

CHAPTER 1

INTRODUCTORY CHAPTER: BIOENERGY, SUSTAINABILITY AND COLOMBIA

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

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

Nevertheless, Bioenergy projects should be handled carefully. The Brundtland Commission has set a high standard through the Sustainable Development concept, one that will be difficult to achieve. The ideal status claimed by the Brundtland Commission, through the Sustainable Development concept, has imposed a high standard. Growth is possible, but some guidance should be provided in order to reap the benefits.

Sustainable production around the bioenergy industry has become a real challenge for Latin American and Caribbean (LAC) countries; of course alternative energies create opportunities but at the same time bring along significant consequences that should be fully understood, addressed and corrected if possible, before a full implementation with undesirable results is carried out. Sustainable development accounts for three basic aspects:

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

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

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

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

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

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

- The third section explains briefly the importance of Life Cycle Analysis (LCA) as contribution of the environmental component within sustainability studies¹. This instrument provides an insight to understand the proper extension of energy crops taking into account highly controversial topics such as carbon emissions and expansion in tropical areas.
- The fourth section will offer a general idea of the biofuel industry in Colombia, and the potential role that it plays in the global bioenergy scenario.

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

1.1 BIOENERGY AND SUSTAINABILITY: GENERAL OVERVIEW

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

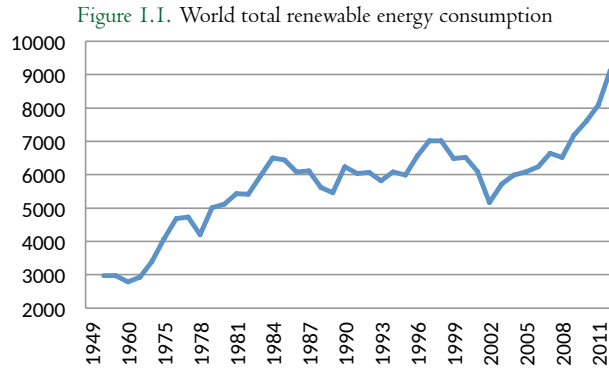
1.1.1 Bioenergy situation in the global energy scenario

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

For that reason, energy alternatives are starting to play important roles in energy consumption today. Some of those, such as nuclear energy, have the potential to cover part of the energy need at a competitive cost. However the radioactive waste management, the constant threat of nuclear material for use in weapons manufacture, and the reported scope of fatal accidents (the most famous ones being Middletown,

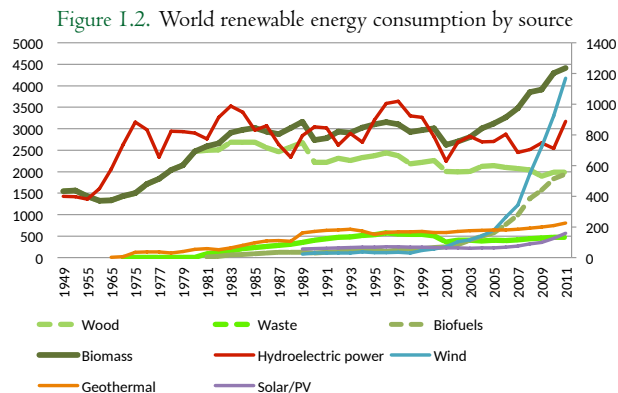
¹It is important to recognize that LCA does not provide a comprehensive analysis in terms of sustainability under a holistic perspective because it does not cover social nor economic aspects. It focuses rather on the so-called environmental sustainability (Čuček, Klemeš, & Kravanja, 2012); however, LCA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

Pennsylvania, USA in 1979, and Chernobyl, ex-URSS in 1986) create resistance among the population and in the general international political community.



