CHAPTER 7

BIOFUEL VALUE CHAINS AND CONTRACTUAL RELATIONSHIPS

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.

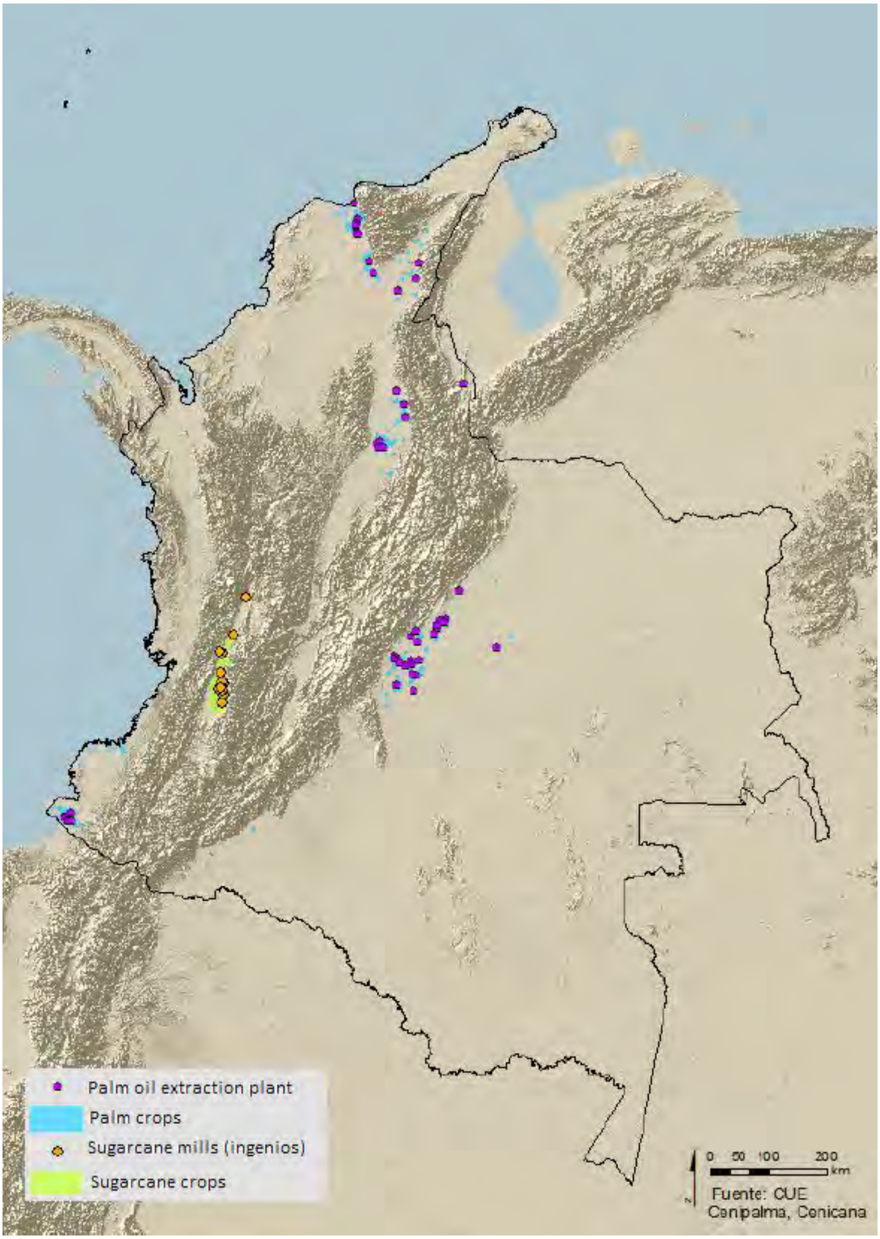
Nevertheless, potential benefits from increased biofuel production, can be achieved only if a sustainable expansion of feedstock cultivation is guaranteed.

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 7.1. Existing sugarcane crops (green) and palm oil crops (blue) in Colombia in the year 2008



Source: Cenicaña and Cenipalma

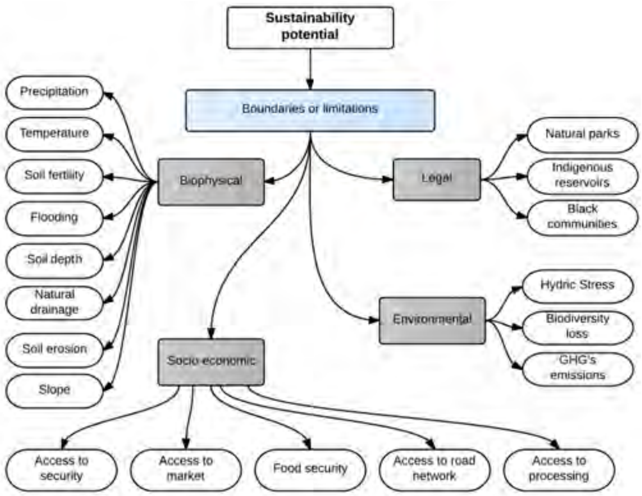
7.2 METHODOLOGY

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 7.2. 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.

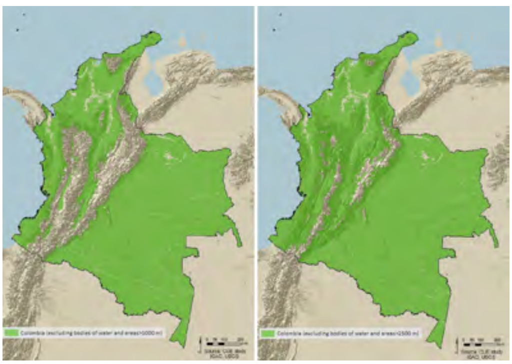
Given the limitation in the resources and the limited availability of the required maps, the study, despite all this, is able to identify focused areas where biofuel feedstock cultivation is suitable to a great extent. Notwithstanding, further studies, based on high resolution maps, will be required 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).

Figure 7.3. Exclusion of zones regarding altitude, urban areas, and bodies of water



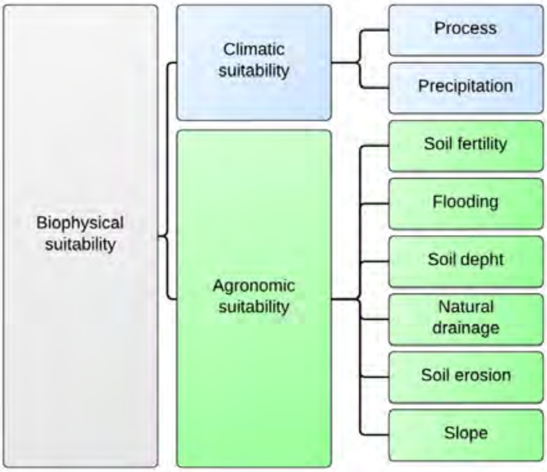
Left panel for palm oil crops and right panel for sugarcane crops. Excluded areas are those which are not green.
Source IGAC

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).

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 7.4. 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 7.1. 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.

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 7.2. 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

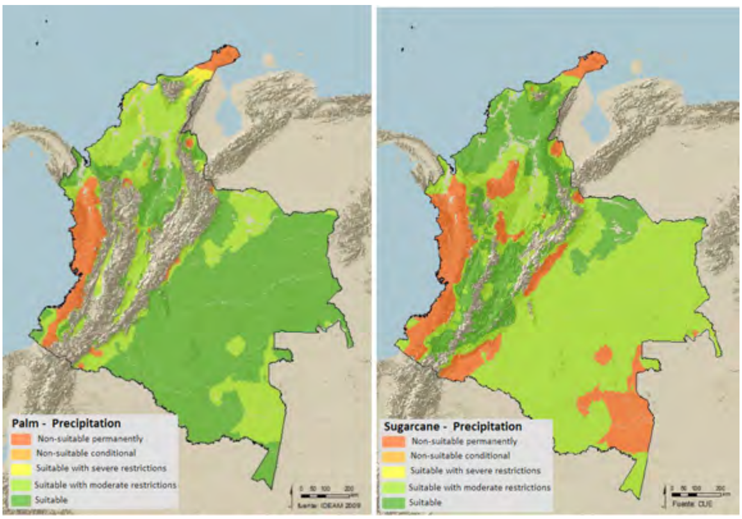
Source: Precipitation map from IDEAM (IDEAM, 2009b) and Cenicaña 2011

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 7.5. 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.

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 7.3. Temperature suitability across Colombia

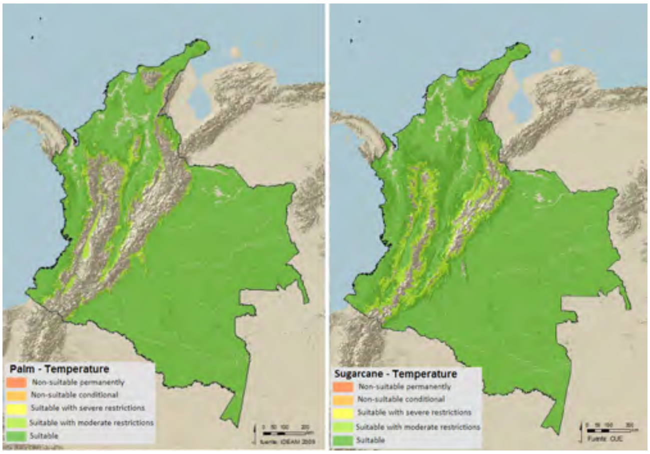
Attribute	Variable	Palm oil	Value	Sugarcane	Value
Annual average temperature (°C)	<10	N2 - Non suitable in a permanent way	0	N2 - Non suitable in a permanent way	0
	10-15	N2 - Non suitable in a permanent way	0	S2 - Suitable with moderate restrictions	4
	15-20	N2 - Non suitable in a permanent way	0	S2 - 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 7.6. Temperature suitability map



Palm oil crop (left), Sugarcane crop (right). Source: IDEAM and CUE maps

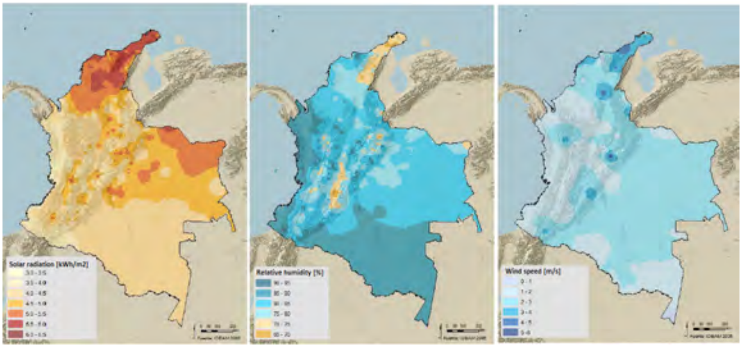
Colombia has optimal conditions for sugarcane and oil palm tree cultivation. Just the most elevated areas are considered not suitable, but they were already excluded under altitude criteria.

