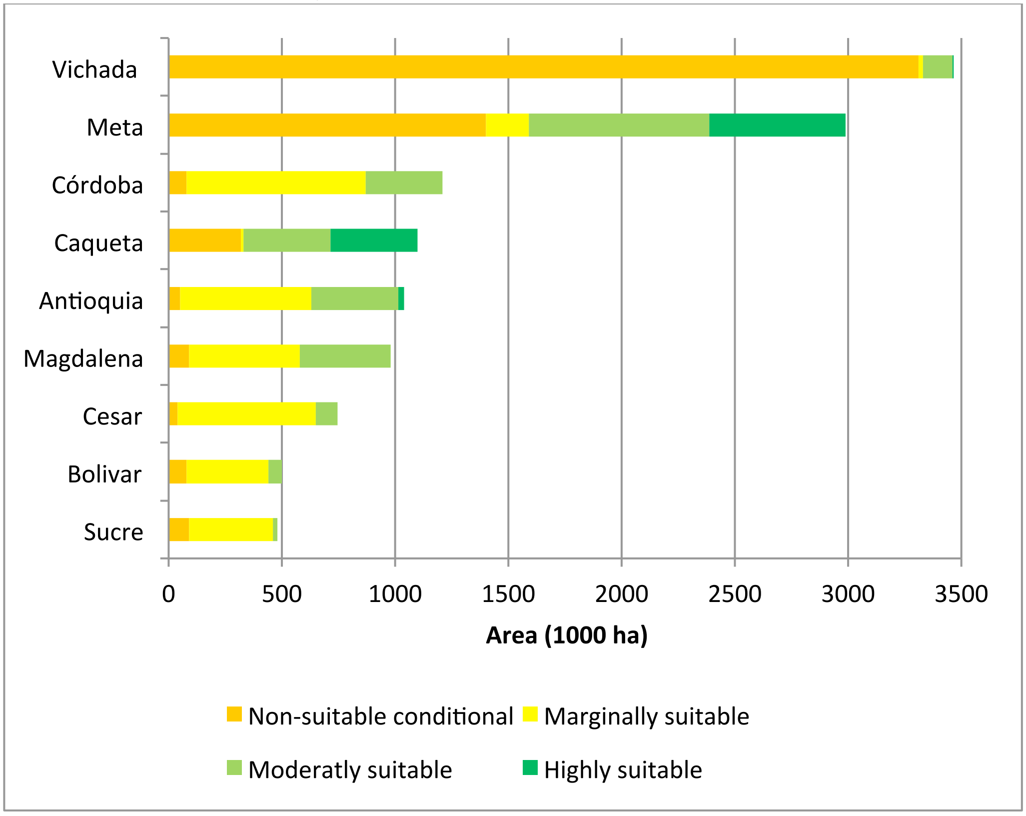


Source: The author. Data source: CUE study

The vast region of the Pacific coast was identified as a non-suitable area for palm oil cultivation due to several reasons. In the first place, land has been allocated to afro-descendent and indigenous communities; hence land availability is restricted. Furthermore, these areas are mainly covered by forest and a subsequent conversion could lead to a biodiversity loss, a diminishment in water deposits and a potential increase in GHG's emissions. High precipitation patterns and limited access to road infrastructure network also contribute as factors that reduce potential investment attraction for bioenergy initiatives. Notwithstanding, in should be born in mind that this location is relatively close to Buenaventura port for export purposes.

Limited availability of infrastructure (in terms of roads and electricity) and the priority of biodiversity conservation that are displayed by the departments of Amazonas, Vaupés and Guainía, lead to a non-favorable classification for palm oil cultivation. Besides, extensive areas of these lands are currently occupied by indigenous communities.

Figure 152 Zones with different suitability for palm oil plantations in Colombia (2)
(plus non-suitable conditional)



(including those suitable areas under certain conditions).

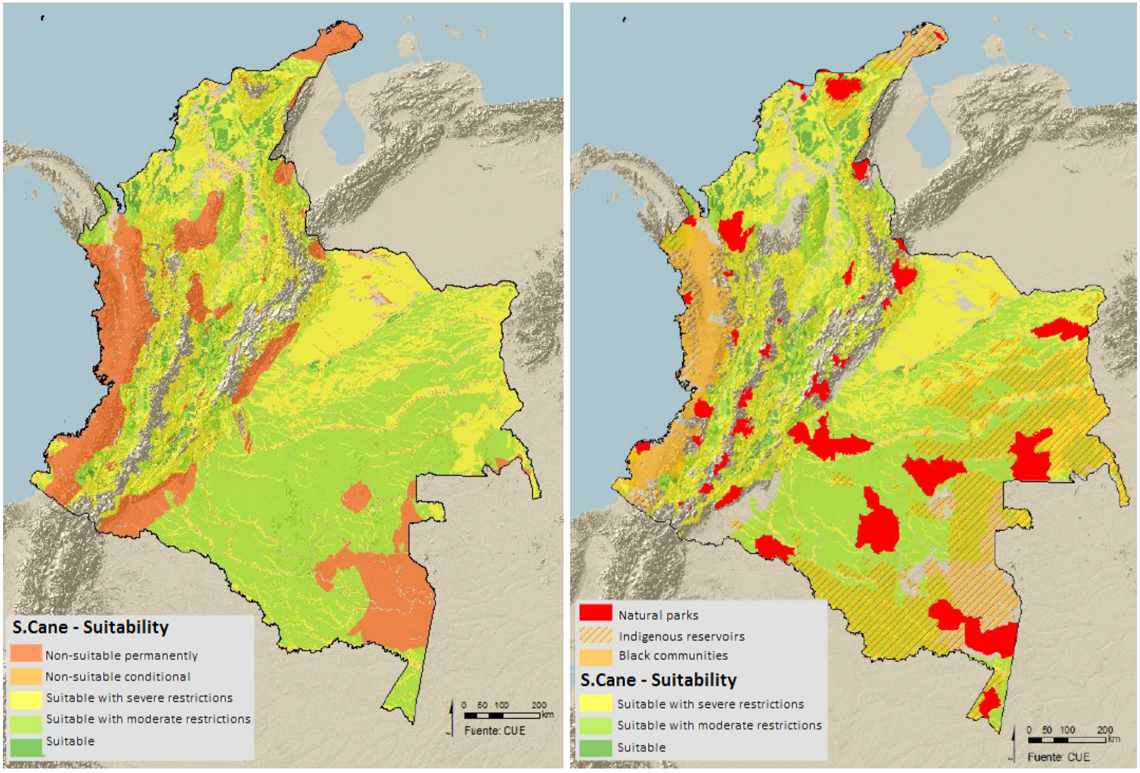
As is shown above, essentially low biomass lands of Vichada and Meta are presented as potential expansion areas. However, these areas have difficult accessibility and therefore they are ruled out from being considered suitable. But, it has to be stressed that through investment in new infrastructure, these areas could be used for palm oil tree cultivation.

7.7.2 Sugar cane

Due to climatic and agronomic conditions, large areas of Colombia are suitable for sugarcane cultivation (see figure below on the left side). Though, these and some other areas are part of protected zones (indigenous reserves and collective land titles of black communities), which constrains or ultimately forbids (in the cases of natural parks) further expansion of sugarcane crops (see figure below, on the right side).

Figure 153 Sugarcane suitability (1)

biophysical suitability (left), overlapped with protected areas (right).

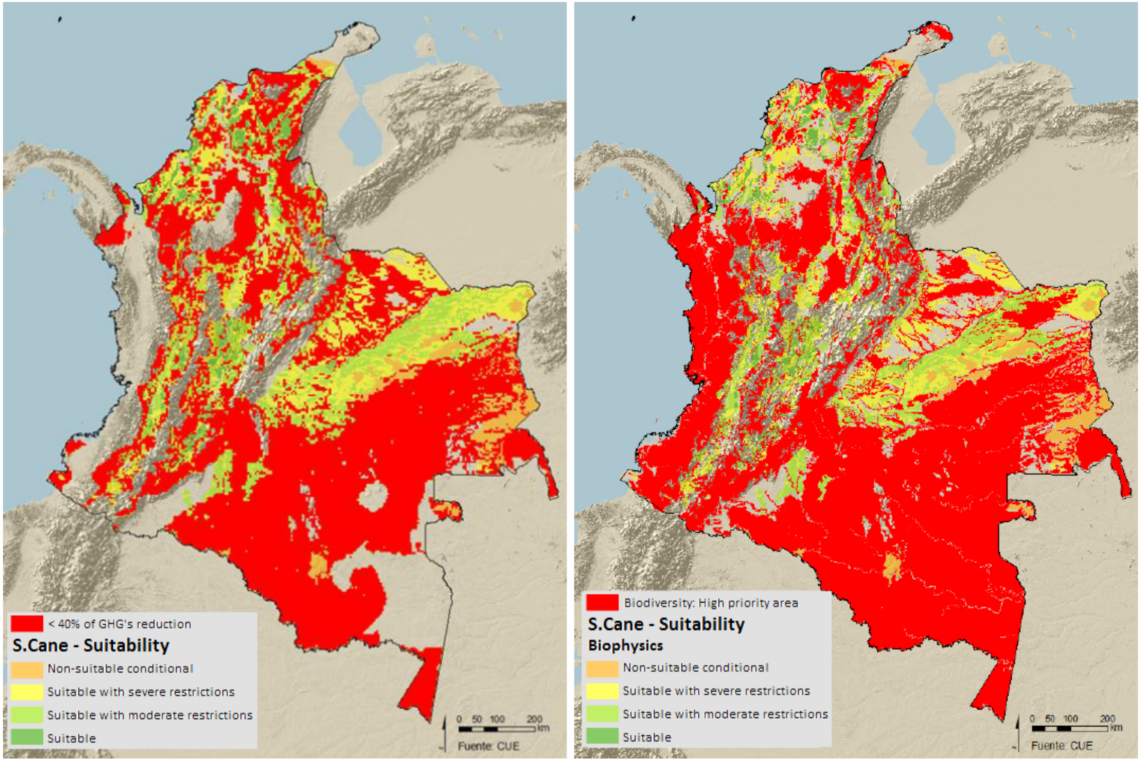


Those areas where sugarcane cultivation does not significantly reduce global warming were excluded (i.e. net saving superior to 40%, next figure on the left side), in comparison with the use of traditional fossil fuels. This situation implies that almost all areas with a relatively high reserve of carbon in biomass, or those that account for a high reserve of carbon in the soil are excluded. Given this description, the set of suitable areas was narrowed down to agricultural land, prairies, degraded, or deforested lands.

Suitable land for sugarcane cultivation without affecting vulnerable areas and zones of great importance regarding biodiversity are determined by excluding protected natural parks (see previous figure on the right side). In the same step were excluded forest lands given their great biodiversity and their relevance regarding the cycle of water (next figure). On the other hand, forest lands are extremely vulnerable and fragile if they are turned into bioenergy feedstock crops.

Figure 154 Sugarcane suitability (2)

It excludes protected areas and biophysically non-suitable areas, overlapped with GHG's savings less than 40% (left), and biodiversity hotspots (right).

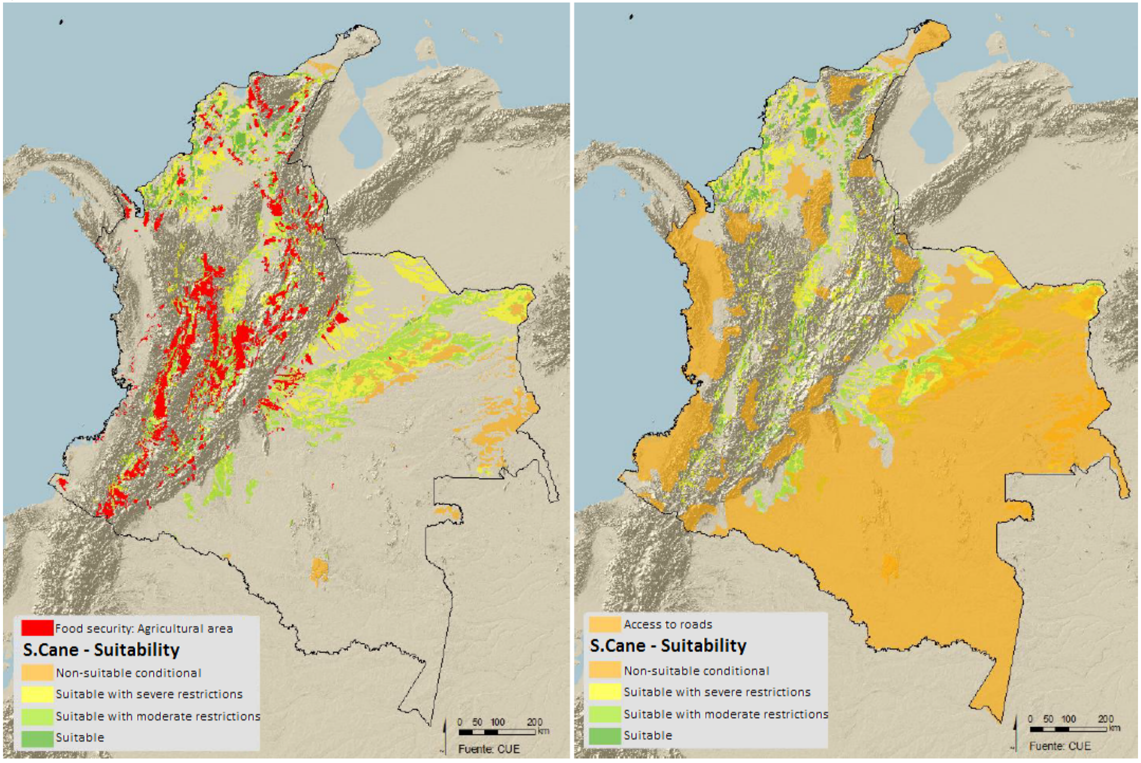


Finally, areas that are being employed for intensive agricultural practices that are established in the mountain valleys along the Andes were excluded (see figure below, on the left side). In this step, current bioenergy crops for ethanol production purposes were excluded, located in the geographic valley of the Cauca River, which is actually coherent with the idea of determining potential expansion areas.

Competitiveness of sugarcane crops located far away from existent road infrastructure and from current established markets is limited, therefore these areas were excluded from the suitability map (see figure below, on the right side). This study put stress on the idea that the region along the Pacific coast, the Amazon jungle and Colombian deep east are quite isolated in these regards.