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.

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.

Figure 7.7. Daily solar radiation, relative humidity, and wind speed



Daily solar radiation (left), relative humidity (middle), and wind speed (right). Source: IDEAM 2005, 2006.

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).

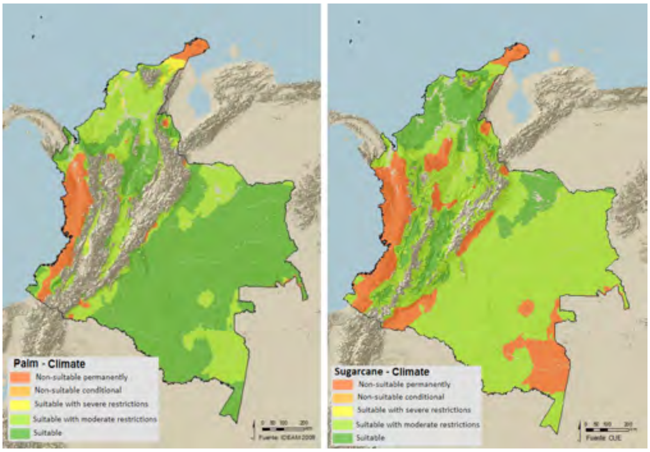
Table 7.4. Matrix to determine climatic suitability

		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 7.8. 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.

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 7.5. Flooding–Crop specific classification

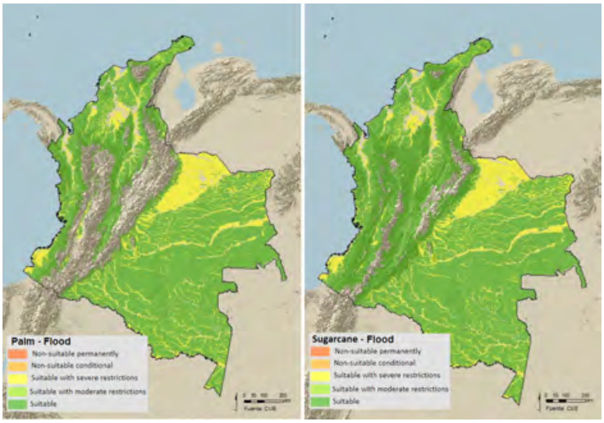
Attribute	Variable	Palm oil	Value	Sugarcane	Value
Flooding	Without flooding	S1- Suitable	8	S1- Suitable	8
	Permanent flooding	N2 - Non suitable in a permanent way	0	N2 - Non suitable in a permanent way	0
	Occasional flooding	S3-Suitable with severe restrictions	2	S3-Suitable with severe restrictions	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 7.9. 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.

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 7.6. Soil erosion–Crop specific classification

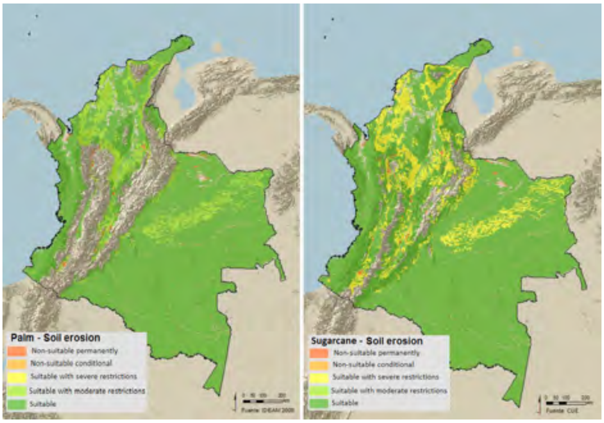
Attribute	Variable	Palm oil	Value	Sugarcane	Value
Erosion	Without erosion	S1- Suitable	8	S1- Suitable	8
	Moderate erosion	S2- Suitable with moderate restriction	4	S3-Suitable with severe restrictions	2
	Severe erosion	N2 - Non suitable in a permanent way	0	N2 - Non suitable in a permanent way	0

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 7.10. 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.

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 7.7. Soil depth–Crop specific classification

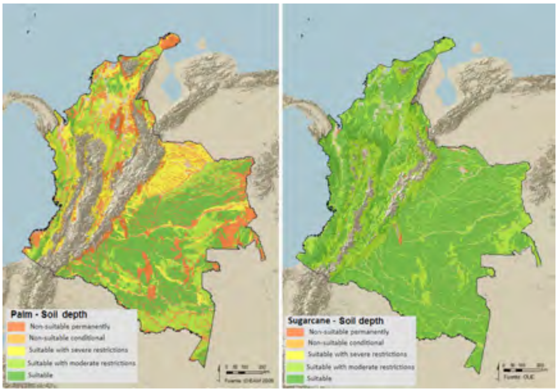
Attribute	Variable	Palm oil	Value	Sugarcane	Value
Soil depth (cm)	>100 cm	S1- Suitable	8	S1- Suitable	8
	50-100	S2- Suitable with moderate restriction	4	S1- Suitable	2
	25-50	S3-Suitable with severe restrictions	2	S2- Suitable with moderate restriction	4
	<25	N2 - Non suitable in a permanent way	0	S2- 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 7.11. 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.

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 7.8. Soil fertility–Crop specific classification

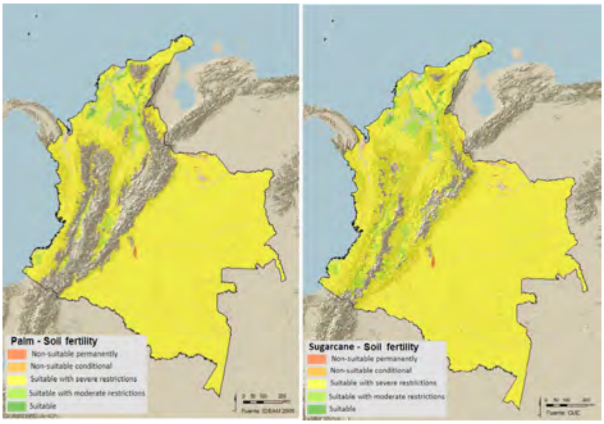
Attribute	Variable	Palm oil	Value	Sugarcane	Value
Fertility	High	S1- Suitable	8	S1- Suitable	8
	Moderate	S2- Suitable with moderate restriction	4	S2- Suitable with moderate restriction	4
	Low	S3-Suitable with severe restrictions	2	S3-Suitable with severe restrictions	2

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 7.12. 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.

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 7.9. Natural drainage–Crop specific classification

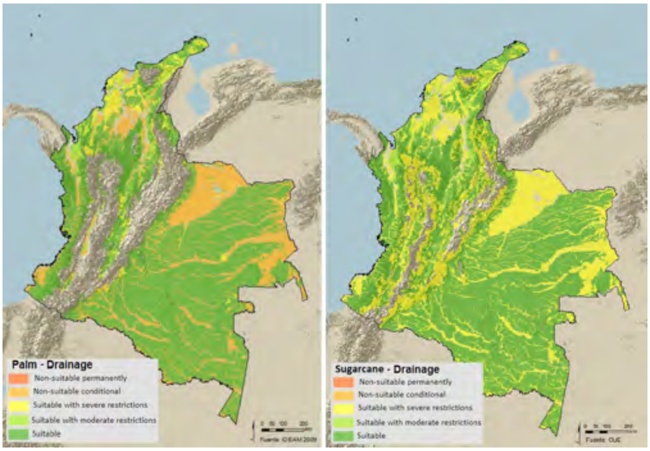
Attribute	Variable	Palm oil	Value	Sugarcane	Value
Drainage	Good or fairly good drainage	S1- Suitable	8	S1- Suitable	8
	Moderate drainage	S2- Suitable with moderate restriction	4	S2- Suitable with moderate restriction	4
	Excessive or bad drainage	S3-Suitable with severe restrictions	2	S3-Suitable with 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 7.13. 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.

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 7.10. Slope–Crop specific classification

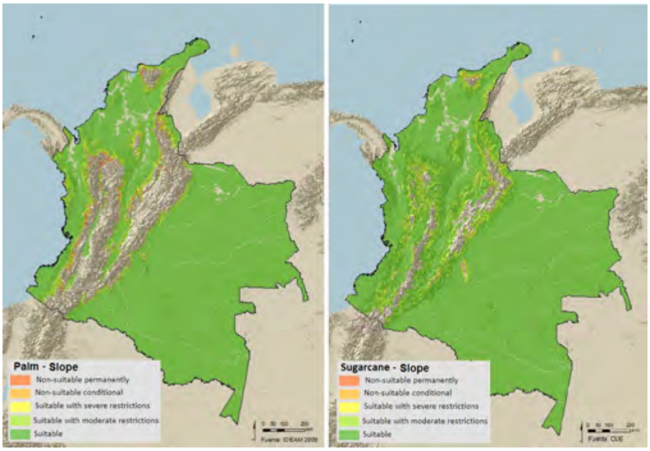
Attribute	Variable	Palm oil	Value	Sugarcane	Value
Slope	0%-12%	S1- Suitable	8	S1- Suitable	8
	12%-25%	S2- Suitable with moderate restriction	4	S2- Suitable with moderate restriction	4
	25%-35%	S3-Suitable with severe restrictions	2	S3-Suitable with severe restrictions	2
	>35%	N2 - Non suitable in a permanent 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 7.14. 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 7.11. Matrix to determine agronomic aptitude

		Fertility and Natural Draimage						
		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)

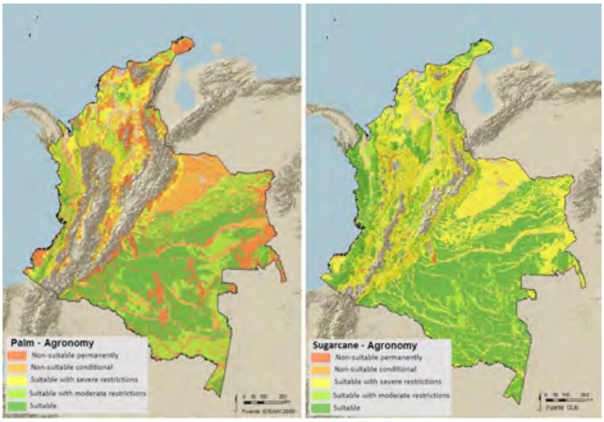
In addition, the slope effect was considered in the following matrix. As it is shown in the above figure, slope does not affect land suitability, given that it is a local effect, and those effects tend to disappear when the resolution of the employed maps improves. It is advised that a slight overestimation of suitability potential might emerge from this setback.

Table 7.12. 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 7.15. 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 7.13. Matrix to determine biophysical aptitude

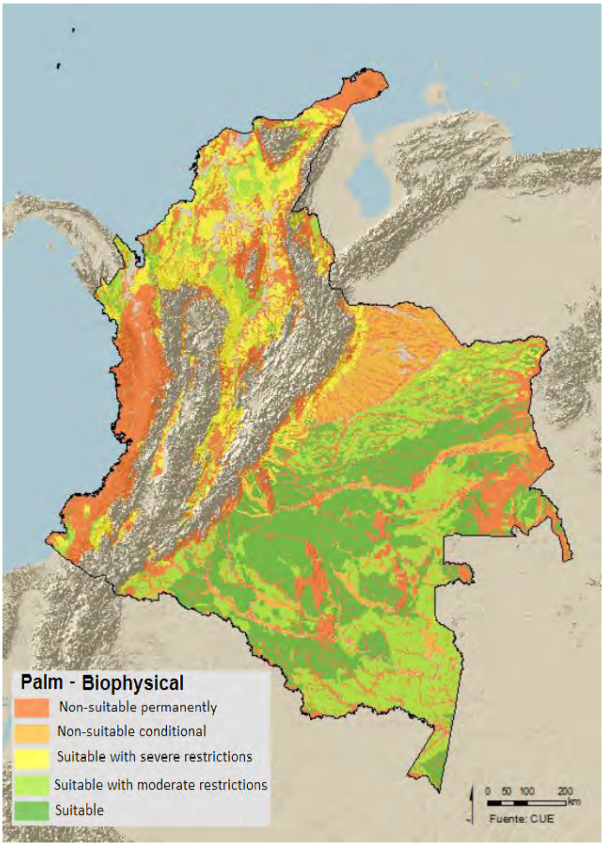
		Climate				
		0	1	2	4	8
Agronomic factors	0	N2	N2	N2	N2	N2
	1	N2	N1	N1	N1	N1
	2	N2	N1	S3	S3	S3
	4	N2	N1	S3	S2	S2
	8	N2	N1	S3	S2	S1

Source: (IDEAM, 2009b)

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.

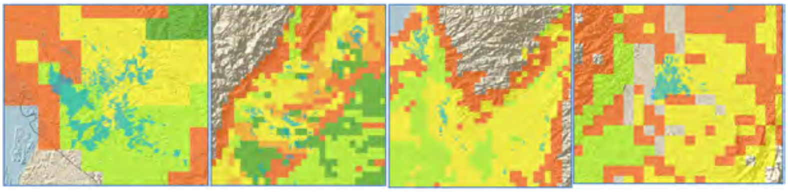
Figure 7.16. Biophysical factor suitability map for Palm oil crops



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 7.17. Detailed biophysical suitability map



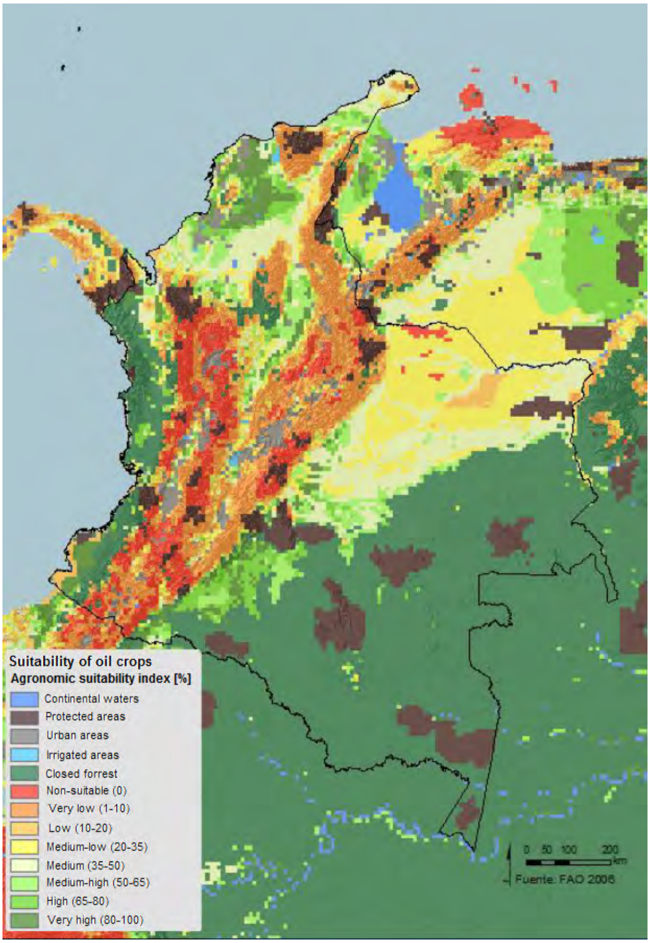
Note: (every pixel:5km x 5km) Every pixel has been zoomed in the current palm oil crops areas (noted in blue) in Nariño (1), Meta (2), Magdalena y Cesar (3) y Santander (4)

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).

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.

Figure 7.18. FAO suitability map for palm oil crops

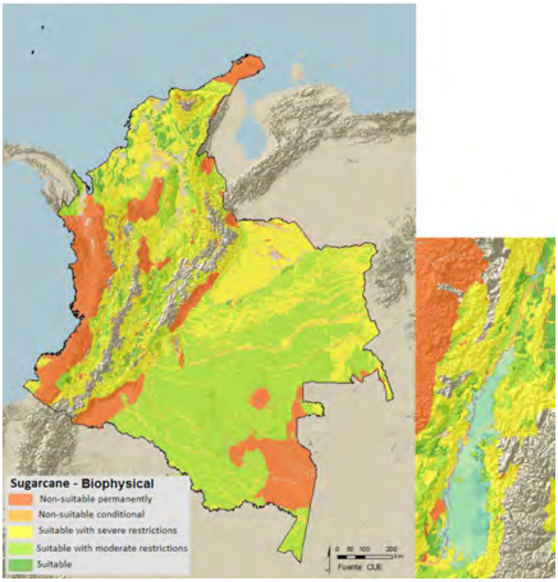


Source: (FAO and IIASA, 2007)

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.

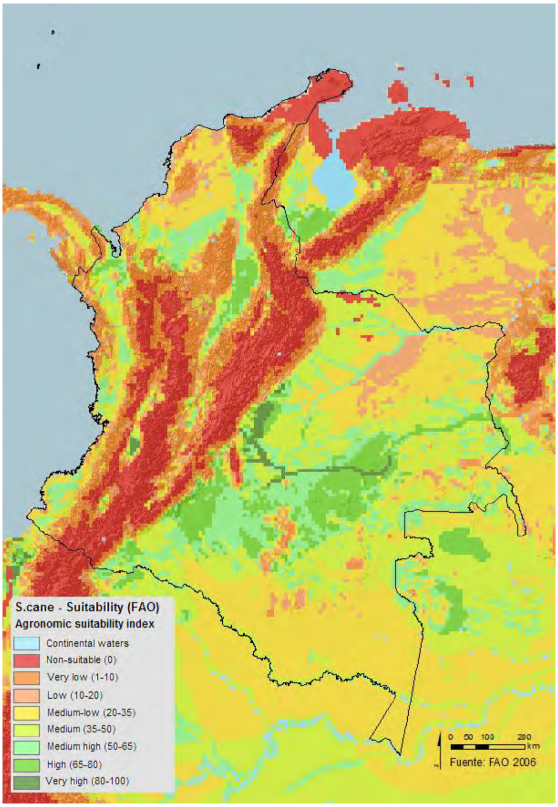
Figure 7.19. Biophysical factor suitability map for Sugarcane crops (left). Detailed zoom in of the Cauca River Valley (blue: current sugarcane crops) (right)



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.

By comparing this map of suitability for sugarcane crops (figure 7.20) with the one presented by FAO (figure 7.19), 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.

Figure 7.20. FAO suitability map for sugarcane crops



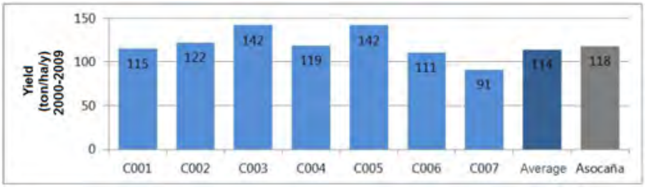
Source: (FAO and IIASA, 2007)

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.

Productivity of the sugarcane

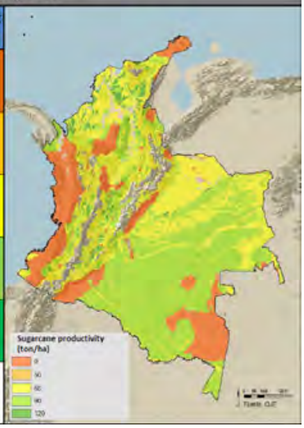
Figure 7.21. Annual yields of sugarcane spotted in the sampled sites



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 7.14. 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

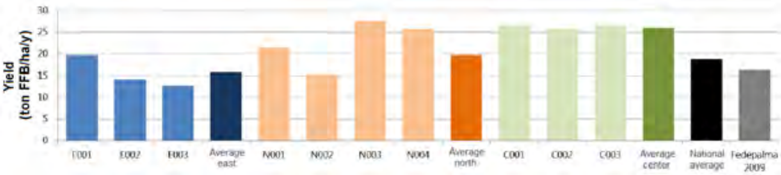


Maximum productivity is based on real numbers from the geographic valley of Cauca River. Below is shown different yields for the farms in the sample (tons per hectare per year). Under optimal conditions the average production is 120 tons /h/y. Mild productivity (suitability class 2) is near to 90 tons /h/y.

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).