Figure 155 Sugarcane suitability (3)

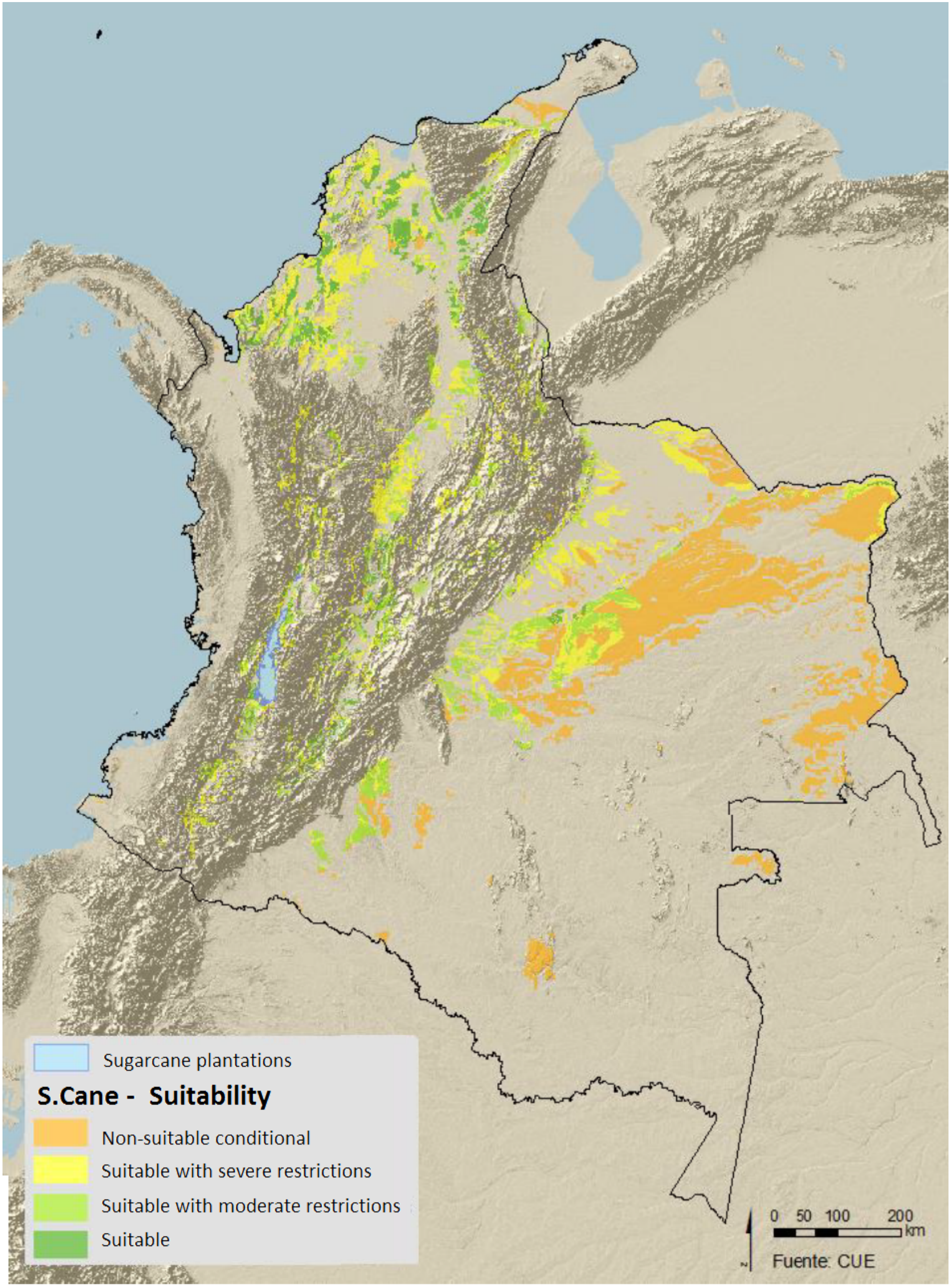
Suitability excludes protected areas and biophysically non-suitable areas, along with GHG's savings less than 40% and biodiversity hotspots, overlapped with agricultural areas(left) and areas with access to road infrastructure (right)



So, the area for a sustainable expansion is reduced i northern plains and some areas in the Andean Valleys and the non-forest area in the eastern region.

Figure 156 Sugarcane suitability (4)

Suitability excludes protected areas, biophysically non-suitable areas, areas with less than 40% in GHG's savings, biodiversity hotspots, agricultural areas currently in use and areas with access to road infrastructure.



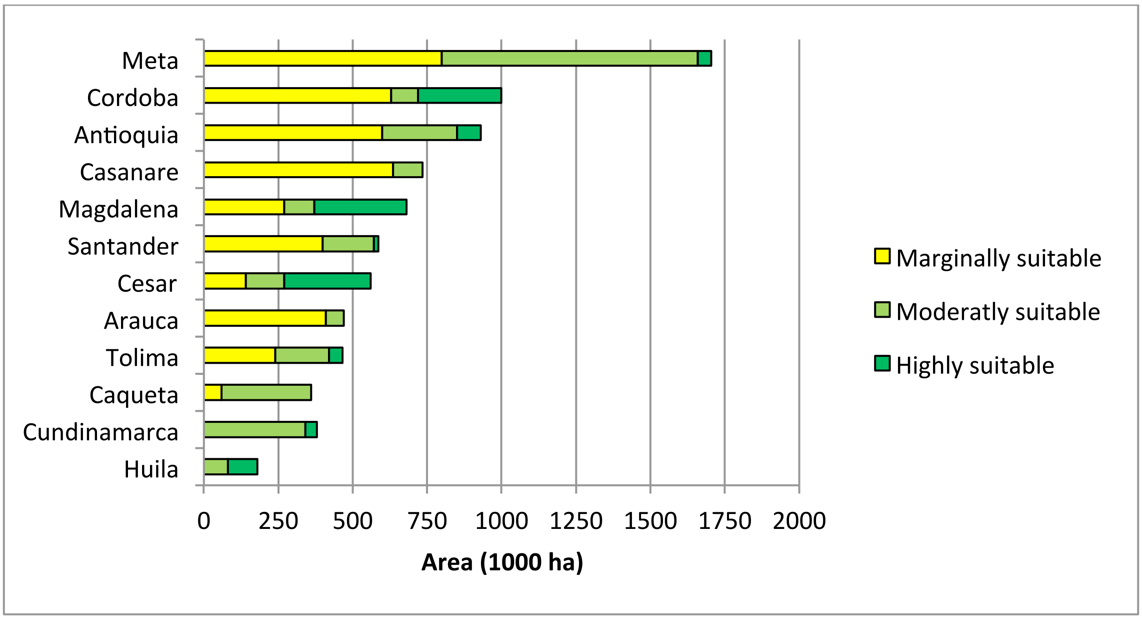
At the moment, near to 40,000 hectares of sugarcane crops are dedicated to ethanol production, and there is a high potential of expansion of up to 1,518,000 hectares of high suitability and 3,400,000 hectares with moderate suitability.

The largest areas with moderately suitable lands are located in the eastern base of the Andean mountain chain in Meta and partially in Caquetá (figure below, on the right side). As happened with the palm oil case, the intention of implementing biofuels initiatives (for ethanol in this case), in the Department of Caquetá might clash with adjacent wet forest that is located within its impact region. Again, careful land planning and local land management should be implemented in order to determine sustainability potential of cultivation of sugarcane in this region.

The departments of Cesar, Córdoba and Magdalena were identified as zones with high potential for sugarcane cultivation. In general, sugarcane crops in the northern area should be established in such a way that water availability can be secured. Furthermore, the inter-Andean valleys in the departments of Tolima, Huila, Antioquia and the area of Cauca River are suitable, but with a limited expansion potential.

Suitable areas for sugarcane cultivation suggested by the Ministry of Agriculture are approximately 3,892,000 hectares (Fernández Acosta, 2009), whereas this study found 10,973,000 hectares as suitable land. Albeit, if those lands that are highly suitable and moderately suitable were considered, which should be the ideal case, given that crops held in suitable lands with severe restrictions are not economically attractive, results dropped, hence drawing a similar result to the Ministry report(4,919,000 ha).

Figure 157 Zones with different suitability for sugarcane plantation in Colombia (1).
(Highly, moderately and marginally suitable)

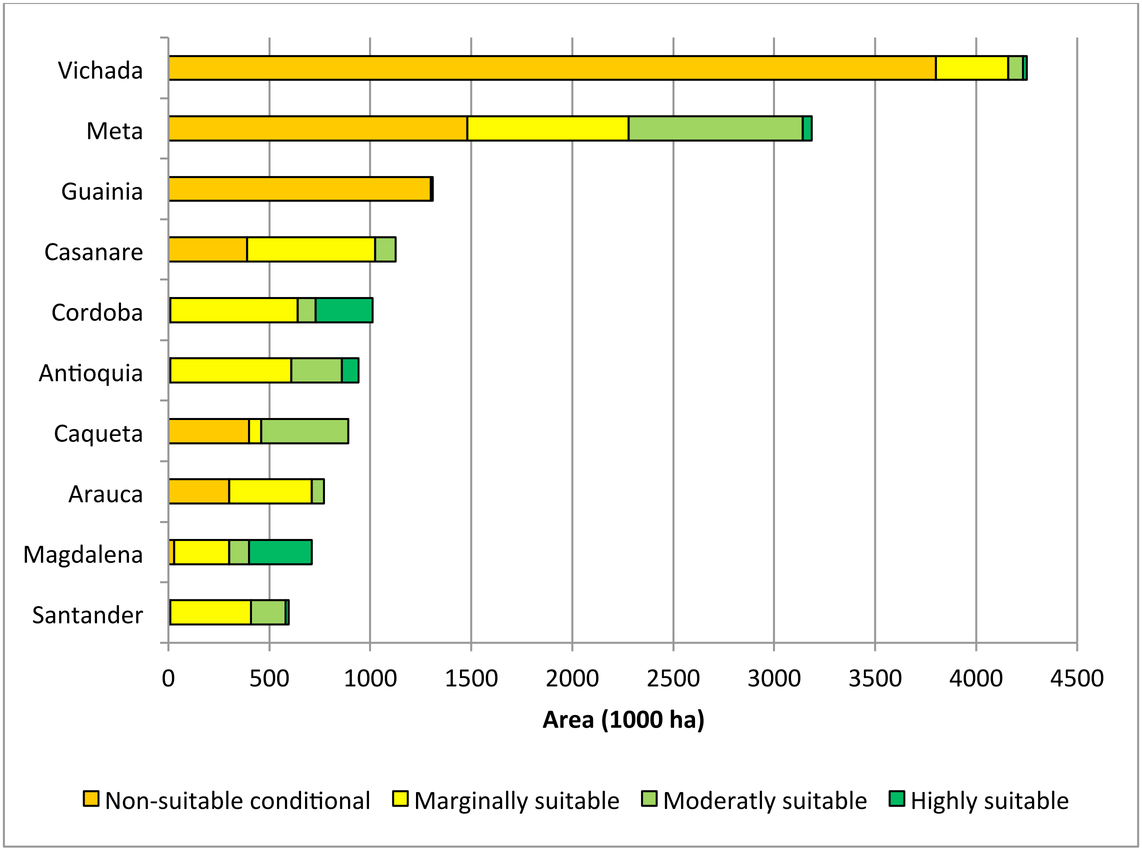


The pacific coast line was identified as a non-suitable area for sugarcane cultivation for several reasons. In the first place, high precipitation is not suitable for sugarcane cultivation and the mentioned area is covered by mainly forestland, therefore a conversion might lead to a loss of biodiversity, reduced water deposits, and it would release a great amount of GHG. In addition, this area is has been allocated to indigenous people and black communities; consequently the legal access to these lands for bioenergy projects is restricted and there is no good road infrastructure either.

On the other hand, distance to ports (for exportation purposes) could be attractive given the short distance to them.

Limited infrastructure (roads and power grid) and the importance in the preservation of biodiversity make that zones located in departments such as Amazonas, Vaupés, Guainía not suitable for sugarcane cultivation. Besides, vast areas of these regions are occupied by indigenous communities.

Figure 158 Zones with different suitability for sugarcane plantations in Colombia (2)
(plus non-suitable conditional)



As is shown in the figure above, particularly in those low biomass areas of Vichada and Meta, there are areas of potential expansion. Nevertheless, these areas, at the present time, have difficulties regarding road network infrastructure, hence, they are considered as non-suitable. However; through investment in transport infrastructure these areas might be suitable for sugarcane cultivation.

These results are always subject to uncertainty due to changes that can be present in climate, such as higher temperatures and heavy rains and droughts. Warmer climates, due to increased water vapour are vulnerable to more an accentuation on the magnitude of climate events (Trenberth, 2012). Ramirez-Villegas,et.al. presented a study of climatic effects on agriculture by the year 2050 in Colombia. In their findings it is argued that disregarding the crops small farmers will be vulnerable to CC. For sugarcane was found that suitability and productivity could drop. In particular they suggested that sugarcane would require lands located above 1500 m.a.s.l. For palm oil was found a risk of floods and salinization of land close to coastal areas. Among adaptation plans it was recommended to employ subsidies and agricultural insurances for small-farmers. Sugarcane could have better performance under genetic enhancement and palm crops could be relocated or blocked through walls (Ramirez-Villegas, Salazar, Jarvis, & Navarro-Racines, 2012).

7.7.3 Stakeholders' engagement: contrast between the expansion potential in this study and former plans

In 2002, during Alvaro Uribe's government was sketched a robust plan to boost a strong biofuel industry in Colombia, however such purpose has lost partially its initial impulse due to political and technical setbacks.

In 2008 was released the general legal framework for he bioenergy sector in the document Conpes 3510, where the Ministry Of Energy was commissioned to guide a comprehensive plan to build a sustainable biofuels industry. Within this task was important to coordinate efforts from different fronts, such as the agricultural sector (small and big farmers)[52], R&D, Infrastructure and environment.

The original plan (sketched in 2002) was to start with E10 and B5, but in 2007 was decided to raise B5 to B10 (starting from 2010). The projection was to reach a blend of 20% in both gasoline and diesel by 2020. From that moment the idea was to supply foreign markets and keep blending level steady for domestic demand. (Contexto Ganadero, 2014; Infante, 2008).

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[52] It is important to bear in mind that farmers are directly represented by Fedepalma (for palm oil), by Asocaña (for sugarcane), and Fedebiocombustibles for the whole biofuel production chain.

Such plan would imply to count on 900 thousand new ha of sugarcane and 1.8 million ha of palm oil by 2020, according to governmental calculations (Infante, 2008). These projections were supposed to provide 126 MBD of ethanol and 108 MBD of diesel. Based on such assumed supply E100 and B75 scenarios were presented as feasible and it does concur with the expansion potential that has been presented along during this mapping excersise.

Fedepalma and Proexport have presented studies where some processing capabilities are explored for palm oil and sugarcane industries correspondingly (Mesa Dishington, 2010; PROEXPORT, 2012). Expansion potential are metioned briefly and they go in accordance with the results presented here. However this is not accompanied by proper GIS studies, therefore it turns out hard to contrast this study with previous ones.

However, nowadays in Bogota biofuel blends reach 8%, and anywhere else 10% for a combined average of 9.2% (Contexto Ganadero, 2014).

It has been recognized as an important challenge Colombian infrastructure and it has been considered to look for alternatives such as the use of pipelines for biofuels transportation[53].

All these targets that have not been accomplished are understood by the producers as a lack of rigour in policies implementation. The agribusiness association Fedebiocombutibles argues that goals have changed since the beginning of the program and biofuels production is not the priority now (Dangond, 2013). It was planned an increase in the blends up to 20% (in diesel) by 2020, however so far the targets have not been reached (15% by 2015%) and it is feel hesitation from the government, due to possible increases in the price of the blended fuel (Contexto Ganadero, 2014).

In contrast the government indicates a decisive support in the augmentation of these fuels, and it acknowledges the environmental benefits, as GHG´s emissions reduction and socioeconomic advantages (income redistribution) related to them. It mentions the implantation of quality labelling to certify fair trade and environmental protection (Hernan Martinez, 2009). However this has not been accompanied by facts that encourage the level of investment that have been done so far (US$ 1300 million) (Dangond, 2013).

Some other setbacks are regarding resources such as labour and land availability. For instance 1.8 million expansion would require nearly 180 thousand new jobs employed directly in the chain.

Economies of scale require of large extension of land, which are not always affordable or possible to find under the technical requirements.

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[53] A 6 inches exclusive pipeline from the Oriental region of Colombia up to Coveñas (in the North coast), might cost US$400-450 million.

So far the academic sector continues in isolated research efforts, while there is expectation for governmental or private support to develop technologies that quicken the pace towards new feedstock processing (as it shown in the last appendix).

Oil business actors remain in a marginal role: Whosalers are allowed to transport E98 from production plants to storage stations. Afterwards the blend takes place and is further sold to retailers to be distributed to the final costumer (which in turn adopts passively the blend imposed by the government).

7.7.4 Conclusion

This particular study shows that there is a considerable potential for palm oil cultivation that adds up to slightly more than 4 million hectares, similarly great is the opportunity for sugarcane, with 4.9 million hectares. In a general sense, the suitable areas for palm and sugarcane cultivation are overlapped, given that most of the exclusion criteria that have been used are valid these 2 kinds of feedstocks (for instance indigenous reservoirs or protected forests). Notwithstanding; those areas considered as highly suitable are quite different: In the case of the feedstock for biodiesel production there is a predilection for the departments of Caquetá and Meta; and contrarily, sugarcane has a bias for the condition presented in Magdalena, Cesar and Córdoba. Likewise, the region of the department of Vichada was shown to be moderately suitable for biofuels feedstock production in general, but first access to the region must be improved significantly, i.e. investment in road infrastructure network.

The study also tackled the topic of GHG's created by LUC. This aspect has become fundamental in policy making and it determines in some way land suitability for bioenergy crops. Therefore, depending on the former land use, carbon debt (assessed in years) might take hundreds of years in the worst scenario (i.e. if wet forestland is cleared for establishment of bioenergy crops). Based on that, it is possible to argue that just those areas with a low carbon reserve, such as mountain shrubs ecosystems or grazing land, are suitable for implementing bioenergy production projects. It is highly recommendable to spare agricultural land from these bioenergy initiatives, due to potential indirect affects in LUC, or more soundly, because food security could be jeopardized. In spite of this, it is quite important to bear in mind that previous pasture lands can also exert some pressure on environmental ecosystems because of iLUC (as could happen in Caquetá in those pasture lands that are close to forests).