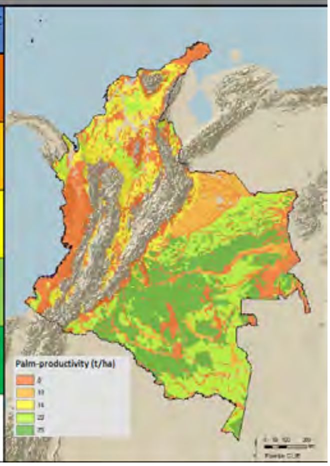
Figure 7.22. Annual yields of Palm Oil in Colombia. (E) East (N) North (Center)



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 7.15. 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

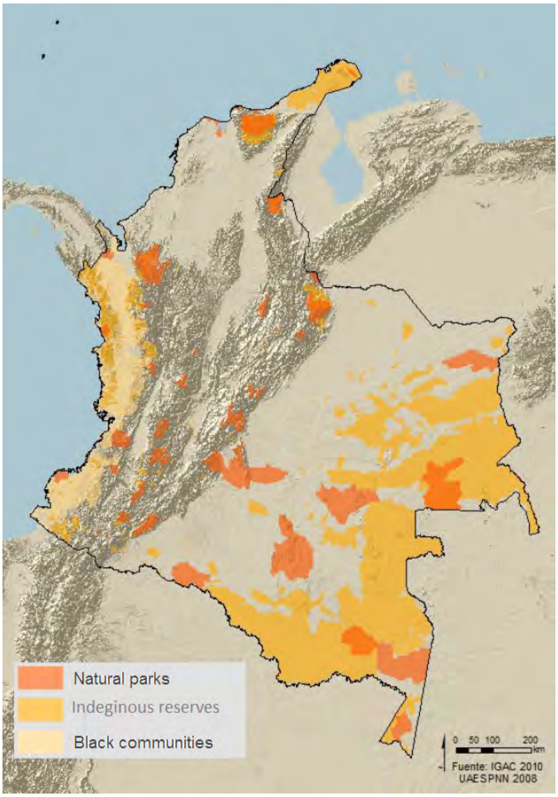


7.4 LEGAL RESTRICTIONS

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.

Figure 7.23. Map of legal restrictions



Grey areas do not represent any restriction

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. 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 7.24. Forest ecosystems protected by the law

law of the Forest Reserve Zones (Law 2 of 1959). Source: (IDEAM, 2007)

7.5 ECOLOGIC LIMITATIONS

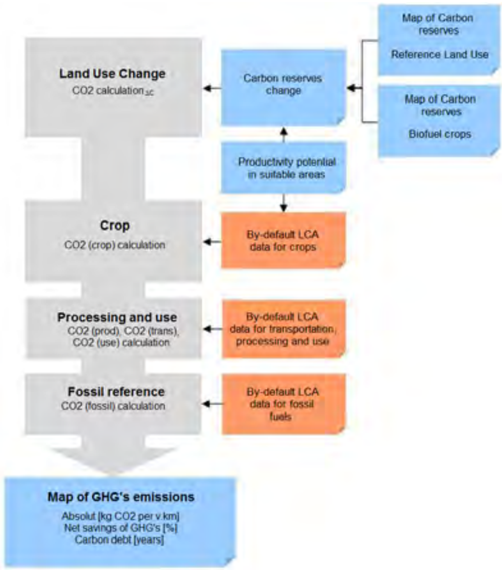
In a former section, it was determined potential areas of suitability for biofuels crops taking into the account biophysical factors. In this section biophysical areas are even more restricted by use of environmental criteria, such as carbon emissions, water shortages and biodiversity.

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 7.25. Concept for modeling a GHG's emissions map

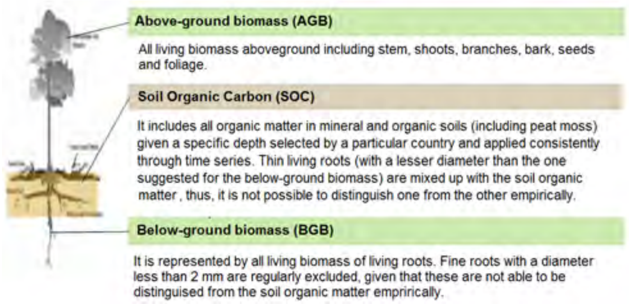


The first step is to calculate the amount of GHG's emissions related to LUC. Later, a biomass map is established, and a map that depicts carbon contained in soil for reference in Colombia. Additionally biomass and carbon in soil reserves were calculated for potential land where potential bioenergy feedstock 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.

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 7.26. Soil carbon reserves



Above-ground biomass, Soil Organic Carbon and Below-ground biomass

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]

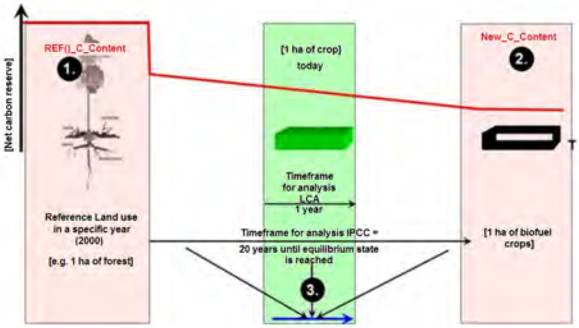
Assessment of carbon emissions is based in the following assumptions:

- 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).

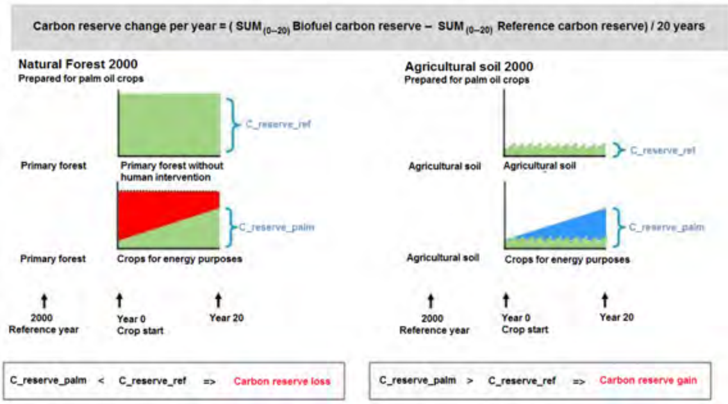
Basically this means, that carbon reserves for soil in 2000 (step 1) is compared with carbon reserves for biofuel crops (step 2). It calculates the difference in carbon reserves for 20 years as an average change in the reserve of carbon per year.

Figure 7.27. 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 7.28. *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.

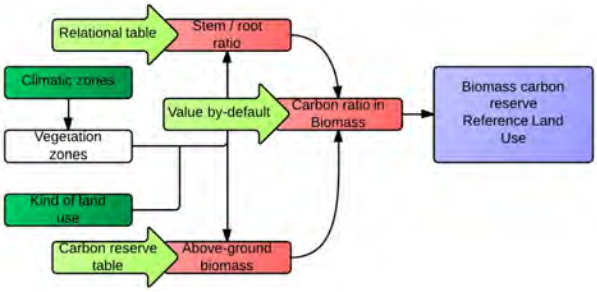
Carbon change in biomass

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

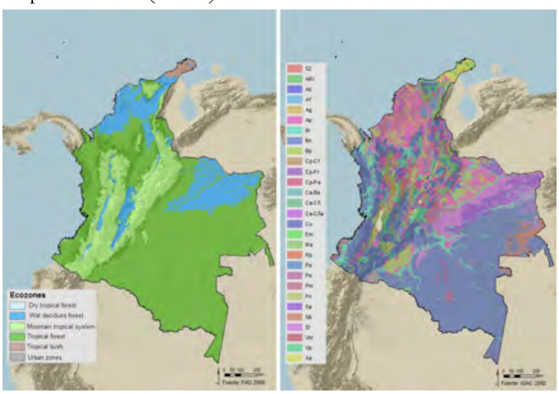
Below is defined a flow chart of those processes that are employed to identify and quantify carbon reserve of biomass for the reference land use (2000).

Figure 7.29. 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 figure 7.30). 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 7.30. 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 km^2),
- wet forest caecilian (184,771 km^2)
- and tropical mountain system (207,296 km^2).

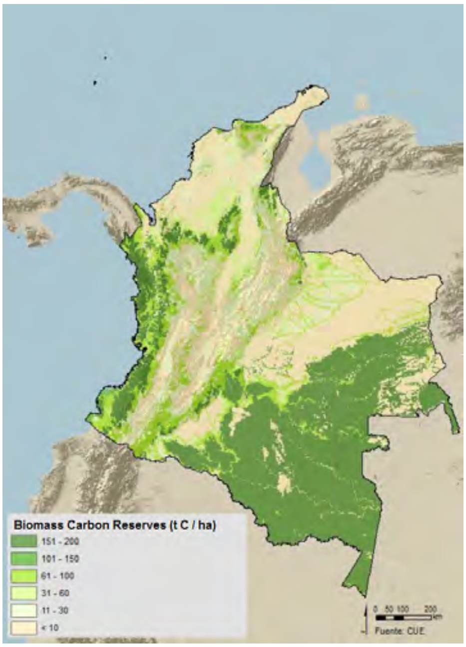
A limited quantity of land is located in tropical bushes (9,637 km^2) and tropical dry forest (1,978 km^2).

Combination of land uses and vegetation zones draw 94 carbon zones. Their superficial areas (km^2) 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 7.31. Total carbon biomass of the reference land use (in tons of carbon per ha)

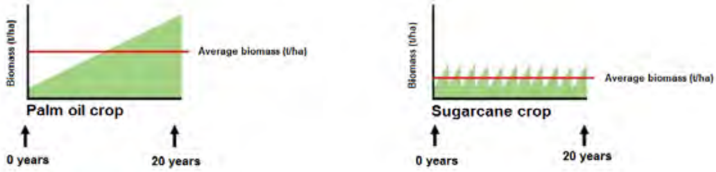


Source: CUE

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.