It is absolutely required to complete a land use planning and put into practice some specific agricultural routines that might alleviate land pressure (such as intensive cropping or grazing), or simply avoiding the use of already active (high productivity) land to dodge iLUC effects.

As a whole, this section identifies areas where the sustainable expansion potential of biofuels at national level can be attractive. These results provide a foundation of scientific knowledge for strategic planning (particularly, in terms of sustainable use of land) regarding renewable energies for transportation and so the path is open for investment in bioenergy projects of this nature. Nonetheless it is fundamental to stress on the fact that further analysis can be applied here, if higher resolution maps become available, as well as refine the set of criteria employed, in order to plan punctual biofuel production projects.

8 GENERAL CONCLUSIONS

Bioenergy in general, and biofuels in particular, have come up to the renewable energy stage with some peculiar strength, overall in terms of alternatives for transportation. Some of the drivers behind this option are shared on a global scale, such as the reduction of GHG's emissions, and enhancement of energy security conditions. Some others have a more local nature, like a diversification of markets for agricultural commodities, dynamization of rural areas, improvement of micro and macro-economic indicators (for instance, income of the rural poor and national balance of payment), among others.

However, production, commercialization, and use of biomass based energy have a really complex set of relationships regarding economic, social and environmental effects. Therefore, even though biofuels are associated with several positive consequences; they are also linked to convoluted issues that require the attention of scholars and policy makers, in order to avoid catastrophic outputs from a poor implementation of a bioenergy agenda. Among those negative results are:

- a potential net energy loss (assessed in non-renewable sources),
- a constant threat to food security given that some feedstocks (in fact, the most used ones) can be employed for food and/or energy purposes at the same time,
- a potential increase of carbon emission through LUC and iLUC effects,
- an eventual worsening of the current social or economic situation for vulnerable population,
- and the imperilment of natural ecosystems.

This reality is the one that Colombia has confronted, since 2005, when it started to walk the path of liquid biofuels for transportation. Given agricultural circumstances for this South American country, sugarcane and palm oil were the main chosen feedstock to start this journey. Of course, it does not imply that other alternatives cannot be explored in the immediate or mid-term, but most bioenergy initiatives in Colombia, nowadays are focused on these two options.

A comprehensive analysis of Colombian biofuels chains and their actual and potential effects, regarding their social, economic and environmental behavior was required in order to establish to what extent liquid biomass-based fuels are sustainable. Actually, that is the reason and core of this thesis document.

The results can be summarized as follows:

Among renewable energies, bioenergy and in particular biofuels, represent a transitory and immediate alternative to solve the stress caused by fossil alternatives. Handled properly, biofuels can become in an appealing alternative to both industrialized and developing countries.

The latter can take advantage of latecomer position, improve the socio-economic situation of the population, and may alleviate environmental issues caused by traditional energy sources.

Biofuels can be classified by their state of nature and by the degree of technology advance. Within this document current and potential impacts of production and use of those liquid biofuels are studied (alcohols and oils) that are produced within the Colombian territory.

Biofuel production is well justified in this case, given that existent energy sources (hydro, coal, gas and oil) properly cover energy needs, except for transportation**. Colombia is not a net importer of oil, yet, but new reserves have not been found and export rates lead one to think of a shortage scenario in the midterm**.

Despite that, **Colombia produce commercially 1GBf (sugarcane-based ethanol and palm oil-based biodiesel)** and those are highly criticized because of the food vs. fuel dilemma, a study needs to be carried out to understand to what extent these alternatives represent a threat, and if they do not, how much and where can they expend. Per se, 1GBf is not bad, but local analysis is required to see the full implications of their implementation. Therefore, biofuels production cannot be ruled out, and on the contrary must be encouraged. The problem here is establishing conditions to guarantee their sustainability without jeopardizing surrounding ecosystems, food provision, and the socio-economic conditions of the population. Actually, Colombia has managed some initiatives (at exploratory level) that aims to better biofuel under better technologies as it can be seen in the final appendix. **This document argues that, in fact, Colombian biofuels, under current circumstances, are sustainable based on the following rational**:

First, Colombia has set firm foundations in terms of biofuel policies (with a set of mandates, tax exemptions and other tributary and financial aids), following the example given by industry leaders such as Brazil. Drivers are properly adjusted and incentives in term of mature commodity markets ease development for these initiatives. Unlike most countries in the region, along with Brazil and Argentina, Colombia is the only country within the LAC region capable to cover domestic supply and eventually think of export possibilities. Regulations still require some fine-tuning and they need to target sustainable certificates that boost a proper entrance to a global green oil market. A constant threat to bioenergy is oil price fluctuations, but R&D efforts can overcome this issue in the long term.

Secondly, Colombia must take into account the environmental context to implement a wide bioenergy project, due to the strong connection that this alternative possesses with global warming problems and agricultural management.

In this regard it is fundamental to stress the importance of biodiversity protection, land degradation, and land management issues that emerge with monocultural practices. If the latter are carried out it becomes crucial to include policies in the local planning schemes for implementation of crop intensification in order to avoid LUC and iLUC effects and expansion of the agricultural frontier.

Most of the problems related with air pollution, and climate change is closely linked with mobile sources of contamination, i.e. the transport sector. For that reason, biofuels production and use are able to mitigate such effects, if it is taken into account that photosynthesis captures carbon emissions during the agricultural stage of biofuel creation. When biofuels are blended with regular gasoline the burning process is cleaner, resulting in a lower level of contamination.

Nevertheless, it is also important to recognize the role played by ergoculture as GHG's emitted by account of agricultural practices. Use of fertilizers and pesticides, along with forest clearance might unleash a high pressure on the atmosphere. Therefore, expansion of energy crops must be implemented carefully, as is explained in the last chapter, which overtakes this kind of hindrances.

Environmental pressure can also be reduced by supporting an active biofuel industry, if more opportunities for development are brought to rural areas, avoiding migration processes.

Thirdly, in economic terms, competitiveness of Colombian biofuels, in international markets, can be imperiled by high cost of labor, despite high yields of agricultural commodities. Some other biofuel producing countries pay less than half the wage established in Colombian territory.

Biodiesel costs throughout Colombia are quite standardized. They are mostly explained by feedstock costs that have been calculated between US$482 and US$618 per ton. Benefits should be shared between farmers and plant owners, and are linked to the amount of oil obtained from each ton of fruit.

Conditions for the final price are discussed informally in this industry, if there is no formal contract that establishes otherwise. As reference, the PSF is used which is usually presented in advance, so levels of uncertainty are reduced.

In the case of sugarcane ethanol, it is required to improve competitiveness in terms of final prices, regarding direct international competitors. Most of the cost, just like in the biodiesel industry is explained by feedstock acquisition cost. A way to solve this issue is via capital investment, but intensive machinery would imply several job losses (8 million shifts if a total conversion is carried out).

In a general sense, the sugar industry (and by-products) is much more organized than the biodiesel industry. Thus, calculation of payments are fully described and distributed between farmers and plant owners. A compensation fund FEPA intervenes in price formation, and act as a kind of insurance for farmers and manufactures.

Recognition of final price in terms of ethanol elaboration, despite having formalization, has created controversy between farmers and sugar processors. On the one hand, a processor wants to give only one third of the final price to a farmer (according with those rules describe in chapter 4), whereas the latter try to get at least 50% of the final price. These discrepancies have brought tension to the ethanol industry. Regulation in this regard, along with some other fine-tuning in terms of compensation of divergences between sugar and ethanol must be introduced and reviewed in further policy analysis.

Fourthly, in this manuscript Policy for Biofuels in Colombia (PNBs) has been studied and it has been concluded that it requires between 6.4 and 9.2 million hectares in order to achieve government plans. According to government target, this land would be taken from fallow and livestock farming land. In chapter 7 it is proven that those levels can be reached, only under severe restrictions (overall in terms of current road infrastructure).

The palm oil industry (and by-products) has grown recently by account of a set of factors (elevated vegetable oil prices and the possibilities of new markets), and domestic conditions (supporting policies for biofuel industry). Yield per hectare has reached near to 4 tons of oil on average, but according to Fedepalma it would be possible to obtain 5.5 tons by 2020, overtaking some countries in South East Asia. It is highlighted that the possibility to concentrate the industry in clusters in order to increase efficiency in the industrial stage and therefore gain competitiveness.

P**articipation of small farmers is significant but there is a high level of land concentration in this sector.** There are just few plantation units that exceed 1000 hectares, but they have almost 40% of the planted area.

There are three types of contractual arrangements for palm oil extraction. Every one of them implies different rights and responsibilities as is explained in chapter 5. The importance of this is the flexibility offered to farmers of any scale.

Colombia needs to improve extraction methods, given its low productivity. Colombian plants can process on average 25 tons/ha, whereas Malaysia and Indonesia exceed 30 tons/ha. Evidence has shown an underuse of the installed capacity.

Strategic alliances are a possibility of distributing both risks and benefits of the industry, and they have proven to provide more stability and access to financial resources in an easier way. By training farmers and extractors they get better results and security in feedstock quality and quantity.

Vegetable oil provision has not been jeopardized so far with bioenergy project implementation; therefore, there is no evidence to point out biodiesel as trigger for food scarcity.

In the case of sugarcane, the industry related to ethanol production in based in Cauca valley, despite other regions that have sugar plantations (like Santander, Antioquia, Nariño, among others). Technical assessments have led to this conclusion by demonstrating that this variety of sugarcane (caña panelera) is not suitable for competitive ethanol production.

Crop performance has improved in terms of sugar content (reaching 13 tons per hectare since 2002), despite yield of sugarcane per hectare has been relatively stable (close to 120 tons/ha). This is proof of enhancement of soil performance and therefore less pressure on surrounding lands for expansion purposes.

There is also land concentration in this industry, but not as strong as in the palm sector. One fourth of land belongs to the ingenios and the remaining land to other owners. Proprietorship and management can be combined, thus 51% land is managed by independent owners. The remaining 49% is managed by different kinds of formal contracts presented in chapter 5.

Based on the existing surplus of sugar since 1987, the ethanol initiative was supported. In this way, food security was not put at risk. Neither the use of juices and molasses from sugarcane, nor the reduction in sugar production and exports since 2005, created any perverse effect on the sugar availability for the domestic market.

Current capacity of potential ethanol processing (1.07 million liters/day) is far from the one established originally by the government (2.7 million liters/day) in order to reach a level of E20 in the entire Colombian territory; however, expansion is still possible under some assumptions exposed in chapters 6 and 7.

Chapter 6 present a LCA for Colombian biofuels: 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. iLUC effects were evaluated in this assessment, by establishing that those crops which satisfy sugar demands in international markets can be set somewhere else.

When the iLUC effect was left out, it was concluded that ethanol made out of sugarcane was generating close to 26% of GHG's emissions in comparison to pure fossil gasoline. However, when it was included 156% of GHG's was created if and only if crops were to be grown in tropical forest.

RED standards use as reference 40% of GHG's savings in order to consider a bioenergy alternative as sustainable. In this case Colombian ethanol saves up to 74% in the best scenario; therefore the requirement is fulfilled.

In **terms of biodiesel, approximately 40% of GHG emissions per vehicle can be saved by using current technology and average cultivation practices, in comparison to fossil diesel alternatives (if LUC and iLUC effect are not considered). These results can be improved if methane is captured using residual waters.**

Palm oil tree cultivations are able to store relatively great amounts of carbon in comparison to other use of lands, thus 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 tree plantations took place in areas that formerly were destined for grazing purposes or agricultural production. This result strengthens the positions of some scholars (Mathews and Tan), and invite one to review results obtained by others like (Searchinger et. Al.). Based on the aforementioned, it can be asserted that Colombian biodiesel made out of palm oil offers a good performance in comparison with some other biofuels produced internationally, and it accomplishes 40% of GHG´s emission savings defined by several international standards.

The non-renewable energy demand for biofuels based on highly productive crops (as the palm oil crop) is considerably less in comparison to other biofuels, especially when lingo-cellulosic biomass is used to provide energy in 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 compost elaboration will be affected negatively.

In general, 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 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 a good performance and it reaches 40% of minimum GHG's emission savings suggested by several bioenergy fuel standards.

Biofuels exported from Colombia can be favored by various mechanisms for subsidies in "sustainable" international markets for biofuels. However, sustainability assessments 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 it evaluates its range of impacts.

The relatively low demand of fossil fuels of sugarcane-based ethanol and palm oil-based biodiesel is explained by the fact that most of lingo-cellulosic material is employed for co-generation.

Finally, the last chapter was shown as exercise to map the potential expansion of palm oil and sugarcane crops for increasing biofuels production. After a biophysical analysis was carried out, several sustainability filters were applied to Colombian territory through GIS tools:

- In those lands produced biofuels must save at least 40% of GHG's emissions in comparison to fossil reference (GHG's net savings).
- Territories of black communities and indigenous reservations are considered as not suitable for commercial biofuel initiatives exploitation.
- Natural reserves, such as forests, were left out because of biodiversity preservation, and resource maintenance.
- Land with current agricultural purposes was left out to guarantee food provision.
- Land without proper road infrastructure was not included to provide a more accurate expansion scenario in the short and midterm.

For palm oil crops, sustainable expansion area is reduced to the northern section of the Llanos (in the eastern side of Colombia), central areas in the Andean Valleys, non-forest land in the eastern zone and small spots in the south-western area of Colombia.

In total 1000000 hectares where identified as highly suitable for palm oil cultivation and near to 2,900,000 hectares as moderately suitable. The larger area for the highly suitable zones is located in the base of the Eastern branch of the Colombian Andean mountain chain, in the departments of Caquetá and Meta. Potential area for expansion goes from 4 million hectares to more than 9 (being flexible with the results). However, it needs to be stressed that this high potential is only possible if it is accompanied by proper investment in roads and some other infrastructure.

In the case of sugarcane, the area for a sustainable expansion is reduced to northern plains and some areas in the Andean Valleys and the non-forest area in the eastern region. This study

concludes that there is a high potential of expansion up to 1,518,000 hectares of high suitability and 3,400,000 hectares with moderate suitability.

The largest areas with moderately suitable lands are located in the eastern base of the Andean mountain chain in Meta and partially in Caquetá.

Suitable areas for sugarcane cultivation suggested by the Ministry of Agriculture are approximately 3,892,000 hectares (Fernández Acosta, 2009)(Fernández Acosta, 2009)(Fernández Acosta, 2009)whereas in this study found 10,973,000 hectares as suitable land (Fernández Acosta, 2009). Albeit, if those lands that are highly suitable and moderately suitable were considered, which should be the ideal case, given that crops held in suitable lands with severe restrictions are not economically attractive, results dropped, hence drawing a similar result to the Ministry report (4,919,000 ha).

In low biomass areas of Vichada and Meta, areas of potential expansion were presented. Nevertheless, these areas, at the present time have difficulties regarding road network infrastructure, hence, they are considered as non-suitable. However, through investment in transport infrastructure these areas might be suitable for sugarcane cultivation.

In summary, in the case of the feedstock for biodiesel production there is a predilection for the departments of Caquetá and Meta; and contrarily sugarcane exhibits a bias for the conditions found in Magdalena, Cesar and Córdoba. Likewise, the region of the department of Vichada showed to be moderately suitable for biofuels feedstock production in general, but first access to the region must be improved significantly, i.e. investment in the road infrastructure network.

It is absolutely required to complete a land use planning and put into practice some specific agricultural routines that might alleviate land pressure (such as intensive cropping or grazing), or simply avoiding the use of already active (high productivity) land to dodge iLUC effects.

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Appendices

Appendix 1

Box 1. Cassava-Based Ethanol Innovative Project

Colombia is highlighted in the LAC region by its efforts in cassava processing. Since 2005 two Colombian firms De Sargo and Central Sicarare have set a common plant located in Codazzi (Department of Cesar, North West of Colombia) being the pioneer to transform cassava starch into ethanol.

Clayuca and CIAT have just inaugurated, on July 22nd of 2, a new cassava-based ethanol processing plant, located in Palmira (on the Cauca Valley).

This project is still in an intermediate stage because, albeit all the facilities are ready to be used, it is a small scale pilot that will be studied in order to be implemented in different localities of the country. It is characterized by its low costs and flexibility, because it is able to operate with sorghum and yam (or sweet potato).

By now, this is a "Social Ethanol" proposal intended to become a development vector for sustainable energy for rural populations that lack connection to the electricity distribution grid and that have a high degree of dependence on fossil fuels.

Financial support came, in the initial stage, from the Colombian Ministry of Agriculture, however the final technical developments were carried out by the Brazilian entities: Universidad Federal de Rio Grande do Sul and Usinas Sociales Inteligentes (Social Intelligent Large Factories).

The production capacity of this plant is between 400 and 500 liters of hydrated ethanol per day. This sort of ethanol allows operating a power generator to produce electricity at 110 and 220 volts. It requires 4 liters to generate one hour of electricity.

Despite firewood use being not very extensive among Colombia territory, it is still an important energy source for isolated rural areas, so the project tries to encourage its reduction, and consequently deforestation and offers cooking alternatives in ethanol-based stoves, diminishing smoke indoors.

Some other production efforts are attractive around cassava: The firms Desaro and Petrotesting from Colombia are doing research since 2003 in order to use cassava as feedstock for ethanol production. They started using 25 different kind of cassava and finally selected the 5 most productive, with a yield of 30 tons/ha however the goal is to get 40 tons/ha. Having in account that the yield interval is between 180 and 200 liter per ton it will produce approximately 8 thousand liters per year in the best scenario.

Note:

Clayuca is a consortium dedicated to support research and development related with cassava (known as yucca in some countries) applications in LAC region. It has 13 country members: Colombia, United States, Venezuela, Ecuador, Peru, Mexico, Nicaragua, Costa Rica, Haiti, Cuba, Nigeria, South Africa and Ghana. For further information see: www.clayuca.org

See: (El Pais Newspaper, 2009; Eneas, 2006)

Appendix 2

Box 2. US-Colombia biofuels trade through a FTA: A temporarily obstructed possibility

Mathew Rooney, Director of US Economic Policy of State Department explained that his country is expected to consume 36 billion gallons of biofuels by 2022, which is based on possible imports from producer countries like Brazil or Colombia(Guzman, 2009).

Colombia government was highly interested in building commercial bridges with the US so the pursuit of a Free Trade Agreement (FTA) became a priority under Uribe Vélez administration. The final document was written in 2006 and approved in the same year by Colombian Senate, nonetheless some concerns related with HHRR violations delayed the approval from the ongoing US Senate, and so the agreement had not come into force.

For biofuel dynamics, a bilateral accord between Colombia and US in a is a possibility of improvement for both countries, because it represents, for the former, a great opportunity to expand international demand, based on "20 in 10" policy established under G.W. Bush administration* and it means, for the latter, additional supply of ethanol and biodiesel which allows to reduce the amount of oil imported form Middle East and Venezuela.

However, there are several arguments that have darkened the implementation of such a pact, despite it has been finally approved: **a**s is seen as a threat to food security. In previous agreements as The Andean trade preference program in 1991 the trend was to export food rather than to provide for local markets (Camastra, 2008); **b.** It is designed to open markets but in an unfair way: The FTA requires that Colombian agriculture remove tariffs and subsides, while US agriculture remains heavily subsidized (Carnoval, 2009); **c.** Some indigenous and African-Colombian communities are endangered if FTA is enacted. Democrats in the US senate considered disapproving the FTA with Colombia based on information that accuses Multinationals and Large landholders to use paramilitaries forces, under government indifference, to threat and displace rural population in order to establish some development projects. This was added to the fact of the murders of indigenous, Union and co-ops leaders (Camastra, 2008; Carnoval, 2009); **d.** Biofuels in particular have not been not part of the discussed agreement: Energy is not part of the executive summary in the proposed document (Hopkins, 2008); the closest approach to bioenergy would be just agricultural commodities without added value.

*Note: In 2007 U.S. president G.W Bush gave "a new proposal to cut U.S. gasoline usage by "20% in 10 years," to be accomplished primarily by mandating higher proportions of alternative fuels and increasing the fuel efficiency standards for cars and light trucks". (Oxford Analytica, 2007)

Appendix 3

Box 3. Eviction processes: Recent history in Colombia

Some lands left behind by displaced population are currently abandoned. Others contrarily, are occupied by third parties, that could be people that have acted in good faith, as displaced peasants from other regions; but there is presence of bad faith occupants, as paramilitary groups, straw men, and some agribusiness companies. Some hectares have changed their owners due to illegal pressures or fraudulent administrative procedures, and now belong to straw men or have been sold to third parties.

According with Ministry of Agriculture there are several kinds of dispossess that have been identified in the country: Forced transfer of the ownership, fake sales, administrative caducity, forced displacement of the owner, and force displacement of occupants and landholders.

This situation has been facilitated by a high informality in the land tenure in Colombia. This is result of both a slow action from the government to allocate uncultivated land to settlers and generalized practice of no registering property documents in The Register of Public Instruments, in order to shun administrative costs or simply because of the discrete role of paper and bureaucracy culture among rural areas.

Just 18% of total displaced population is officially recognized as a formal owner of the abandoned land. The rest of them do not have a legal ownership, so are catalogued as occupants or landholders. With this background, it turns to be quite complex to advocate for reallocation of land or relocation of population if legal documentation is not in order.

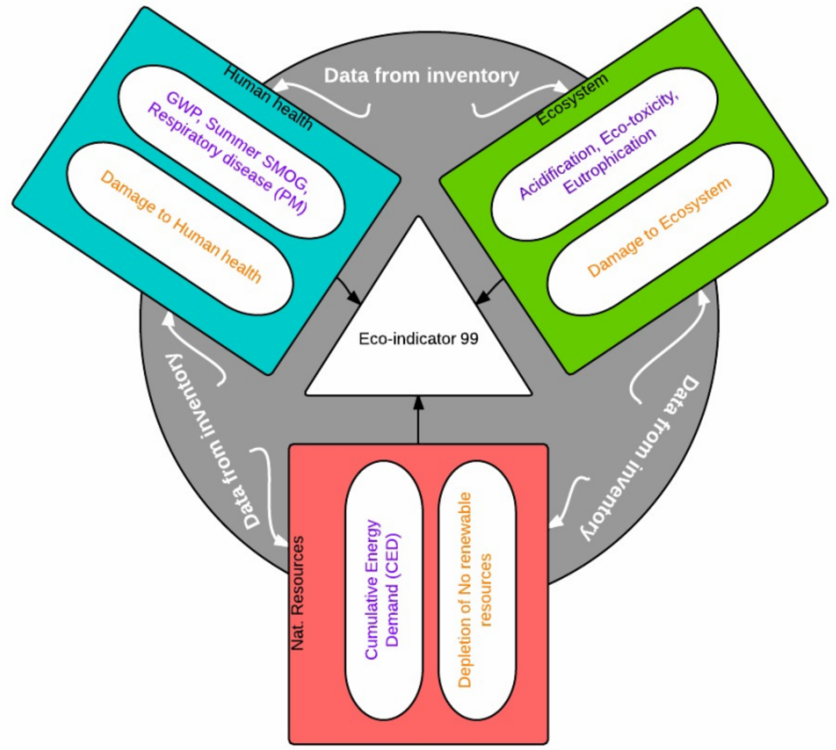
“We are small farmers without land and we see how common savannas that we worked in are fenced off and packed with palm oil and livestock. These lands that allegedly could not be entitled to farmers and fishermen, were now allocated to palm oil producers”.

Macro-projects have influenced the loss of collective territories, according to Colombian General Lawyer's Office report, and argue that indigenous people have loss territory because of natural resources exploitation projects that have been implemented without consultation. This institution also reports that illegal armed groups threaten, intimidate, murder and displace managers, leaders and other members of small communal councils and indigenous reservations who oppose illegal crops (coca, poppy and marihuana) or development projects in collective territories.

Appendix 4

Endpoint and midpoint indicators

In order to assess the impact of a particular product on the environment, some midpoint indicators are quantified; i.e. eutrophication, acidification, summer smog and eco-toxicity. Later on these categories are related to endpoint-oriented, such as Human health, Ecosystem and Natural Resources.



Note: Purple font corresponds to midpoint indicators and orange font to endpoint indicators

Regarding ISO 14040, LCIA (Life cycle impact assessment) is developed though two mandatory steps (classification and characterization) and two optional steps (normalization and weighting). In a first step were selected those indicators that are relevant for this study. Category selection must reflect a set of environmental aspects related with the studied production system, taking into account target and scope. Impacts created by biofuels are not limited to potential global warming effects, but also include impact on the ecosystems, on humans and on resources (Searchinger et al., 2008). For this particular study were selected those indicators (endpoint and midpoint) more employed by the scientific community (See figure above).

Classification results as an exercise of evaluating the contribution of every substance to each environmental problem. Afterwards, through a **characterization** mechanism emission impacts are modelled. Cause-effect mechanism is based on models of destination, exposure and effect. Impact is expressed as an assessment of impact in a common unit to all the contributors to the impact category (e.g. kgCO2 equivalent per GHG that contributes to CC category) through the implementation of characterization factors. A characterisation factor is a specific factor of a substance calculated with a characterization model to express the impact of the elemental flow (expressed in terms of the common unit mentioned above).

As alternative, different characterized impact assessments are related to a common reference in a process of **normalisation**. For instance the common reference can be the impacts caused by a person during a year, and this would ease the comparison between categories. A

weighting of these environmental impact categories is applied, unveiling the importance of those impacts considered within the study.

In this document were used the following midpoint categories, given their international acceptance and wide implementation: (CML (Centre of environmental Science)(Guinée, 2001), Eco-indicator 99 (Goedkoop & Spriensma, 2007),CED (Cumulative Energy Demand) (Hischier et al., 2010)).

Methodology for Impact assessment CML

Explanation for those categories used in this section is found in this link *http://media.leidenuniv.nl/legacy/new-dutch-lca-guide-part-2a.pdf* *(section 4.3.3.2 pg 57).*

Characterisation values are listed in *http://media.leidenuniv.nl/legacy/new-dutch-lca-guide-part-2b.pdf* *(section 4.3.1 pg 51)*

Indicator	Abreviation	Units	Comments	Reference
Eutrophication	EUTRO	kg PO4 eq	It includes all impacts due to excesive levels of macronutrients within the environment caused by emission of nutrients to the air, water and soil	CML
Acidification	ACID	kg SO4 eq	It includes a great deal of impacts in soil, aboveground and underground water, ecosystems and materials	CML
Eco-toxicity	ETOX	PAF m2yr	Potentially affected fraction (PAF). It is assessed based on toxicity data of terrestrial and water organisms (it covers microorganisms, plants, algae, amphibians, worms, mollusc, crustacean and fish)	EI99
Photochemical Oxidation	SMOG	kg C2H4 eq	Formation of reactive substances (particularly ozone), which turn to be hazardous to human health, environment and crops.	CML
Respiratory diseases	MP	DALY (disability adjusted life years)	Inclusion of PM10,PM22, PST, NOx, CO, VOCs and Sox	EI99

Midpoint indicators were calculated by use of models relatively robust, hence there is less uncertainty in comparison to endpoint methods. In contrast, endpoint indicators draw the relative importance of extraction and emission from LCA inventory and that sort of information is easy to process by decision-makers.

Methodology for Impact assessment Eco-indicator 99

All the explanation regarding classification of impact categories (midpoint)in terms of effect on human health, ecosystems and resources and its corresponding normalisation and weighting until a final point (Environmental impact point) are located in http://www.pre.nl/content/reports.

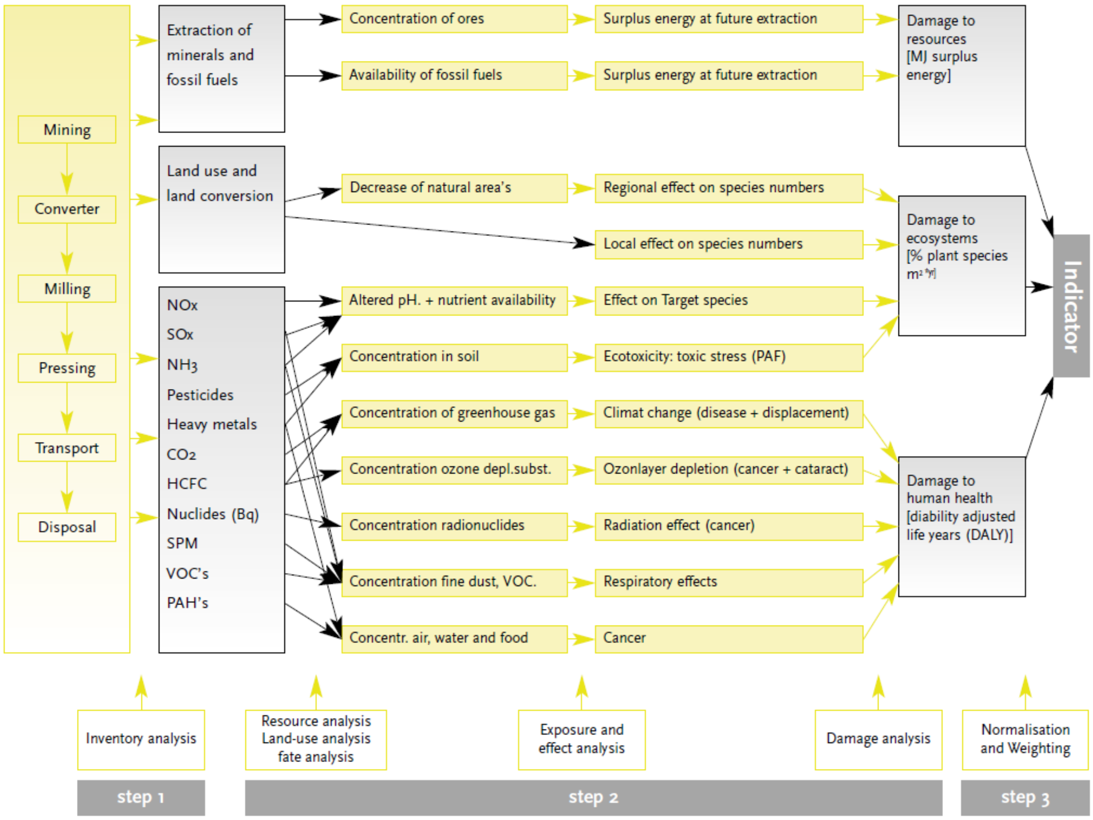
The goal of the Eco-indicator 99 is to provide a holistic evaluation of the impact on the environment based on a broken down perspective. Thus, the starting point was to define "environment". This was carried out with a panel of European scholars, experts in LCA, where there were identified three protection areas (Human health, ecosystem and natural resources); which are described as follows:

Human health: this category includes the number and duration of diseases and losses of labour days due to premature death due to environmental issues. The damage to human health is expressed in DALY (disability adjusted life years) and the effects that are taken into account are: CC, ozone layer depletion, carcinogenic effects, respiratory effects and ionizing radiation.

Ecosystem quality: under this category is covered diversity of species, particular vascular plants and inferior organisms. Deterioration of the ecosystem quality is expressed as a percentage of disappeared species in a particular area due to the environmental burden and the effects of eco-toxicity, acidification, eutrophication and land use.

Natural resources: this category contemplates the excess of required energy in the future in orter to achieve minerals and fossil fuels of a minor quality. Damage is assessed as the extra energy required for future extractions. Depletion of agricultural resources and bushels of sand and gravel are included in land use.

The figure below presents an explanation of the damage model



Source: (Ministry of Housing & environment, 2000)

As it is indicated in the figure above, these three protection areas can be weighted among them to obtain a single added score. Weighting factors employed in the Eco-indicator 99 come from a panel of experts in LCA. There are some other endpoint methodologies (such as EPS 2000, and ecological scarcity), nevertheless; eco-indicator 99 is widely accepted between scholars internationally. Result indicate that members of the panel found that the damage on human health is as important as the one caused to the ecosystem, whereas damage of natural resources possess a an mid level importance.

Weighting of protection areas depend on personal preferences and therefore it is not representative. Furthermore, mechanisms to assess - damage are adapted to European environmental conditions and might not be suitable for Colombian conditions. Nonetheless, the advantage in the Eco-indicator is that all results are summarized in one single score, which eases decision-making process. Therefore, the implementation of the Eco-indicator 99 with several midpoint indicators is fully justified if results are discussed and analysed properly. LCA calculations were carried out with Simapro v7.2 (PRé Consultant, 2010).

Limitations of the study

Assessment of environmental impacts in the life cycle usually requires of a great deal of information and assumptions in the model. Through real data collection in field for every stage of the life cycle and based on the state of the art in the emission models was tried to achieve maximum precision in the numbers.