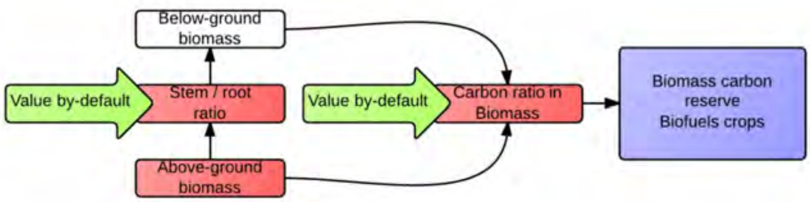
Figure 7.32. Cumulated biomass of palm oil (left) and sugarcane (right)



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 7.33. 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 7.16. 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

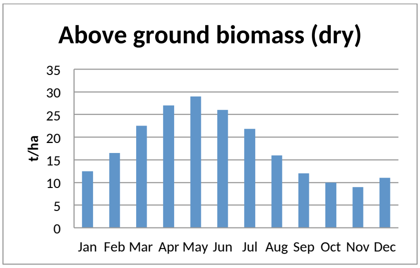
Source: (Vlek et al., 2005)

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).

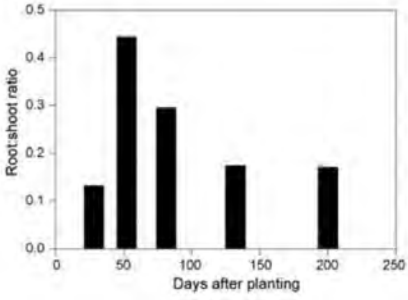
Figure 7.34. Development of a simulated plant for the AGB of sugarcane in Brazil



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 7.35. Ratio Stem-root (based on dry weight) for sugarcane planted in pot



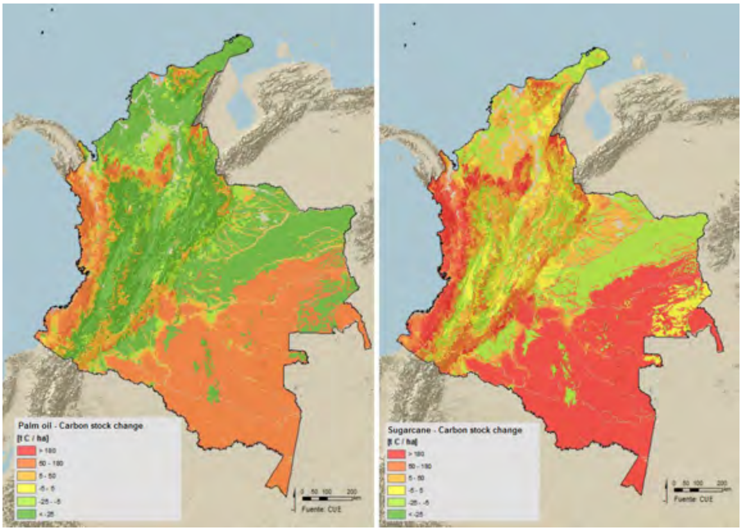
Source: (I.C. Macedo, 2010)

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).

$$\begin{aligned} AGP_{t1} &= (AGB + BGB)_{\text{biofuels}} - (AGB + BGB)_{\text{Initial}} \\ AGB_{t1} &= \text{Above–ground biomass after the land use change } (tC \text{ per } Ha) \\ (AGB + BGB)_{\text{Biofuels}} &= \text{Above–ground biomass for biofuel feedstocks } (tC \text{ per } Ha) \\ (AGB + BGB)_{\text{Initial}} &= \text{Above–ground biomass for the reference soil } (tC \text{ per } Ha) \end{aligned}$$

Figure 7.36. 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

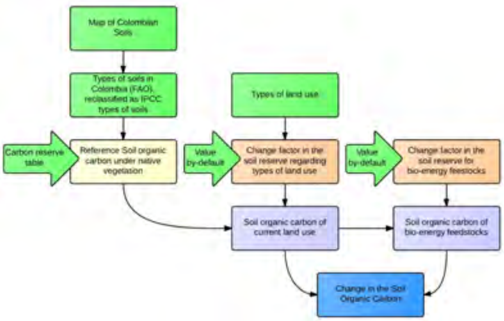
Despite the fact that both types of carbon (organic and inorganic) are found in the ground, land handling and use have a great impact on reserves of soil organic carbon (SOC). Lands of mineral type are, most of the time, classified as moderate to good in terms of drainage and are predominant in almost 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 7.37. 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 (SOC_0), the reference reserve of SOC (SOC_{REF}) 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 (SOC_{REF})

Estimation of the SOC_{REF} 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 7.38. 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 SOCRef 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.

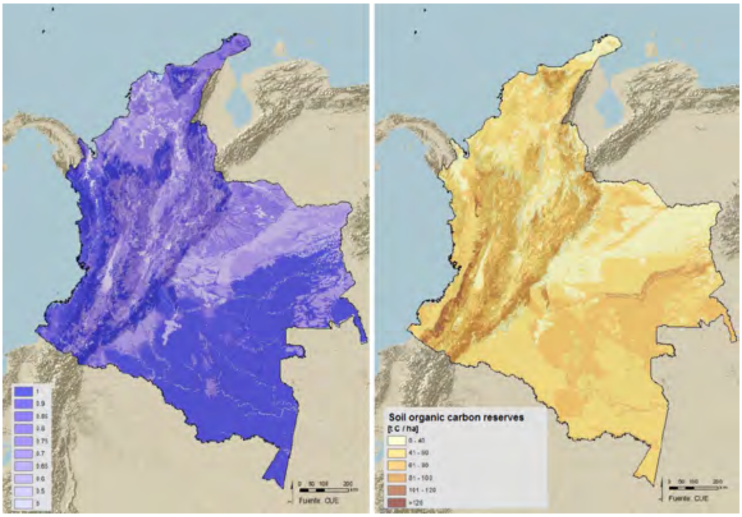
Based on that, Soil organic carbon can be represented as follows:

$$SOC_O = SOC_{REF_{C,S,i}} \times MF_{C,S,i} \times IF_{C,S,i}$$

SOC_O = 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 9.16. Values for SOC_0 are calculated based on the change relative factors in reserves and the value of SOC_{REF} (see figure below).

Figure 7.39. Relative Change factors of reserves (left) and SOC_0 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 (SOC_0 that is equal to SOC_{REF}) times the factors of relative change in the reserves for sugarcane and palm oil.

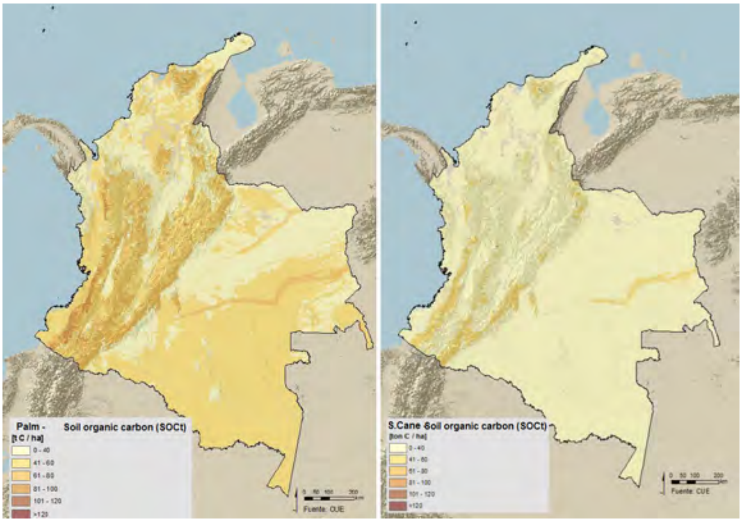
Factor of relative change of reserves in those crops cultivated in the long run in wet climates (i.e. sugarcane) is approximately 0.5 (IPCC, 2006).

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 7.40. 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 7.41. SOC Change after turning the reference soil into palm oil crops (assessed in tons of C per ha)

Source: CUE

Figure 7.42. SOC Change after turning the reference soil into sugarcane crops (Assessed in tons of C per ha)

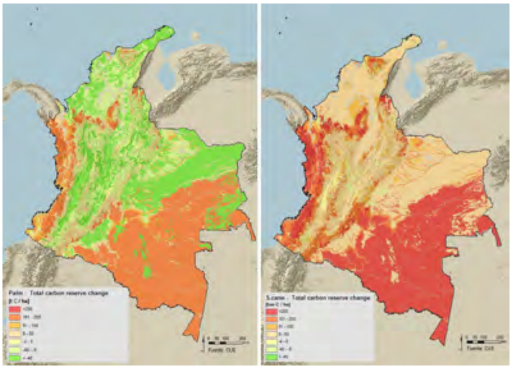
Change in the total reserve of carbon by account of land use change (LUC)

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.

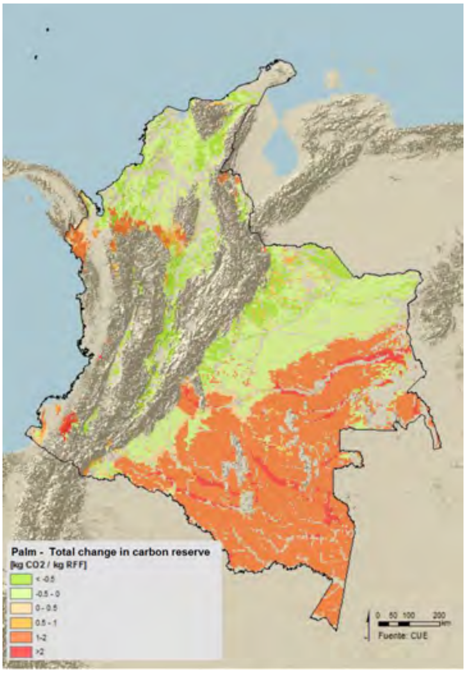
Figure 7.43. Change in the carbon reserve due to *LUC* from current use



Change to palm oil production (left), and sugarcane production (right)

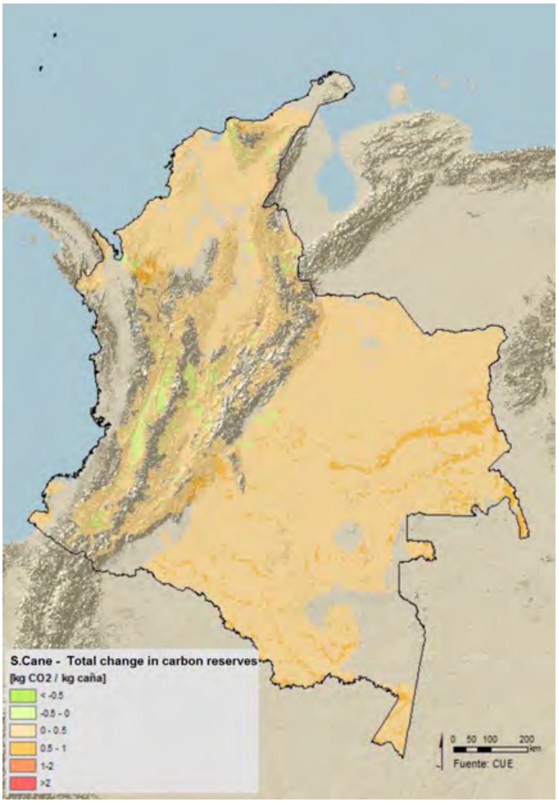
Notwithstanding, not all these lands are suitable for cultivation. With the purpose of including the biophysical aptitude for biofuels feedstock cultivation, the amount of GHG's emissions per kg of biomass harvested is calculated (sugarcane and bunches of fresh fruit of palm oil).