Notwithstanding, this methodological approach has limitations, given that there is no LCA adapted for the Colombian conditions. By default in this exercise were used the indicator standardized for the European case and it is expected to implement adjustments in future research endeavours, given that current results of total environmental impact might be indicative but need to be analysed critically.

Results of endpoint and midpoint indicators are presented for fossil fuels, sugarcane-based ethanol and palm oil-based biodiesel:

Fossil fuels

Midpoint indicators

The figure below shows environmental impacts for a standard vehicle for Colombia and California. In general the LCA indicates a higher impact in the Californian case, given that usually the life span of these vehicles in Colombia is longer, creating a lesser effect on the infrastructure aspect (grey bar).

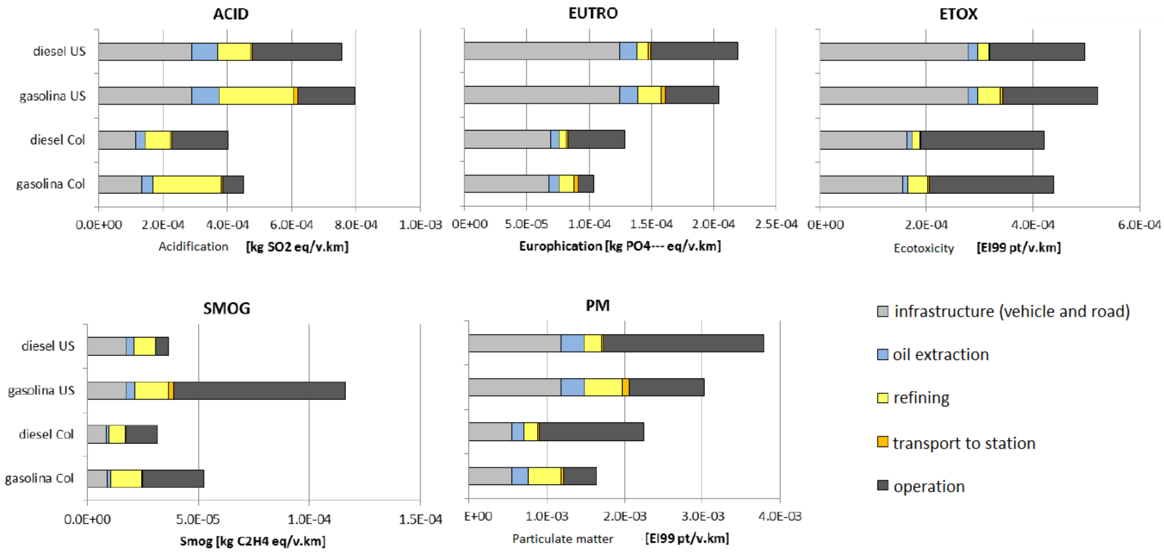


Figure: Comparison between standard vehicles (California vs Colombia)

If gasoline and diesel are employed in a similar vehicle, impacts do not differ significantly, except for PM and SMOG. In general, vehicles that are powered with diesel create a higher amount of emissions that those powered with gasoline, due to an incomplete combustion. SMOG results are due mainly to carbon monoxide. Given those uncertainties in the Eco-invent inventory for international data, impact of diesel in the American case seem to be underestimated. In the case of Colombia, data have been verified and adapted for this study and results are reliable.

Aggregated environmental impact

Total environmental impact (assessed with the eco indicator 99) is larger (per driven km) in US than in Colombia (145% for diesel and 130% for gasoline). As it was previously discussed an explanation is the lifespan of the vehicles and that fuel consumption and emission flows are more favorable in the Colombian case[54] (in comparison with the international fleet).

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[54] Renault Logan complies with the European emission standards EURO4.

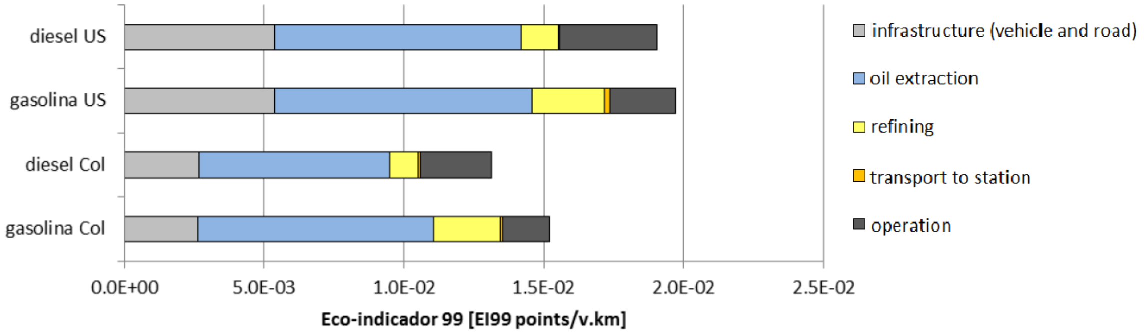


Figure: Total environmental impact. Comparison between vehicles in California and Colombia

As is it shown in the chart above, this higher environmental impact is due to extraction of crude oil by depletion of non-renewable resources. The higher impact on oil refining is related to a higher consumption og energy per MJ of fuel compared to diesel.

Results of sugarcane-based ethanol and palm oil biodiesel

Midpoint indicators

If GW is left aside, both Et-Oh and biodiesel exhibit a higher level of impact in comparison to its fossil counterparts, in terms of environmental indicators. Most of them take place in cultivation stage.

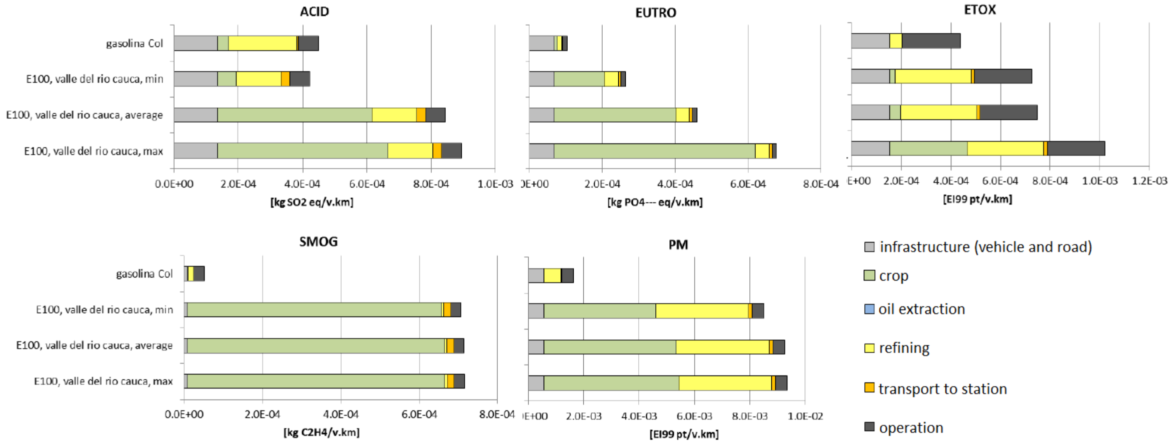


Figure: Environmental impacts for ethanol

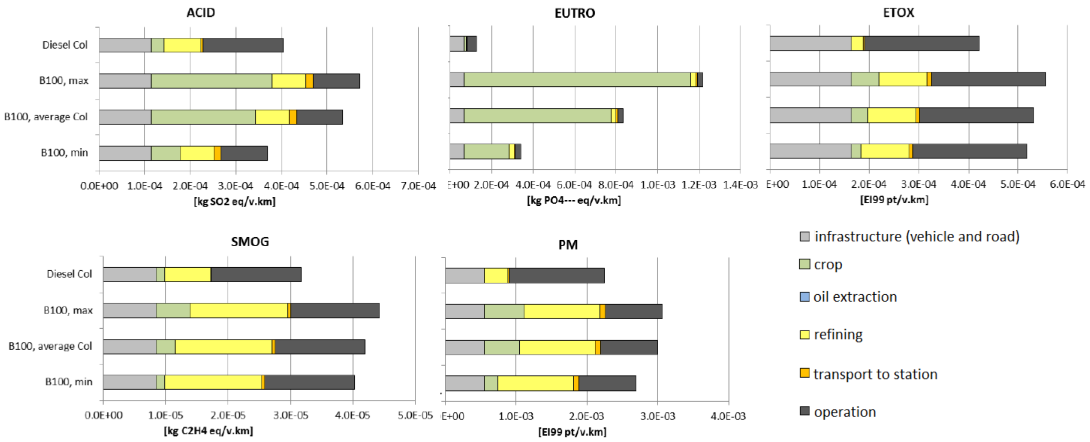


Figure: Environmental impacts for biodiesel

Impact in acidification and eutrophication is caused mainly by emission in the crop by use of fertilizers (ammonia and phosphates). Eco-toxicity is due to heavy metals employed in fertilizers, burnt fuel and tires' wearing (mainly zinc), causing soil and atmospheric pollution.

Summer smog and respiratory diseases can be caused by a frequent practice in sugarcane cultivation which is the pre-harvesting burning process (in the case of palm oil this phenomenon come from the production and use stages). For ET-OH there is no consensus on the net effect of such practice on human health: while some studies show indicate that there is no significant effect on the local population (Jose Goldemberg, 2007), whereas some other studies unveil negative effects on children and elderly people, due to respiratory diseases (Nicolella & Belluzzo, 2011). Within this study the PM effect due to pre-harvesting burning task is assumed in low density areas in terms of population. In ethanol production stage is possible to assume that the biggest impact is given by PM and NOx due to bagasse combustion (for ethanol) and cogeneration (for biodiesel).

Environmental aggregated impact

As it is observed in the figures below, the impact of ethanol and biodiesel (in environmental terms) is higher than fossil fuel (141% and 143% correspondingly). Cultivation stage is the major contributor to global environmental impact and it is caused by impact on human health (caused by PM in the pre-harvesting burning) (35% of the Eco-indicator). In addition some land does not allow natural vegetation regeneration, contributing to 50% and 70% to the global impact (for ethanol and biodiesel respectively).

For biodiesel, the remaining impact is created by heavy metal emissions (close to 10 to 20%) and fertilizers production (approx. 10%).

For ethanol the main environmental burden can be explained by NOx and PM emissions by bagasse combustion. In the case of biodiesel fiber and shells combustion is the cause of the aforementioned.

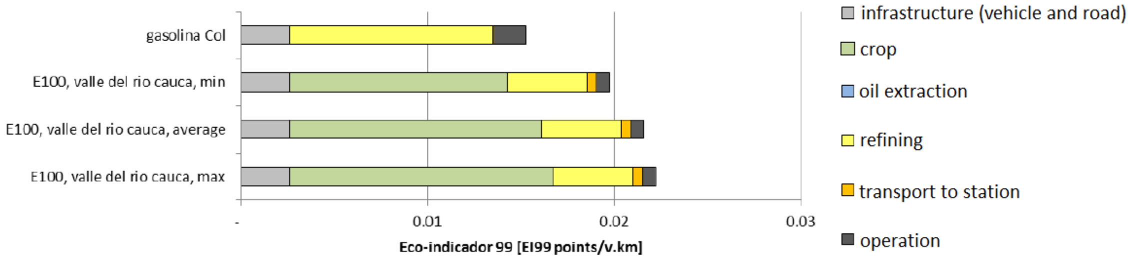


Figure: Total environmental impact (Eco-indicator 99) for sugarcane-based ethanol

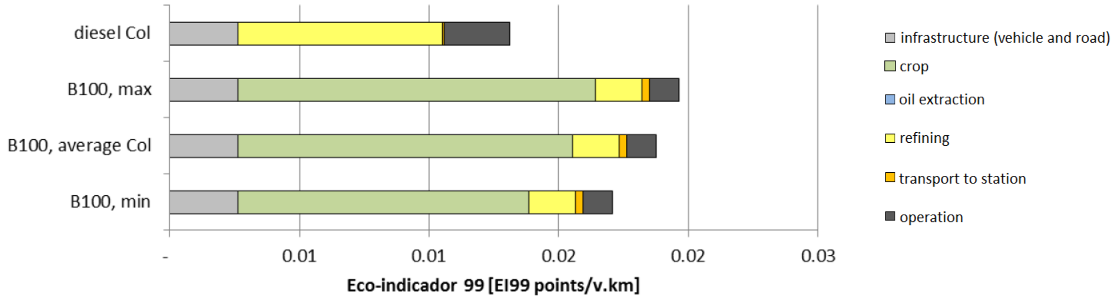


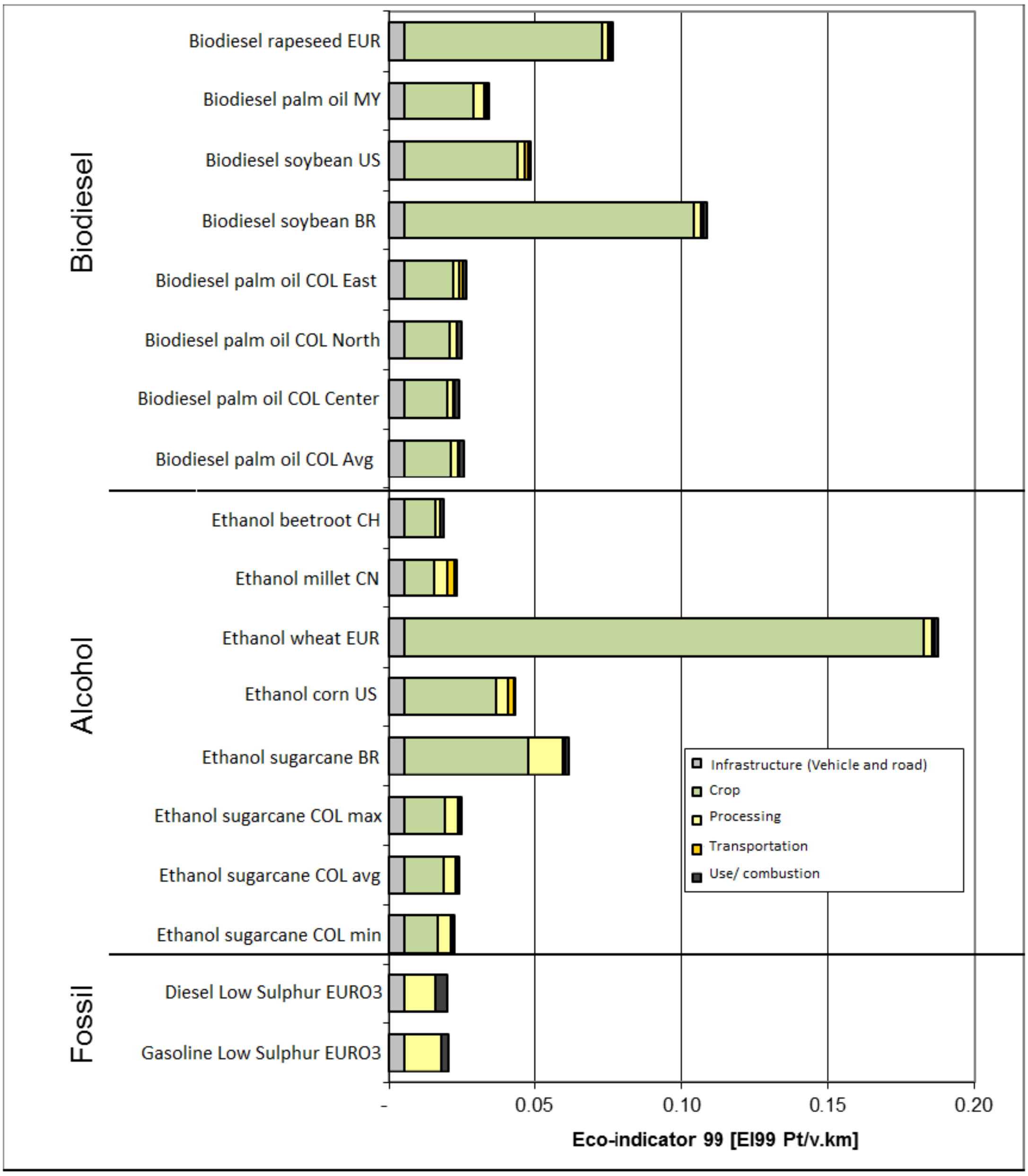
Figure: Total environmental impact (Eco-indicator 99) for palm oil-based biodiesel

Impact values

Values for the information presented formerly for both bioethanol and biodiesel indicators are related below:

Table: Midpoint and End point indicators for sugarcane-based ethanol and palm oil biodiesel

	Indicator	ACID	EUTRO	ETOX	SMOG	MP	EI99
Gasoline	Units	kg SO2eq/v.km	kg PO4-eq/v.km	PAF*m2yr/v.km	kg C2H4eq/v.km	DALY/v.km	EI99 points/v.km
	E100 Col, max	8.94E-04	6.79E-04	7.72E-01	7.16E-04	3.55E-08	2.22E-02
	E100 Col, avr	8.44E-04	4.59E-04	3.20E-01	7.15E-04	1.42E-08	2.15E-02
	E100 Col, min	4.22E-04	2.63E-04	2.18E-01	7.07E-04	1.16E-08	1.97E-02
	Gasoline	4.49E-04	1.04E-04	1.44E-01	5.25E-05	8.06E-09	1.52E-02
Diesel	Indicator	ACID	EUTRO	ETOX	SMOG	MP	EI99
	Units	kg SO2eq/v.km	kg PO4-eq/v.km	PAF*m2yr/v.km	kg C2H4eq/v.km	DALY/v.km	EI99 points/v.km
	B100 min	3.69E-04	3.41E-04	7.47E-02	4.02E-05	9.16E-09	1.71E-02
	B100 avg	5.35E-04	8.34E-04	1.46E-01	4.19E-05	1.09E-08	1.88E-02
	B100 max	5.72E-04	1.22E-03	2.00E-01	4.43E-05	1.12E-08	1.96E-02
	Diesel Col	4.04E-04	1.29E-04	1.42E-01	3.17E-05	8.27E-09	1.31E-02



While the Colombian vehicles were adapted to the EcoInvent inventory standard vehicle, the other biofuels were taken from Zah et.al. (Zah et al., 2007).

The main goal of a LCA is providing an assessment of the environmental impact of the more important biofuels within the Colombian context (sugarcane ethanol and palm oil biodiesel). Likewise is very important to build a comparison in reference to traditional fossil fuels (gasoline and diesel). The average environmental impact was compared to international sustainability standards, which provide a first approach on the potential of the Colombian biofuels as a good for international trade. In addition, critical and sensitive factors which take part in the environmental performance are defined and assessed in order to create plans of action and improvement.

Average environmental impact assessment of Colombian biofuels is based on data from those fields where the feedstock is produced. Data was contrasted and complemented by experts and literature review, and the EcoInvent database.

Sugarcane-based ethanol

What is the total environmental impact for the Colombian sugarcane-based ethanol?

The aggregated environmental impact of bioethanol- assessed with the Ecoindicator 99 – is slightly higher than regular fossil gasoline (141%). Cultivation stage is the major contributor to the total environmental impact and it is mainly caused by the effect on the human health due to emission of particulate matter released by the pre-harvesting burning process (35% of the Ecoindicator 99), and the land use that avoid regeneration of natural species. In comparison with some other biofuel from elsewhere around the world, Colombian biofuels exhibit attractive performance and they are considerably favorable.

Nonetheless, it is important to remark that this indicator was built based on European conditions and the assessment has not been adapted for the Colombian conditions. Thus, this study could work as a comparative reference, but requires a proper fine tuning This could be the start of future research that establish adapted inventories

What is the scope of impact of Colombian ethanol?

Biofuels exhibit some other environmental impacts, which are not shared by traditional energies, as contrarily occurs with GHG's and Non-renewable energy cumulative demand. Extraction of crude oil and further refining are relatively simple and create less impacts regarding eutrophication, acidification in comparison to biofuels.

These impacts of biofuels occur mainly in the cultivation stage, due to the need of large extensions of land and several production factors such as machinery and fertilization. Fertilizer production is energy intensive and the crop itself is accompanied by several emissions (ammonia, nitrates, phosphates, heavy metals), therefore quality of land, air and water are affected (acidification, eutrophication and eco-toxicity). Additionally, the pre-harvesting burning has a significant impact on the air quality and it might affect the quality of the environment as a whole and of course human health (by smog and particulate matter). Is not conclusive the effect on human health on the nearby population: whereas some authors argue that there is no evidence of harm on the locals (Jose Goldemberg, 2007), some other authors disagree and explain that such practice affects in major extent to elderly people and children due to respiratory diseases (Nicolella & Belluzzo, 2011).

However, these environmental impacts depend highly on the sensibility of the environment and therefore they have a local scope. As there is no impact assessment methodology created specifically for the Colombian case, European models were employed.

Biodiesel

What is the environmental impact of Colombian palm oil based biodiesel?

The aggregated environmental impact of Colombian palm oil-based biodiesel –assessed with the EcoIdicator 99- is higher that is fossil equivalent (by 143%). As in the case of ethanol the cultivation stage, of palm oil-based biodiesel is the major contributor to total environmental impact and it is caused by land occupation, which avoids regeneration of natural vegetation (approximately 70% of the impact) and fertilization (approximately 20% of the impact).

As it was mentioned before, the indicator is based on the European environment and the impact assessment has not been adapted to Colombian conditions.

Values are related to reference fossil fuels (which has been valued as 100%). Green area means lesser emissions of GHG and minor impact and minor environmental impact in comparison to gasoline (Biofuels adapted to Ecoinvent standard vehicle, other type of biofuels brought from Zah et al 2007).

What is the scope of impact of Colombian biodiesel?

Some other environmental indicators, in addition to GHG emissions and Non-renewable energy cumulative demand, were taken into account, and they showed that biofuels have higher impacts than regular fossil fuels. Production of fertilizers is particularly energy intensive and the emissions that come from the crop (such as ammonia, nitrates, and heavy metals) disturb the quality of air, water and soil (impacts on acidification, eutrophication and eco-toxicity). Summer smog is mainly caused by emissions from biofuels within processing and using stages (COx and SOx). The main impact that emerges from biofuel production regarding PM is associated with NOx from the cogeneration process.

As it was mentioned, these impacts hinge on the sensibility of the environment and therefore they are a reflection of a local phenomenon. As there is no specific methodological approach to assess environmental impact and neither designed for the Colombian conditions, this study is supported on European models. Indicators such as GWP and CED can be used, but some other indicators must be interpreted with caution.

Final conclusions

In addition to GHG and Nonrenewable energy cumulative demand, some other environmental indicators are considered. Based on this information it can be established that biofuels have some impacts that are not present in regular fossil fuels. Impacts on acidification, eutrophication and eco-toxicity are caused mainly by use of fertilizers and pesticides. These negative impacts can be mitigated through the implementation of good agricultural practices and the use of alternative treatments, such as, organic controls of insect and pests. In such sense agricultural research and land management result crucial to achieve better results regarding environmental performance. Cenicaña and Cenipalma, along with the Ministry of Agriculture, have an important role to play within the Colombian context.

Results of the ecoindicator 99 show the midpoint assessment, indicating that biofuels in general create a higher environmental stress in comparison to regular fossil fuels. Even though, the midpoint methodology is not adapted to Colombian conditions, it is important to analyze beyond GWP and Cumulative Energy Demand, and look to other environmental aspects.

Appendix 5

Wastes on land (sugarcane)

Deposits of heavy metals are calculated as the balance between the input of heavy metals due to fertilization and output due to dirt remotion (Jungbluth et al., 2007). The emission by account of pesticides is presented as follows:

Table 95 Residuals to the ground by pesticides and fertilizer application

Residuals to the ground by pesticides and fertilizer application (kg / kg of sugarcane)								
Parameter	**C001**	**C002**	**C003**	**C004**	**C005**	**C006**	**C007**	**Average**
Cd	-2,30E-10	2,00E-10	-3,40E-10	-3,50E-10	-3,60E-10	3,60E-09	7,30E-09	1,10E-09

Cu	1,70E-08	3,60E-07	6,40E-09	6,20E-09	4,30E-09	1,60E-06	2,30E-06	5,10E-07
Zn	1,60E-07	2,30E-06	8,30E-08	7,50E-08	6,80E-08	9,60E-06	1,20E-05	3,00E-06
Pd	3,70E-09	7,30E-09	4,00E-09	9,10E-10	3,60E-09	5,40E-08	1,20E-07	2,30E-08
Ni	1,30E-08	2,90E-08	6,70E-09	6,30E-09	6,00E-09	1,40E-07	3,20E-07	6,40E-08
Cr	8,90E-09	2,00E-08	4,10E-09	3,80E-09	3,40E-09	1,20E-07	8,40E-06	8,10E-07
Hg	3,40E-18	2,50E-09	0,00E+00	0,00E+00	0,00E+00	1,30E-08	1,60E-08	3,90E-09
Glyphosate	0,00E+00	2,60E-08	2,70E-08	3,50E-08	2,90E-08	6,00E-08	8,90E-08	8,90E-08
Sulphur	0,00E+00	1,60E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Roundup	0,00E+00	0,00E+00	0,00E+00	1,10E-07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Ametryn	4,90E-08	4,90E-08	2,70E-08	3,20E-08	2,70E-08	0,00E+00	0,00E+00	0,00E+00
Diuron	1,20E-07	0,00E+00	3,00E-06	1,70E-07	3,00E-06	1,50E-10	1,80E-10	1,80E-10
Terbutryn	5,10E-06	6,20E-06	5,40E-06	6,40E-06	5,40E-06	0,00E+00	0,00E+00	0,00E+00
2,4-D	5,10E-09	4,30E-09	3,70E-09	4,40E-09	3,70E-09	5,50E-09	6,70E-09	6,70E-09
Sodium hypochlorite	0,00E+00	1,50E-06	0,00E+00	0,00E+00	0,00E+00	2,10E-06	2,50E-06	2,50E-06
Atrazine	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,80E-07	2,30E-07	2,30E-07
Hydrocarbons, aliphatic, chlorinated alkanes	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,30E-07	2,80E-07	2,80E-07
Fluazifop	0,00E+00	0,00E+00	4,60E-08	6,00E-08	5,00E-08	0,00E+00	0,00E+00	0,00E+00

Source: CUE based on emission models

Appendix 6

Description of the stages in the sugar production process in the sugar mill (ingenio)	
Process	**Description**
Receipt and preparation of sugarcane	Arriving sugarcane is weighted and led to the loading place, where cranes put it into wagons or baskets, to be further directed to the preparation zone
Preparation and milling	Sugarcane is led by a system of conveyor belts to the cutters and fiber-breaking machines. This equipment works by the power of steam turbines or electricity, and it have high-speed spinning knives, and under them it is a layer of sugarcane, which is fractioned in order to ease juice extraction. Prepared sugarcane arrives to the milling tandem, which is formed by 6 crushers of 3 or 4 weights each. Such weights are metal rollers and the sugarcane layer passes through them, and by use of pressure juice is extracted. These crushers can be driven by steam turbines or electricity. Water is added to sugarcane along the way, hence sucrose is extracted from the fibers.

Steam generation	Resulting bagasse, which comes from the last milling section is fed to the boilers and it is used as fuel for creating high-pressure steam. This steam is employed in the turbines and in the preparation equipment, as well as in the turbo-generators used for electricity generation to feed the processing facilities (surplus is sold to public energy grid). Exhaust steam is employed in evaporation and juice heating processes.
Heating and juice clarification	The juice extracted from mills is weighted on scales. Subsequently it is sulphatized, and lime is added, in order to put contaminants away, and it is heated with vegetable steam in interchangers up to 102-105° C. Once the juice is alkalized it goes through a tank where some gases (non-condensable) are released. Afterwards juice is fed to clarificators, where insoluble solids are separated from the juice, in a decanting process, with a mud-like substance as the output product.
Filtration	Muds go through a sucrose recovery process by way of filtration. Resulting juice is returned to the process and it is mixed with the juice that comes directly from the mill.
Evaporation	Clarified juice is received in the evaporators, with a content of solids (15° degrees brix), it is concentrated up to 60°-70° brix. This concentrated juice is called "meladura" (honey-like kind of substance). Evaporation station has between 4 and 6 stages where juice is reduced to sucrose content as the process progresses. This substance goes through a "meladura" clarification process as well.
Crystallization and centrifugation	The sucrose embedded in the meladura is crystallized, and it is oversaturated, by effect of the evaporation process. Resulting material has a liquid part (honey) and a solid part (sugar crystals) called "cooked mass". Crystals are separated from honey by centrifuges. During the centrifugation process, sugar is washed with hot water or steam to remove the honey layer that covers these crystals and afterwards honey is taken to dryers. This process is applied three times and only then an exhausted honey is obtained (called "Honey C" or "Miel C"), which is used for animal fodder. In those sugar mills associated with ethanol processing plants, only two crystallizations take place and the by-product (Honey B or Miel B) is sent to the distillery as raw material for alcohol fuel production.
Drying	During the drying process the excess of moisture is taken away by way of hot air, with the purpose of complying with international quality standards. Right after, sugar is packed.
Sugar refinery	Refined sugar manufacture requires raw sugar to feed the process. Raw sugar is dissolved in water, making a syrup-like substance, which is filtered in DSM sieves in order to take away insoluble residuals. Later on, it goes through a clarification process, and afterwards it undergoes a de-coloration by using active carbon. Clarified and discolored syrup goes through crystallization, centrifugation and drying process, obtaining refined sugar
Transportation from the sugar mill to ethanol production plant	Transportation of the honey B is carried out by use of pipelines between the sugar mill and the ethanol distillery facilities.

Source: Cenicaña website

Appendix 7

Transportation distances per every 100 tons of sugarcane

Item	Transport by truck > 28 t (km)	Quantity (tons per 100 of sugarcane
Sugarcane	23,27	100
Lime	493,7	0,08
Flocculant	33,3	0
Sulfuric acid	184,7	-
Sulphur	448,3	0,01
Water	0	57,55
NaOH, Sodium hydroxide	30	0,02
Biocides	620	0
Surfactant	620	0
Charcoal	24	1,4
Total	2405.6 ton - km	

Source: CUE based on data field

Appendix 8

Emissions per 1 kg of bagasse combustion and per every 100 tons of sugarcane (kg unless indicated otherwise)

Substance	Quantity per 100 ton	Quantity per kg of bagasse
Residual heat (MJ)	1,00E+06	5,80E+00
Carbon dioxide	1,20E+05	7,10E-01
Nitrogen oxide	4,90E+03	2,00E-04
Particles, < 25 µm	2,50E+03	1,00E-04
Biogenic carbon monoxide	3,90E+02	1,60E-05
Biogenic methane	2,40E+01	1,80E-07
NMVOC, different methane compounds of volatile organic, no specified origin	3,40E+01	1,40E-06
Sulphur dioxide	1,40E+02	5,60E-06
Monoxide of di-nitrogen	1,30E+02	5,20E-06
Acetaldehyde	3,40E+00	1,40E-07
Aliphatic hydrocarbons to alkanes, unspecified	5,10E+01	2,10E-06
Aliphatic hydrocarbons, unsaturated	1,70E+02	7,00E-06
Arsenic	5,60E-02	2,30E-09
Benzo(a)pyrene	2,80E-02	1,10E-09
Benzene	5,10E+01	2,10E-06
Br	3,30E+00	1,40E-07
Ca	3,30E+02	1,30E-05
Cd	3,90E-02	1,60E-09
Cl	1,00E+01	4,10E-07

Cr	2,20E-01	8,90E-09
Cr VI	2,20E-03	9,00E-11
Cu	1,20E+00	5,00E-08
Dioxins, assessed as 3, 7, 8 tetrachlorodibenzodioxin-p-dioxin	1,70E-06	7,00E-14
Ethyl benzene	1,70E+00	6,80E-08
F	2,80E+00	1,10E-07
Formaldehyde	7,20E+00	2,90E-07
Hexachlorobenzene	4,00E-07	1,60E-14
Hg	1,70E-02	6,80E-10
K	1,30E+03	5,30E-05
Mg	2,00E+01	8,10E-07
Mn	9,50E+00	3,90E-07
Na	7,20E+01	2,90E-06
Ammonium	9,70E+01	3,90E-06
Ni	3,30E-01	1,40E-08
P	1,70E+01	6,80E-07
Polycyclic aromatic hydrocarbon	6,10E-01	2,50E-08
Pb	1,40E+00	5,60E-08
Pentachlorophenol	4,50E-04	1,80E-11
Toluene	1,70E+01	6,80E-07
m-xileno	6,70E+00	2,70E-07
Zinc	1,70E+01	6,80E-07

Source: Cue based on data field

Appendix 9

Description of the ethanol manufacture process	
Process	**Description**
Raw materials	Raw materials for alcohol manufacture are clarified juice, honey B or "miel B" and "melaza", and they all come from the sugar refinery
Fermentation	Fermentation for producing sugarcane-based ethanol is a microbiologic process, in which the sugar embedded in the raw materials are turned, by way of yeast application, into ethanol and carbonic gas (CO2). Fermented "must" or wine that comes from the final fermentation equipment is taken to a sedimentation tank where yeast decants, goes out from the bottom and goes to the yeast activation tank, whereas the liquid known as wine is sent to distillation process.