Figure 7.44. Change in carbon reserve due to current land use change to palm oil crops (tons of CO2 per kg of FFB)



Source: CUE

Figure 7.45. Change in carbon reserve due to current land use change to sugarcane crops (tons of CO2 per kg of FFB)



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 CO2 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, page 322 shows sensibility to transportation purposes.

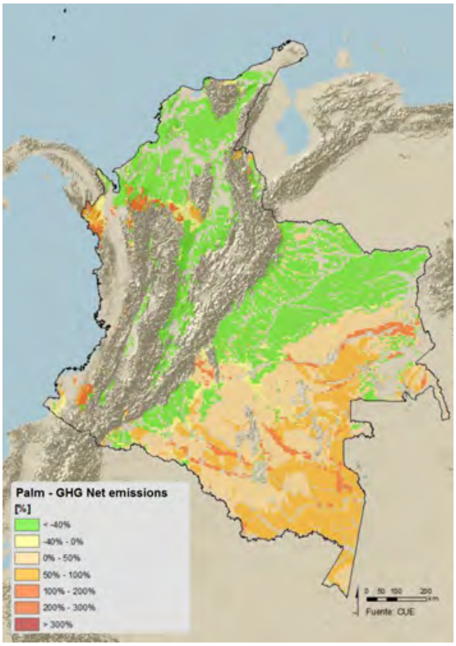
Use and reference fossil fuel: For biofuel use and reference fossil fuel (substitution) values defined by LAC are employed.

Table 7.17. 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

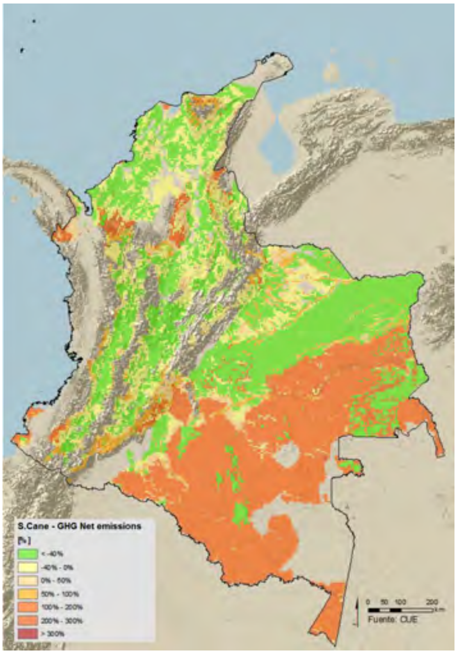
Source: CUE

Figure 7.46. Relative GHG's emissions for palm oil-based biodiesel



Savings are represented in green whereas emissions in red

Figure 7.47. 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.

Carbon debt by region for biofuels in Colombia

LUC in most cases creates carbon emissions. The quantity of CO_2 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.

$$CD = \frac{CO_{2\Delta C_{LUC}}}{CO_{2crop\_no\_luc} + CO_{2prod} + CO_{2trans} + CO_{2fos} \times \alpha \times produc}$$

$CD =$ 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 7.48. Carbon debt of palm oil-based biodiesel produced in Colombia [years]

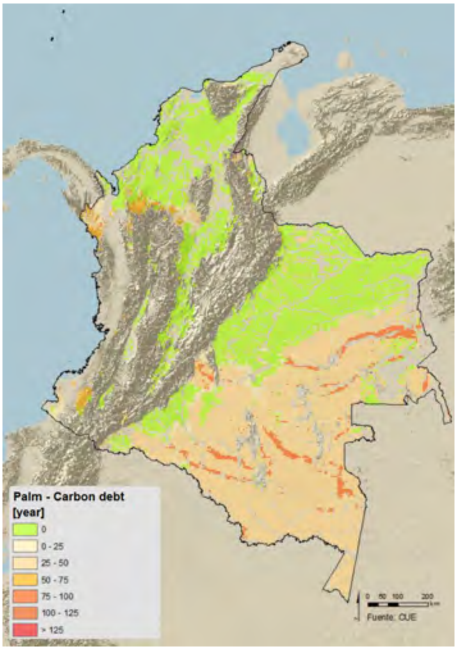
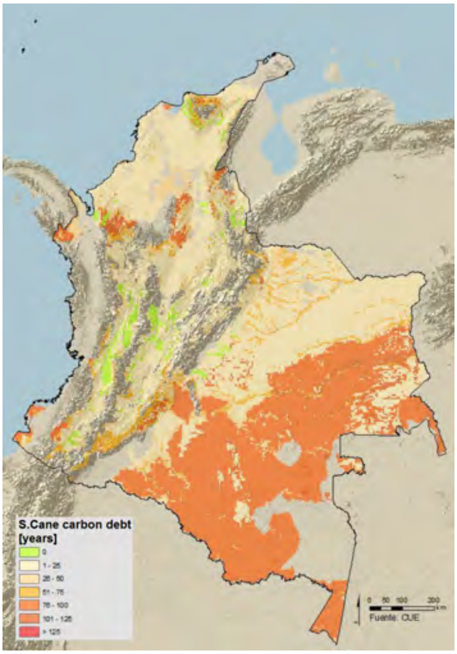


Figure 7.49. Carbon debt of sugarcane-based ethanol produced in Colombia [years]



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).

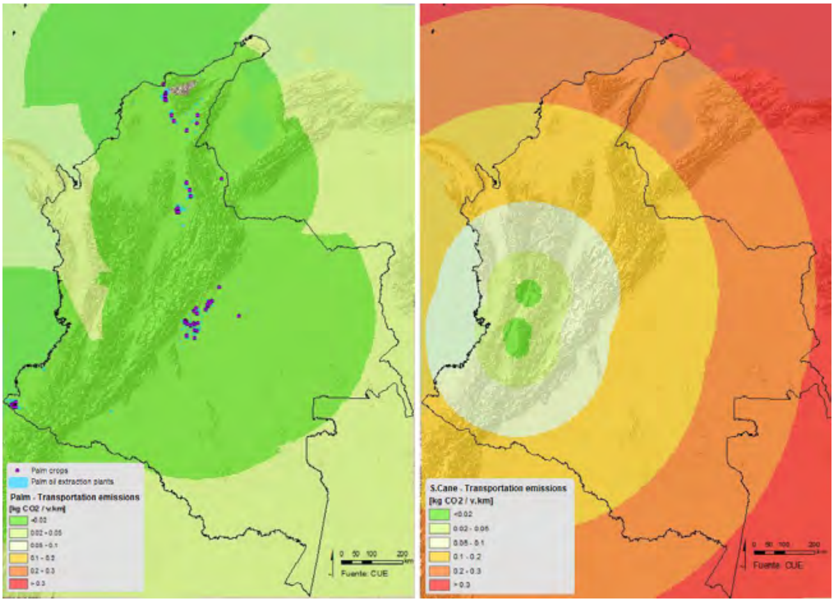
Transport distance is multiplied times the quantity of biofuels that are required to operate a vehicle during a kilometer (biofuel ton/driven kilometer). Values are obtained from the LCA and the units of assessment are tkm per vehicle driven kilometer, noted here as v.km.

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 7.50. 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.

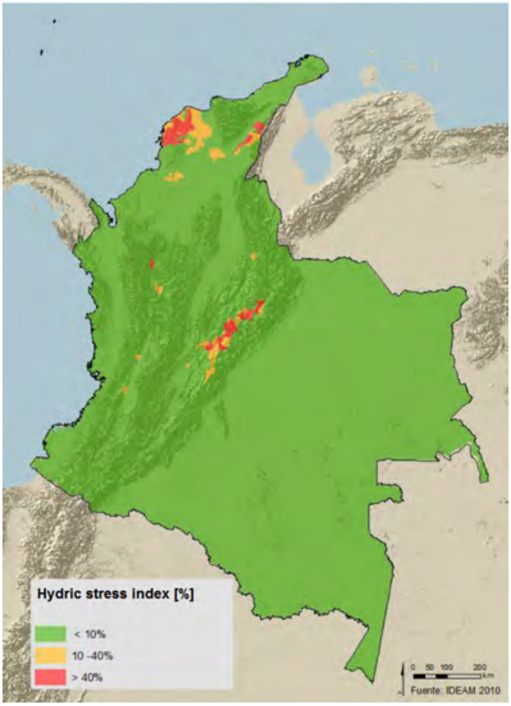
Table 7.18. Classification of hydric stress

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.

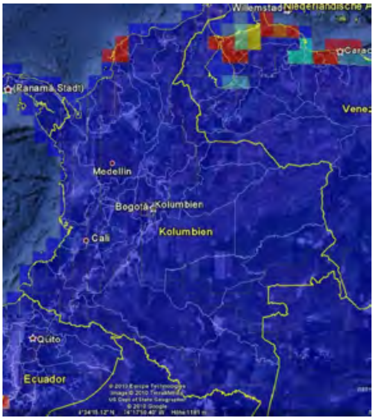
Figure 7.51. Hydric stress in Colombia



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).