Distillation	This type of wine has alcohol diluted in water and some other impurities that must be separated from the alcohol through distillation process. This process takes advantage of the boiling temperature of ethanol that is below the boiling temperature of water, hence those vapors of alcohol leave from the upper part of the must column, whereas the lower part releases vinasses, which is residual made out water and some contaminants. Those vapors, in the first column, contain near to 45% alcohol and they are sent to a rectification column, to get 95% alcohol in the upper part. In the lower part is left a residual called "flemaza", which has some alcohol traces.
Dehydration	Ratified alcohol in distillation has 95% v/v ethanol and 5% v/v water. It is necessary to reduce the amount of water from this mix in order to be used as fuel, therefore a molecular sieve is used and through a synthetic resin retains water contained in the rectified alcohol, up to a concentration of 99.5% and a minimum quantity of water, reaching established standards of alcohol fuel.
Vinasse concentration	One fraction of vinasse that goes out from the must column is reused in the fermenting process and the rest is led to flubex evaporators, in which water is taken away in form of steam in order to concentrate vinasse, reduce the amount of it and ease further treatment.
Storage and delivery	Finally the product is sent to storage area, which is permitted to keep 20 days of production to cover market demand.
Compost	Industrial-size compost plant transform organic residuals created in the sugar and ethanol production processes, such as cachaza, ashes, agricultural wastes, concentrated vinasse. These residuals are turned into a stable and hygienic product that can be applied in agricultural practices as organic fertilizer and soil booster.}
Water treatment	Residual water treatment plant (RWTP) receives all flemazas and some other residuals (condensed) of vinasse concentration.

Cenicaña website

Appendix 10

Water treatment mass balance

In the next 2 tables are presented the flow of residual water and its composition. Water flow was analyzed from the location object understudy, whereas data of composition were found in the literature (Hampannavar & Shivayogimath, 2010).

Entry of residual waters and the production of 100 tons of sugarcane (ton/100 tons of sugarcane)	
Substance	Quantity
Input	

Flemazas	7,32E+00
Condensed	6,88E+00
Total	1,42E+01
Output	
Treated water	1,27E+01
Mud	2,10E+00

Source: CUE based on data field

The total flow of muds within the pools system (250 m^3/h) was close to 11% of the water input (Dilek, Yetis, & Gökçay, 2003).

Composition of residual water and treated residual water per m^3 (kg/m^3)				
Substance	**Input**	**Output**	**Removal**	**Standard**
Chemical oxygen demand (COD) as O2	2,5	0,4844	81%	0,25
Biochemical oxygen demand (COD) as O2	0,75	0,07111	91%	0,05
Dissolved organic carbon (DOC) as C	0,0458	0,0075	84%	
Total organic carbon (TOC) as C	0,0673	0,0073	89%	
N	0,0275	0,0203	26%	0,01
P	0,0019	0,0007	63%	0,002

Source: CUE

This process is based on the description of the process reported in Ecoinvent registered as “treatment, residual waters, treatment of residual waters, class 2/m^3/CH” and the methane emissions were adapted as a function to the composition of input and output material.

Methane is captured in an anaerobic reactor and is burnt. Nonetheless, it assumed a loss of 15% of methane. CH4 emissions were calculated using the factor suggested by IPCC

Methane emissions during residual water treatment		
Parameter	**Quantity**	**Unit**
Removed COD	2,86E+01	kg/100 tons of sugarcane
Methane	6,01E+00	kg CH_4/100 tons of sugarcane
Released CH_4	9,02E-01	kg/100 tons of sugarcane

Source: CUE based on data field

Appendix 11

Mass Balance for compost stage

Below it is shown the material input for compost for "average" and "optimized" scenarios per every 100 tons of sugarcane.

Material inputs for compost per every 100 tons of sugarcane (tons)		
Input	**Average**	**Optimized**
Ashes form the boiler	1,6	0,25
Dust from sugarcane residual	0,13	0,13
Sugarcane leaves	0,58	0,58
Muds (RWTP)	2,1	2,1
Mud filtered	4,17	4,17
Vinasse 35%	2,36	2,36
Vinasse 55%	0,24	0,24

Source: CUE from data field

The next 2 tables display mass balances for compost material. Composition data from different input material were taken from the literature, while compost composition was calculated based on the principles of mass balance.

Mass and compost balance for every 100 tons of sugarcane (average scenario)										
Substance	**This study**	**Humidity**	**Quantity**	**Water**	**Organic material**	**C**	**N**	**P2O5**	**K2O**	**C/N**
	Ton/100 ton of sugarcane	%	ton (dry weight)	ton	%	%	%	%	%	-
Input										
Ashes form the boiler	1,6	5	1,52	0,08	-	-	-	0,87	1,67	-
Dust from sugarcane residual	0,13	50	0,07	0,07	74	41	0,15	0,12	-	273,33
Sugarcane leaves	0,58	50	0,29	0,29	74	41	0,15	0,12	-	273,33
Muds (RWTP)	2,1	63	0,78	1,32	-	31,6	4,17	10,34	-	7,58

Foam and impurity on top of sugarcane juice (cachaza)	4,17	80	0,83	3,33	80	44,4	1,5	1,8	0,3	29,60
Vinasse 35%	2,36	65	0,83	1,53	86,85	52,2	0,58	0,07	5,52	90,00
Vinasse 55%	0,24	45	0,13	0,11	86,85	52,2	0,58	0,07	5,52	90,00
Total entry	11,18		4,45	6,73						
Output										
Compost	6,13	27,5	4,44	1,69	26,15	18,73	0,76	1,63	1,2	30,89
Evaporated water	5,05	100	-	5,05						
N2O	0,00041		0,00019				0			
CH4	0,00004		0,00004							

Emissions of N2O were calculated based on nitrogen inputs, employing a value of 1.222% (IPCC, 2006). Methane emissions are calculated based on the IPCC of 10 g of CH4 per kg of dry matter (IPCC, 2006).

Mass and compost balance for every 100 tons of sugarcane (optimized scenario)										
Substance	**This study**	**Humidity**	**Quantity**	**Water**	**Organic material**	**C**	**N**	**P2O5**	**K2O**	**C/N**
	Ton/100 ton of sugarcane	%	ton (dry weight)	ton	%	%	%	%	%	-
Input										
Ashes form the boiler	0,25	5	0,24	0,01	-	-	-	0,87	1,67	-
Dust from sugarcane residual	0,13	50	0,07	0,07	74	41	0,15	0,12	-	273,33
Sugarcane leaves	0,58	50	0,29	0,29	74	41	0,15	0,12	-	273,33
Muds (RWTP)	2,1	63	0,78	1,32	-	31,6	4,17	10,34	-	-
Foam and impurity on top of sugarcane juice (cachaza)	4,17	80	0,83	3,33	80	44,4	1,5	1,8	0,3	29,60
Vinasse 35%	2,36	65	0,83	1,53	86,85	52,2	0,58	0,07	5,52	90,00
Vinasse 55%	0,24	45	0,13	0,11	86,85	52,2	0,58	0,07	5,52	90,00
Total entry	9,83		3,17	6,66						

Output										
Compost	4,36	27,5	4,44	1,69	26,15	18,73	0,76	1,63	1,2	30,89
Evaporated water	5,47	100	-	5,47						
N2O	0,0003						0,0003			
CH4	0,00003		0,00003							

Appendix 12

Agrochemicals employed in different areas of the palm oil crop (kg/ kg FFB)										
Agrochemical	E001	E002	E003	N001	N002	N003	N004	C001	C002	C003
Glyphosate	4.40E-05	6.21E-05	1.98E-05	1.50E-04	2.10E-04	6.95E-07	3.75E-04	1.28E-04	1.32E-04	1.28E-04
Bipiridilium compounds	1.88E-05	1.71E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Urea compounds	1.27E-05	1.21E-05	3.35E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ethoxylates alcohols *	1.57E-05	2.21E-05	2.06E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Organophosphate compounds	5.88E-05	5.07E-05	0.00E+00	1.12E-05	1.57E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.13E-06
Acetamide compounds	6.08E-06	1.43E-06	3.08E-05	0.00E+00	0.00E+00	0.00E+00	1.40E-05	0.00E+00	0.00E+00	8.06E-06
Phthalimide compounds	0.00E+00	0.00E+00	0.00E+00	6.49E-07	9.09E-07	1.44E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pyrethroid compounds	0.00E+00	0.00E+00	0.00E+00	7.69E-08	1.08E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzimidazole compounds	0.00E+00	0.00E+00	0.00E+00	1.86E-05	2.60E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
N Cyclic compounds	0.00E+00	0.00E+00	0.00E+00	1.00E-06	1.40E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dithiocarbamate compounds	0.00E+00	0.00E+00	0.00E+00	1.35E-06	1.89E-06	0.00E+00	2.24E-04	0.00E+00	0.00E+00	0.00E+00
Triazine compounds	0.00E+00	0.00E+00	0.00E+00	1.14E-06	1.59E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thiocarbamate compounds	0.00E+00	0.00E+00	0.00E+00	4.98E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Herbicides	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.81E-05	0.00E+00	0.00E+00
Insecticide	5.58E-06	2.86E-06	0.00E+00	5.41E-08	7.57E-08	1.44E-04	0.00E+00	1.17E-04	1.85E-06	1.08E-05
Fungicide	0.00E+00	0.00E+00	0.00E+00	2.85E-07	3.99E-07	0.00E+00	0.00E+00	6.70E-05	0.00E+00	0.00E+00

* All agrochemicals can be accessed in a local shop but this one. Alcohol is obtained directly from the plant

Appendix 13

Description of the Palm oil process	
Process	**Description**
Loading	FFB are weighted and discharged from the trucks to the wagons of the palm FFB train
Sterilization	Sterilization is carried out with low pressure steam for about 90 minutes
Threshing	Fruits are separated from the bunch through a mechanical process. Those bunches, without fruits, are called "tusas" and they are transported by way of conveyors to trucks and after that they are taken back to the field for compost process.
Digestion and crushing	Digestion is the process employed to release the oil from the fruit by breaking those cells that contain the oil. Usually a digester is a cylinder, heated with steam, and attached to a shaker. This shaker hits fruits and makes oil extraction easier
Clarification and drying	Oil is clarified by gravity, using the difference of densities. Clarified density is stored in tanks. Oil is dried to reduce moisture, through heating in a system of tanks or via atmospheric drying.
Effluents treatment	The water contaminated with oil is a by-product of the clarification process. This water goes through centrifuges with the aim to recover the remaining oil. The rest of the liquid is treated in the Residual Water Treatment Plant (RWTP)
Fiber-breaking and meal extraction	The mix of nuts and fibers is separated. Nutshells are broken and kernel meal is taken aside. Kernel meal goes through the drying silo and it is crushed to extract oil. Palm kernel oil is sold and kernel cake meal is used as fodder. Fibers and shells are picked up and employed as fuel in the boiler.

Appendix 14

Air emissions as product of the combustion of 1 MJ of fiber, 1 MJ of shells per each 100 tons of FFB (kg unless indicated otherwise)			
Emission	**1 MJ of fiber**	**1 MJ of shell**	**100 tons of FFB**
Residual heat (MJ)	1	1	303.209
Carbon dioxide	0.24	0.15	62750
Nitrogen oxides	1.14E-04	1.50E-04	3.88E+01
Particulate matter	5.84E-05	7.68E-05	1.98E+01
Carbon monoxides	9.11E-06	1.20E-05	3.09E+00
Methane	5.65E-07	7.42E-07	1.91E-01
NMVOC, non-methane volatile organic compounds	7.94E-07	1.04E-06	2.69E-01
Sulphur dioxide	3.24E-06	4.26E-06	1.10E+00
Nitrogen monoxide	2.99E-06	3.93E-06	1.01E+00
Acetaldehyde	7.94E-08	1.04E-07	2.69E-02
Aliphatic compounds, alkane, unspecified	1.18E-06	1.56E-06	4.01E-01
Aliphatic compounds, unsaturated	4.03E-06	5.30E-06	1.37E+00

Arsenic	1.30E-09	1.71E-09	4.41E-04
Benzo[a]pyrene	6.50E-10	8.55E-10	2.20E-04
Benzene	1.18E-06	1.56E-06	4.01E-01
Brome	7.81E-08	1.03E-07	2.65E-02
Calcium	7.61E-06	1.00E-05	2.58E+00
Cadmium	9.11E-10	1.20E-09	3.09E-04
Chlorine	2.34E-07	3.08E-07	7.94E-02
Chromium	5.15E-09	6.77E-09	1.75E-03
Chromium VI	5.20E-11	6.84E-11	1.76E-05
Copper	2.86E-08	3.76E-08	9.70E-03
(Dioxins) 2,3,7,8-Tetrachlorodibenzodioxin	4.03E-14	5.30E-14	1.37E-08
Ethyl benzene	3.90E-08	5.13E-08	1.32E-02
Fluorine	6.50E-08	8.55E-08	2.20E-02
Formaldehyde	1.69E-07	2.22E-07	5.73E-02
Hexachlorobenzene	9.37E-15	1.23E-14	3.17E-09
Mercury	3.90E-10	5.13E-10	1.32E-04
Potassium	3.04E-05	4.00E-05	1.03E+01
Magnesium	4.70E-07	6.17E-07	1.59E-01
Manganese	2.22E-07	2.92E-07	7.54E-02
Sodium	1.69E-06	2.22E-06	5.73E-01
Ammonia	2.26E-06	2.97E-06	7.67E-01
Nickel	7.81E-09	1.03E-08	2.65E-03
Phosphorous	3.90E-07	5.13E-07	1.32E-01
PAH, Polycyclic aromatic hydrocarbon	1.43E-08	1.88E-08	4.85E-03
Lead	3.24E-08	4.26E-08	1.10E-02
Pentachlorophenol	1.05E-11	1.38E-11	3.57E-06
Toluene	3.90E-07	5.13E-07	1.32E-01
m-xylene	1.56E-07	2.05E-07	5.29E-02
Zinc	3.90E-07	5.13E-07	1.32E-01

Appendix 15

Waste waters treatment

Most of the waste or residual waters are generated during the oil extraction process in the extraction plant. Residual water has high levels of organic matter and it is treated generally in open pools.

Chemical oxygen demand (COD) of residual waters can be substantially reduced, the treatment system has a great setback due to the fact that it emits high methane concentrations, which is, as it has been mentioned, a potent GHG; therefore federation of palm oil cultivation presented a project design document (PDD) of the Clean

Development Mechanism (CDM) of the UNFCCC with the purpose of capturing to some extent such methane and burn it through the use of an close anaerobic reactor (Fedepalma, 2006a). In this study, the future methane capture is taken into account for the “optimized scenario”.

In general sense, inventory for this part of the process was based on the process from Ecoinvent called “Treatment, residual waters, from households, for residual water treatment, class 2”, whereas the COD, the amount of residual waters and methane emissions were modeled for the Colombian conditions. The functional unit is residual water treated for processing of 100 tons of FFB’s.

Entry

The amount of residual waters and the content of COD of waste waters have been taken from different processing plants of FFB’s and are condensed in. Main residual or waste waters are created in the extraction process.

Total residual waters and COD content per 100 tons of treated FFB (tons)	
Input	**Amount**
Total residual waters	106.6
COD content	5.23
Extraction residual water	99.6
COD content	5.19
Refinery residual water	3.92
COD content	0.02
Transesterification residual water	3.08
COD content	0.02

Source: CUE based on data field

Effluents and emissions

After the treatment of waste waters, the treated stream is led to surface waters (mainly rivers). Content of COD is based on assessment, and emissions of methane were calculated based on the elimination of COD (factor of 21%). For the optimized scenario, where 85% of methane is captured and burned, the values registered in the PDD are used.

Table 96 Quantity of treated water and methane emissions

Quantity of treated water and methane emissions per 100 tons of FFB (ton)		
Output	**Average**	**Optimized**

Total residual water	68.69	68.69
COD content	0.32	0.32
COD removal	4.91	4.91
Methane	1.03	0.05

Source: CUE based on data field

Appendix 16

Source: www.renault.com

Appendix 17

Surface extension of the carbon zones (km2), types of land use by vegetation zones in Colombia

Surface extension of the carbon zones (km2), types of land use by vegetation zones in Colombia								
Cover type	**Cover sub-type**	**Cover name**	**Main use**	**Tropical rainforest**	**Tropical shrub land**	**Tropical dry forest**	**Tropical moist deciduous forest**	**Tropical mountain system**
Natural and semi-natural vegetation	Forest	Natural forest (Bn)	Preservation areas, National natural parks, reservoirs and territories for indigenous people and black communities	426’889	-	-	861	51’355
		Fragmented natural forest (Bi)	Selective extraction of flora and fauna, crops and pasture lands in forest areas that are being turned into grazing land	72’140	-	8	5’731	19’661

	Bushes	Natural and/or induced bushes (Ma)	Selective extraction of products as firewood, fibers and fruits, silvopasture uses and fallow lands	2’491	1’174	-	3’511	5’527
	Other type of vegetation	Herbaceous savannah vegetation (Sl)	Extensive and very extensive livestock farming	28’721	-	-	27’298	50
		Wooded savannah vegetation (Sa)	Extensive and very extensive livestock farming	15’485	-	-	32’392	12
		Bushy savannah vegetation (Sb)	Sporadic extraction of fauna and flora and very extensive livestock farming	18’667	-	-	-	-
		Xerophytic vegetation (Xe)	Semi-nomad livestock farming, species extraction for craft-making and eco-tourism	265	6’650	158	2’775	391
		Moor vegetation (Vp)	National natural parks, protected areas, grazing of bovine and ovine land and potato cultivation	-	-	-	-	13’016
		Mangrove vegetation (Vm)	Selective use of fauna and flora; protected areas	3’803	14	202	717	-
		Very sparse herbaceous vegetation on rocky land (Pe)	Eco-tourism in areas of National natural parks	8’256	-	-	1’400	-
Cultural vegetation	Grasslands	Natural and/or naturalized grass (Pn)	Extensive livestock farming	35’781	-	34	13’884	29’359
		Natural and/or naturalized grass with trees and bushes (Pa)	Extensive and semi-intensive livestock farming	3’268	-	340	12’961	13’440
		Induced grasses (Pm)	Extensive and semi-intensive livestock farming	18’612	-	405	24’222	1’112
		Grasses, stubble, scrubland and marginal forest (Ap)	Extensive livestock farming; and wood, fiber and fruit collection	63’603	5	299	38’944	316
	Crops	Transitory (Cu)	Intensive agriculture with annual species such like rice, cotton, sorghum, maize, bean and potatoes	2’646	-	113	3’278	1’112
		Semi-permanent (Cs-Cña)	Agriculture practices for sugarcane and by-products	136	-	-	2’263	316
		Semi-permanent (Cs-Cñ)	Agriculture practices for sugarcane for "panela" purposes	3	-	-	342	649
		Semi-permanent (Cs-Ba)	Banana and plantain plantations for exports purposes mainly	452	-	-	195	-
		Permanent (Cp-Cf)	Agriculture practices for coffee	535	-	-	527	10’294

		Permanent (Cp-Pa)	Agriculture practices for palm oil	1’098	-	-	510	-
		Permanent (Cp-Fr)	Agriculture practices for fruit production purposes (cocoa, citrus, vineyard, deciduous and others)	-	-	-	-	130
	Associated crops	Crops with stubble, and marginal forest (Ac)	Traditional agricultural practices with species such like bean, maize, cassava, and others, mixed up with some other covers	7’497	-	47	6’279	14’351
		Crops with stubble, and marginal forest (Af)	Traditional agricultural coffee practices associated with plantain, sugarcane, fruit production and marginal forest	262	-	-	423	5’293
	Forest	Planted forests (Bp)	Forest plantations for timber production, soil protection and recovery	27	-	-	188	1’457
Bodies of water	Swamps and marshes	Swamps and marshes (S2)	Swamps and marshes	5’218	-	-	30	4
Bodies of water and swamps zones	Natural, Artificial and continental	Lakes, lagoons, dams, rivers and creeks (ARI)	Energy generation, small-scale and commercial-scale fishing practices, household, commerce and agricultural consumption. Transportation	14’702	-	2	39	10
	Natural, continental	Swamps and marshes (Ag)	Selective extraction of fauna and flora; small-scale fishing, extensive but temporary livestock farming, eco-tourism	4’435	31	66	5’173	43
Uncultivated land	Exposed rocks	Eroded soils, rocky soils, sandy covers and degraded lands (Em)	Extraction of material for crafts and construction	67	1’759	109	825	1’466
Perennial snows (Np)			National natural parks, protected areas, eco-tourism and research	-	-	-	-	333

Source: CUE

Appendix 18

Map of natural potential vegetation

Most uses of Colombian soil are, or can be, potentially turned into natural forest, where biomass carbon would reflect conditions of vegetation zones.

Vegetation zone	AGB (tons of dm/ha)	RS-R	Total biomass (tons of C/ha)
Tropical forest	300	0.37	193.2
Deciduous humid forest	220	0.24	128.2
Dry tropical forest	210	0.28	126.3
Tropical bush	80	0.4	52.6
Tropical mountain system	145	0.27	86.6

Some other uses of Colombian soil include anthropogenic restrictions to potential vegetation in term of soil cover instead to evolve into natural forest. Spatial distribution of potential biomass of the ecosystem is associated with vegetation zones and types of land use, therefore they can

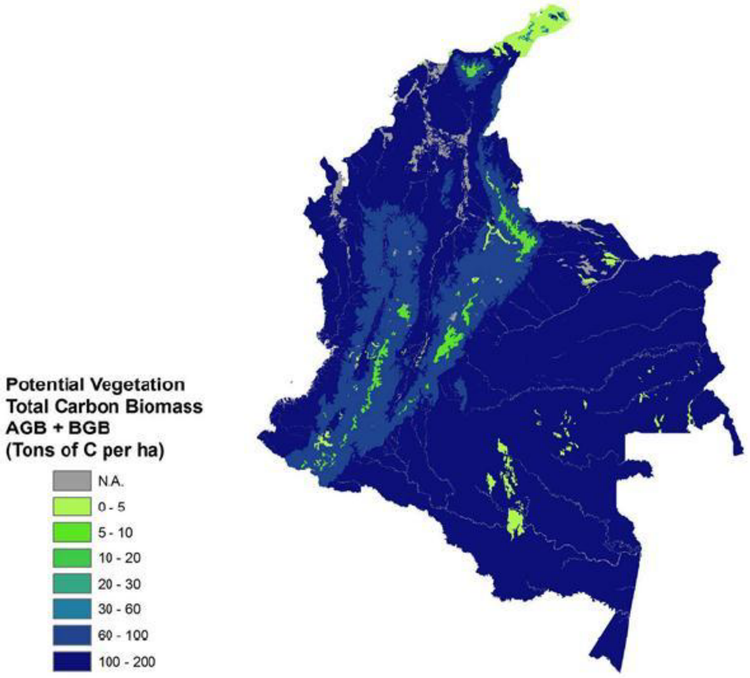
1) potentially evolve in to natural forest or they are forest already; or

2) they can maintain current biomass conditions, due to environmental and human limitations.

Type of cover	Vegetation zone	AGB (tons of dm/ha)	RS-R	Total biomass (tons of C/ha)
Xerophytic vegetation	Tropical bush and dry forest	5	0.36	3.2
Xerophytic vegetation	Caducious humid forest	8	0.36	5.1
Bush vegetation	Tropical mountain system	8	1	7.5
Mangrove vegetation	All	180	0.5	126.9
Waste land and sparse land	Tropical and rainy forest	1	0.1	0.5

Colombian surface (1,114,000 km^2) is broken down in several vegetation regions:

- 42% is occupied with natural forest (480,000 km^2),
- 52% of its territory has the potential to turn into natural forest (590,000 km^2)
- and remaining 6% are occupied by those land use types (bushes, mangroves, waste land, rocky and sparse land) which incur in environmental limitations, keeping biomass levels in their current levels.



Appendix 19

Prospects of biofuels production in Colombia beyond first generation biofuels.

In general sense, it can be said that biomass ethanol can be elaborated from sugars, starches and lignocellulose materials. Colombia has exhibited a prominent behaviour regarding sugarcane yield, according to FAO (108.4 Ton/ha average between 2008-2012) (FAOSTAT, 2014), and therefore the core of this thesis has been biased to this feedstock. However, cassava-based ethanol is also produced in minor proportion in Colombia[55]. Corn has not been considered to produce ethanol in a commercial scale in Colombia due to its low yield (2.28 ton/ha compared to 10.07 ton/ha produced in US). On the other hand, lignocellulose ethanol has counted with some initiatives that so far have been explored on paper, but which have not been deployed properly. In fact most advances have been made focused on conditioning and pre-treatment processes of lignocellulose material, to expose sucrose material with a minor energy consumption, less capital investment and higher efficiency in the use of raw materials (Cardona Alzate, 2009).

During 2009, it was reported an initiative between 3 firms (Inar Ltda, Equitec S.A and G&B) to design, built and manage a processing plant fed with sugarcane bagasse, in a region where sugarcane for panela production is raised (Suarez river basin) (Forero, 2009). The cost of the whole project escalated to 167 million dollars in 2010, and the feedstock was supposed to come from 210 small panela production firms committed to provide approximately 1000 tons of bagasse, which in turn can produce 90.000 l/d (Acuña, 2010). Unfortunately the project has not reported any further results, neither in conventional press nor in academic publications.

Nowadays the panorama is quite blurred for these initiatives, in the Suarez river basin (Hoya del río Suárez) after the bad experience suffered in the past: In 2008 was inaugurated a pilot plant that was built to process nearly 60.000 ha of sugarcane, but after a couple of months later and some tests it was noticed that such infrastructure (with several some disasters in the deployment) was able to process only half ha. Finally the project, with an investment of nearly 3US million, was basically abandoned by the government and left to Universidad Industrial de Santander for academic purposes (Publicaciones Semana, 2010).

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[55] Cantaclaro is a processing plant located in Puerto López and it counts with an installed production capacity of 25000 l/d (reported in 2011). See http://www.fedebiocombustibles.com/v3/nota-web-id-270.htm

Likewise research efforts have been conducted in the development of other feedstock alternatives. For instance, in 2009, it was presented in Mexico the result of an experiment conducted on residues from the palm oil production in order to produce ethanol. The idea consists applying chemical delignification (by using Sodium Hypochlorite in the emptied shells of the palm seeds) to pre-treat the material and reach embedded cellulose. Results support technical feasibility of such treatment, but they do not indicate neither costs nor prospects of implement this technology by the building of a plant (not even in pilot stage) (Piñeros, Rincón, Bourdon, & Velásquez, 2009). Similar work, on the same feedstock, has been documented by researchers of the Univeridad de los Andes, whose experiments are focused on trying with different enzymes (A. F. González, Jiménez, Susa, Restrepo, & Gómez, 2008).

Something similar has happened with the use of timber and wood, in general, as source of lignocellulose for ethanol production in Colombia. Some scholars of the Universidad de Antioquia have conducted some work in order to identify those timber-yielding species that have been used for reforestation and commercial purposes. At first sight it was identified a set of species[56] within Colombia territory that count on high volumetric yield of biomass and short harvesting periods (Gómez, Ríos, & Peña, 2012) which guarantee a continuous and abundant supply of lignocellulose feedstock. It was also found that the species pinus patula is probably the most plentiful within the timber Colombian industry, and it counts with the highest contents of cellulose and hemicellulose and low content of lignin. Nonetheless; there is a technical hindrance given that releasing those sugars is a complex procedure, not only for this species but also to all the broad group of soft woods. However, given its abundance and wide use it has been foreseen that the amount of material can offset the difficulty to process it, providing good chances to use such option for ethanol production.

There is an alternative that has been explored in Medellin in the National University, where banana shell and cassava starch (separately) were used as feedstock to feed a fermentation process for further ethanol production. The result that is particularly interesting here is the one obtained in the experiment on banana shell, given that does not rival directly with the product as food, but it is a by-product that is usually thrown away or used for compost elaboration (Monsalve Gil, Medina de Pérez, & Ruiz Colorado, 2006).

Finally, another option for ethanol production is the use of household solid wastes, with pre-treatment via enzymatic reaction and microwave applications. Results indicated, that despite of interesting yields in technical terms, it has had not reached enough competitiveness in the economic aspect to think in funding such alternative (A. F. González et al., 2008).

Regarding biodiesel production, within first generation biofuels feedstock can be found vegetable oils and animal fat. An alternative can be residual oils that have been used in the food industry. Palm oil has been the chosen feedstock for biodiesel production in the case of Colombia. Despite its prominent production (in 2012 was the fourth world producer, with close to 1 million MT, FAOSTAT 2014), it remains far from the global leadership in palm oil production[57]. Nevertheless, the Colombian incursion as biodiesel producer is noteworthy and so far fulfil the needs of diesel blends, dictated by the national government[58].

Regarding alternatives to first generation biodiesel (i.e. 2nd and 3rd Generation), in Colombia have been studied the possibilities of producing it from castor oil seeds and microalgae. An isolated experiment on household solid wastes has been notified as well.

Castor oil biodiesel has been studied in Colombian, since 2004, as an alternative to palm oil biodiesel. All the tests have been conducted at laboratory level (Cardona, C.E., Sanchez, &

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[56] Within this set are Eucalyptus camaldulensis, pine trees Caribaea, Oocarpa y Tecunumanii and eucaliptos Grandis, Camaldulensis and Tereticornis

[57] In 2012 Indonesia and Malaysia produced 23.6 and 18.7 million MT of palm oil (FAOSTAT, 2014). In addition, thanks to a broad experience these two countries are in the forefront of productivity with average production rates of 6000 l/ha, whereas in Colombia this rate reaches 4.400 l/ha (Cardona Alzate, 2009)

[58] A blending level of 15% biodiesel would require nearly 425 thousand ha by the year 2020, according to Cardona's calculations (Cardona Alzate, 2009).

Rincón, 2007). Within the program of Industrial Chemistry of the Universidad Tecnológica de Pereira, in 2012, was presented a thesis that covers most of the research undertaken regarding a potential castor oil biodiesel production. Basically this document presented a set of tests applied to castor oil seed genetically modified and it was verified that most of technical parameter of regular biodiesel are fulfilled by this option. The genetic modification brings along some advantages like low content of free-fatty acids, therefore it is easier trans-esterification process; low iodine content which guarantees a better oxidative stability and enhancement of engine lubricity. However some nuisances are exhibited as well, like a major ability of corrode the system in comparison to regular biodiesel (Huertas Greco & Sánchez Medina, 2012).

Since 2009, it can be found within the Colombian academic literature some reports and papers on research which presents a different approach to third generation biofuels is the elaboration of biodiesel based on algae use. In particular in the Universidad Industrial de Santander has been conducted some experiments, at laboratory level, on Chlorella vulgaris, Chlorella protothecoides, Nannochloropsis oculata, which are a kind of algae with high oil content. The advantages of these species over traditional terrestrial oily seeds are high growth rates (which doubles size in about 24 hours), high yields (which can be 300 times the yield of terrestrial seeds) and adaptability (given that they can be produced in salt water, residual water and degraded lands not suitable for food production). Despite the appeal of such option it seems that the combination of an absent supply of microalgae in combination with a reduced number of publications regarding transesterification of these species have leaded to a poor support in this front.

Pyrolysis has been applied to household solid wastes, in a temperature range between 450 and 700°C, reaching a liquid product with similar characteristics to commercial diesel 8500cal/g vs 9900 cal/g, and a solid product superior in calorific content, if it compared to regular coal. However, high content of sulphur discourages the use of such products for their environmental performance (A. F. González et al., 2008).

Despite biogas is not direct application of transportation alternative of biofuels, it can be mentioned that hydrogen production from porcine farming wastes has been run on experiments via anaerobic digestion.

It is important to be aware that palm oil and sugarcane processing industries can exert some pressure on the Colombian government given the employment that they both represent and the income reported to the nation's wealth. Additionally there is no evidence that, in Colombia, diversion of feedstocks (sugar and palm oil) threatens food security. Therefore, such fact, combined with isolated efforts on research provide a bleak landscape for second generation biofuels technologies (and beyond) in the near future, but the possibility of using by-product of such industries such as . Colombia remains updated in terms of the technologies that have been studied in the forefront in the field of biofuels, however further investment and infrastructure acquisition is required to develop a mature supply of advanced biofuels.