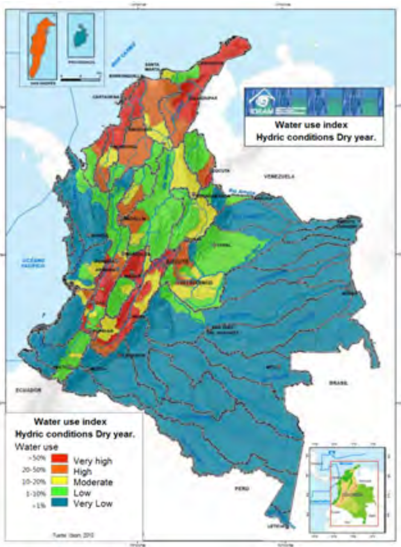
Figure 7.52. Comparative Hydric stress Map for Colombia



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 7.53. Water use index in Colombia for a dry year



Source: (IDEAM, 20010)

7.5.3 Biodiversity

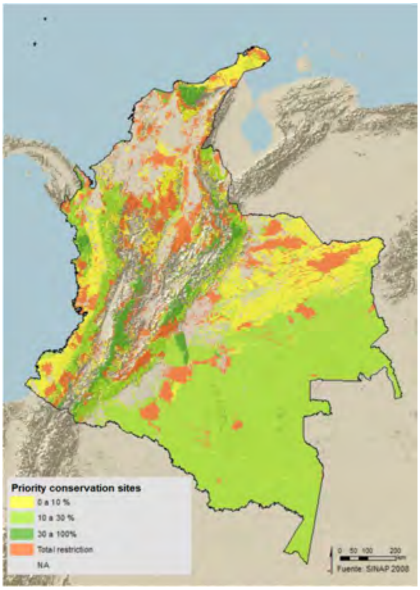
There are different biodiversity indicators for Colombia, such as the ones presented in the study of palm oil found in Mora et.al (2009). Some indicators, like specific ecosystem or habitat fragmentation, are quite theoretical and cannot be used directly to evaluate energy crop expansion, due to the 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 7.19. Restriction levels for areas of priority preservation according to SINAP

Level of restriction	No–preserved areas (%)	Description
Total restriction	0	Priority conservation areas acording to SINAP
Severe restriction	0–10	High value ecosystem with less than 10% disturbed land
Moderate restriction	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

Figure 7.54. Priority conservation areas according to SINAP guidelines



Source: (Corzo et al., 2008)

The figure 7.54 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.

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 7.55. Colombian forest areas

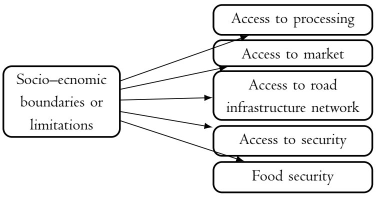
Source: (IGAC, 2003)

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.

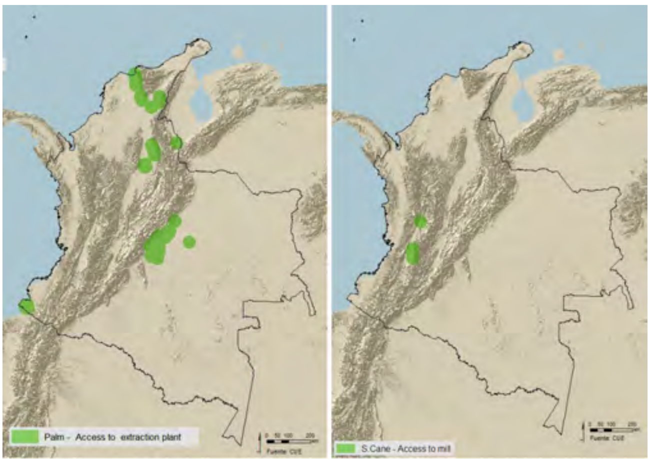
Figure 7.56. Access to processing facilities



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

Figure 7.57. Summary of the socio-economic factor taken into consideration



Palm oil on the left side. Sugarcane on the right side. Distance considered: 30 km

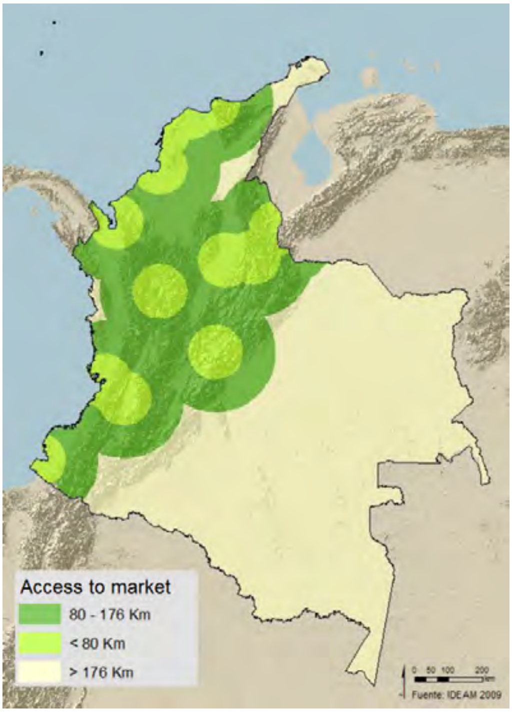
Ideally, bioenergy feedstocks are cultivated close to an already existent processing plant, to make use of its services, and also to gain acceptance of crop introduction in the population that inhabit the nearby area. In the next map are presented those areas that are 30km away from a processing unit of palm oil or sugarcane. Nonetheless, it was not considered access quality, meaning, general road conditions, like slope, paving treatment, etc.

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.

Figure 7.58. Access to markets



Source: (IDEAM, 2009c)

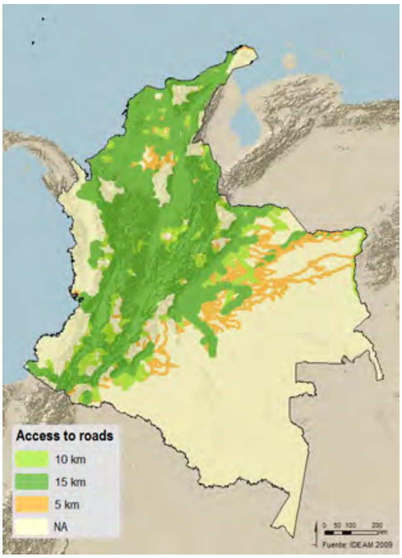
Distances less than 80km are indicated in light green; whereas mid-range distances (80km to 176km) are indicated in dark green.

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 7.59. Access to main terrestrial roads and rivers



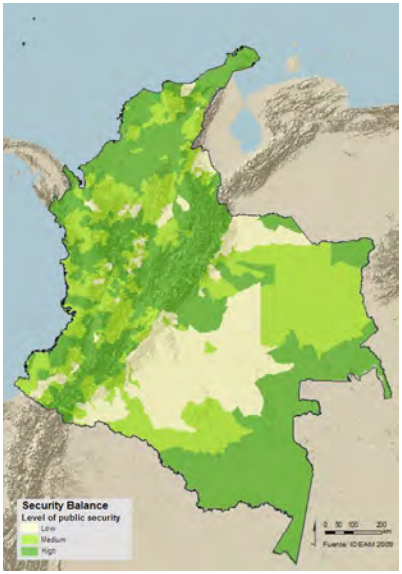
Source: (IDEAM, 2009c)

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 7.60. 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.

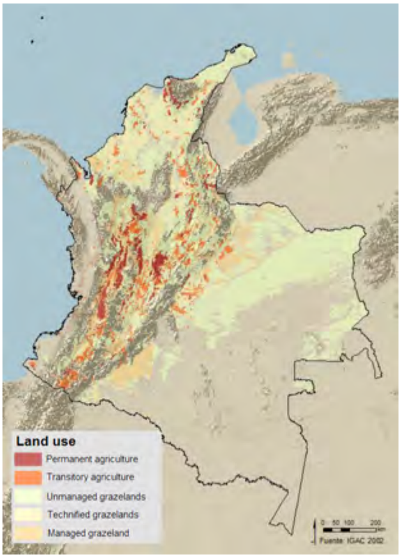
7.6.5 Food security

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.

Figure 7.61. Map of current agricultural production



Source: (IGAC and CORPOICA, 2002)

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.

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.

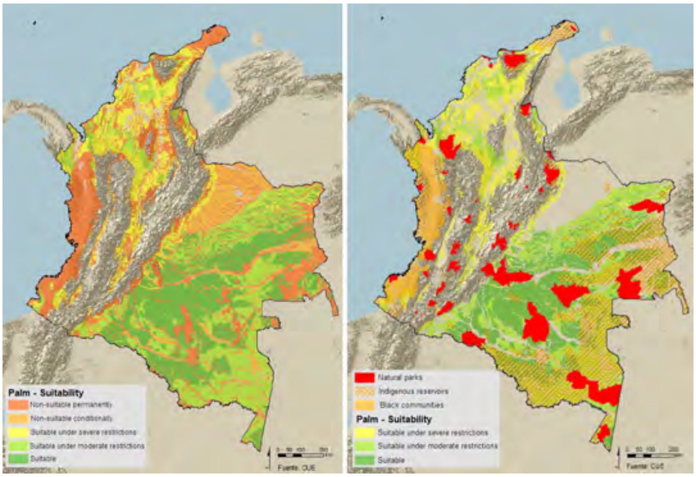
There are, of course, some other factors that influence suitability and sustainability of those crops for biofuel production (such as economic factors, temporary or seasonal issues, among others). Some of these factors were discussed when suitability maps were presented.

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.

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.

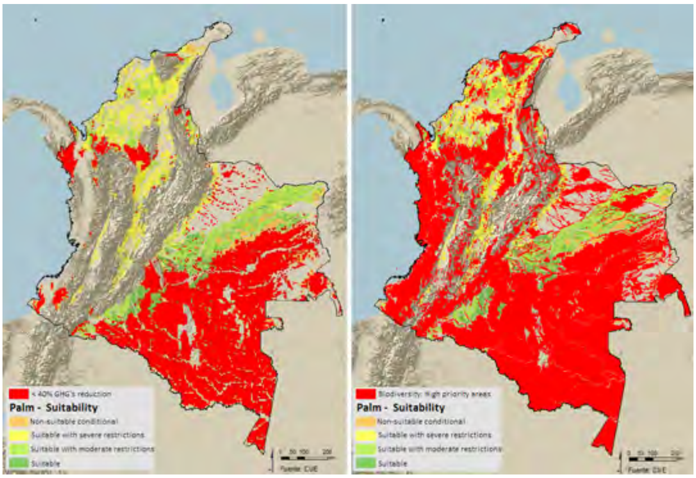
Figure 7.62. Palm oil suitability (1)



Biophysical suitability (left), overlapped with legal limitations (right). Source: CUE

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 7.63. Palm oil suitability (2)

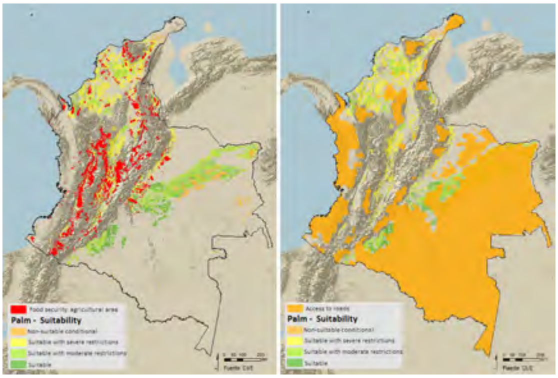


Excluding non–suitable areas regarding soil and climate conditions and protected areas, overlapped with protected areas and areas with less than 40% GHG's savings

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.

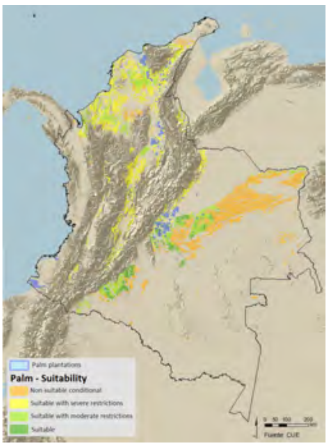
Competitiveness of crops located far from the road network, processing facilities and existing markets is limited; therefore these areas were classifies as "non–suitable condition" in the suitability map. Areas along Pacific coast, amazon region and areas on the eastern side of Colombia are remote.

Figure 7.64. 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)

Figure 7.65. 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

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.

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.

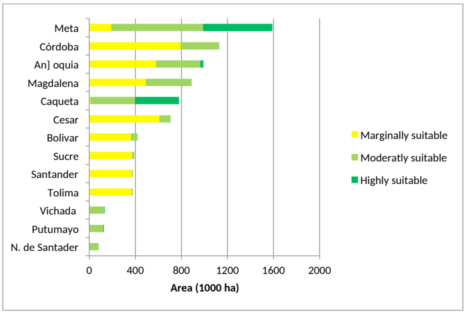
There is another area that exhibits high suitability conditions for palm oil tree cultivation, located along the shore of Magdalena River (in the departments of Antioquia, Santander and Bolívar) and especially close to the river mouth in the Department of Magdalena (in the western side of the Sierra 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.

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.

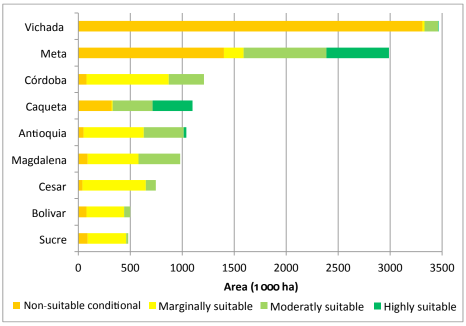
Figure 7.66. Zones with different suitability for palm oil plantations in Colombia (1)



(Highly, moderately and marginally suitable). Source: The author. Data source: CUE study

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 7.67. Zones with different suitability for palm oil plantations in Colombia (2)



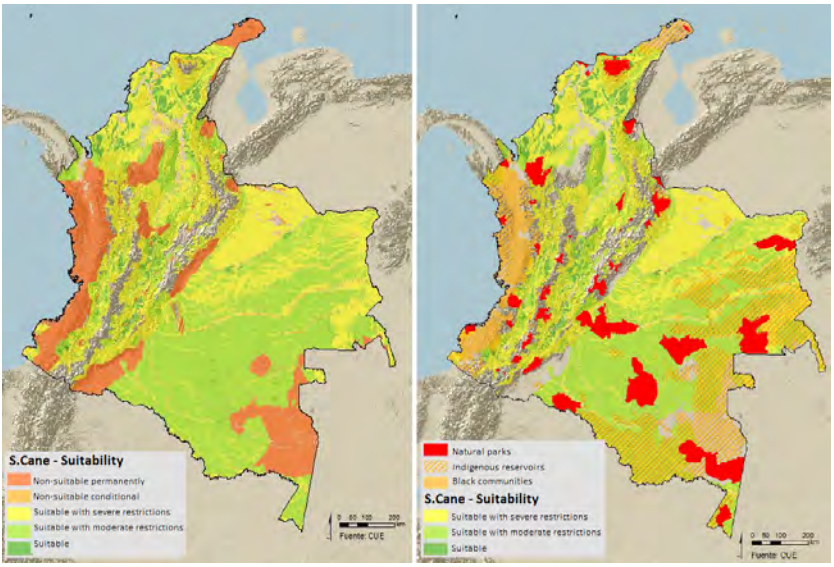
(plus non-suitable conditional). (including those suitable areas under certain conditions)

As is shown on the figure 7.67, 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 7.68. Sugarcane suitability (I)

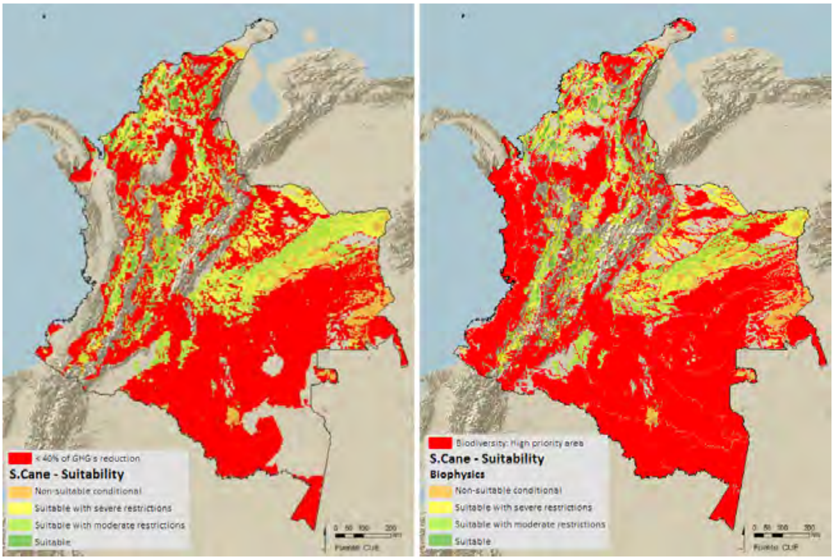


biophysical suitability (left), overlapped with protected areas (right)

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 7.69. Sugarcane suitability (2)

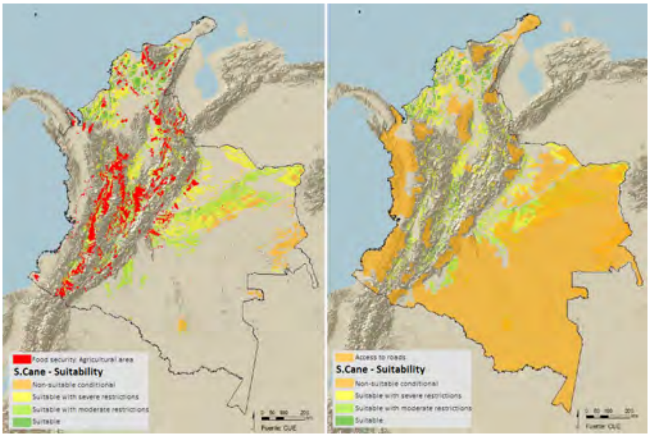


It excludes protected areas and biophysically non–suitable areas, overlapped with GHG's savings less than 40% (left), and biodiversity hotspots (right)

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.

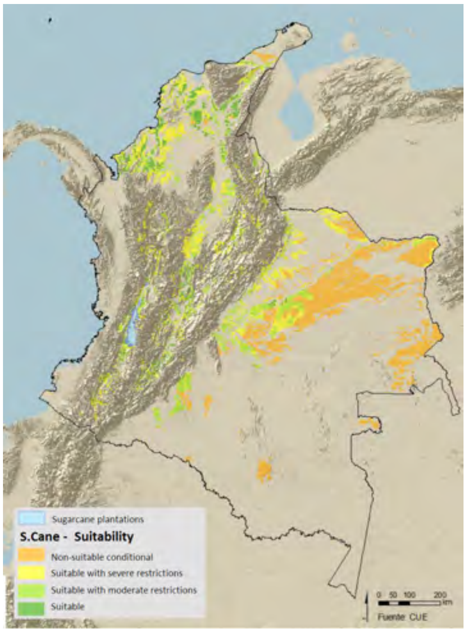
Figure 7.70. Sugarcane suitability (3)



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 7.71. 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

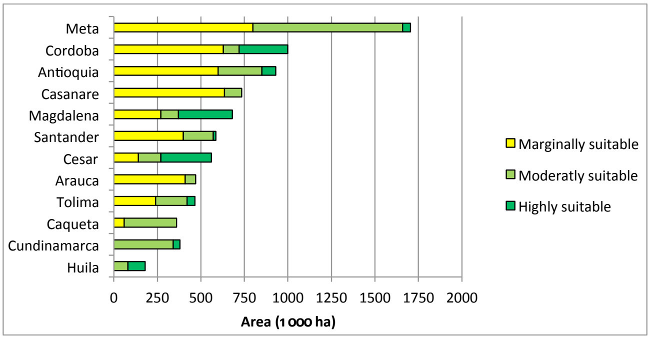
At the moment, near to 40,000 hectares of sugarcane crops are dedicated to ethanol production, and there is a high potential of expansion of up to 1,518,000 hectares of high suitability and 3,400,000 hectares with moderate suitability.

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 7.72. Zones with different suitability for sugarcane plantation in Colombia (I)



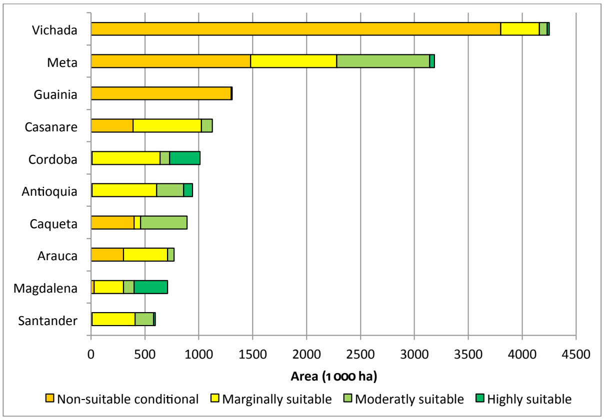
(Highly, moderately and marginally suitable)

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 7.73. 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).

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[I].

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.

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

[I] A 6 inches exclusive pipeline from the Oriental region of Colombia up to Coveñas (in the North coast), might cost US$400–450 million.

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.