Source: (EIA, 2012)

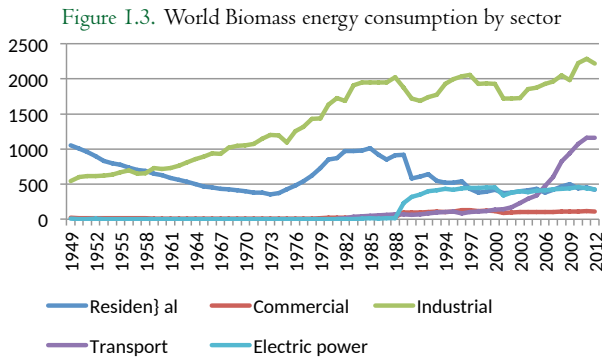
Renewable energies have been available for a long time and they are advancing on many different fronts. In general, it can be seen that renewable energy use has been increasing (See figure I.1). However, since 2001, there has been a noticeable upsurge in its consumption, with an average growth rate of 5.9%, but it is still uncertain if the cycle observed during the 90's will be repeated. Nevertheless, this evolution can be separated by source, as is shown in Figure I.2. Here, it is seen that some sources of renewable energy (RE) have experienced a substantial growth: it is noteworthy the case of Solar/PV, but even more noticeable, in terms of dimension, the growth exhibited by Bioenergy (particular modern bioenergy represented by biofuels). Bioenergy covers nowadays nearly 10% of total global primary energy supply (i.e. 50EJ). However, a big share of all bioenergy applications (62%) is represented as traditional fuelwood for cooking and heating (Lamers,



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

Junginger, Hamelinck, & Faaij, 2012). In the last decade the upsurge of modern biofuel applications has been substantial: within the period of 2000 to 2009 biodiesel production has move from 30 PJ 572 PJ, while bio-ethanol started with 340 and ended ud with 1540 PJ (Lamers, Hamelinck, Junginger, & Faaij, 2011). Use of wind power is still limited and the scale small (its highest point is less than one tenth that of Biomass used in the same period). An insignificant but stable part is played by both geothermal and solar power. Despite their enormous prospects they have not been embraced sufficiently by the market.

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



Source: (EIA, 2012)

This Biomass study can be even more detailed if it is broken down by sector as is presented in figure I.3. Biomass energy has traditionally been used (and it is still used) largely by industry, in the form of roundwood, wood byproducts and wood waste. Residential use is secondary to industry, and it has fallen constantly in the analyzed period, mainly due to conversion methods for cooking and heating in depressed regions, through substituting fuelwood and other sorts of biomass by kerosene, natural gas or gasoline².

²Private–Public Initiatives are being developed to reduce the use of fuelwood indoors because of the

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

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

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

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

There have been some setbacks in the augmentation of bioenergy initiatives around the world. In the period 2007–2008 the use of biofuels had an escalation in OECD countries mainly.

Such situation led to infrastructure investments that failed due to the economic environment that was present those days. The consequences were that some of the productive capacity was idle (by the time of the IPCC report) and some facilities were shut down. On the upside, Latin American and Asian (South Pacific) markets are growing, therefore the decline in the use of biofuels can be offset for this fact (Chum et al., 2011; IEA, 2010). Those active players in the current biofuel initiatives (with strong policy support) are expected to be the most benefited of the projected expansion for this market (From 2.1 EJ/y in 2008 to 16.2 in 2035) (Chum et al., 2011; IEA, 2010).

Finally, it is noticeable that the transportation sector is definitely driven by an active fuel substitution creation policy. In a very broad sense there have been identified

risk that it represents to health, as the documented experience of alternative stoves in Philippines. Decision makers are addressing their policies to fight this situation. "Household use of traditional bioenergy locks people in the developing world, particularly women, into a cycle of poverty and ill health" See (UN–Energy, 2007)

policies (such as promotion of domestic production and consumption and trade boosters or barriers) that add dynamism to the sector (Lamers et al., 2011). Biomass energy used in transportation is basically concentrated in liquid fuels (bioethanol and biodiesel) and it has grown at an average rate of 20% from 2000 to 2012. So far, Brazil, the EU and the US have been the main consumers and in major extent producers of liquid biofuels for the last decade, however more countries are emerging as potential producers and exporters of biofuels.

1.1.2 Bioenergy/biofuels production

Among different sources of renewable energy, bioenergy is highlighted by its scope and versatility. In contrast to other possibilities, like wind, hydro and solar power, it goes beyond electrical production and furthermore is capable of providing an attractive answer for transportation requirements. Biomass is understood as any non-fossil material of biological origin such as energy crops, forestry, residues and organic wastes³ and it can be used or transformed in an energy carrier. This can be extended to include fuels produced directly or indirectly from biomass. Some of these kinds of fuels are known as biofuels⁴ amongst which the most remarkable examples are, bioethanol, biodiesel, and biohydrogen⁵. Some other examples of bionenergy products can include fuelwood, charcoal and methane⁶.

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

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

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

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

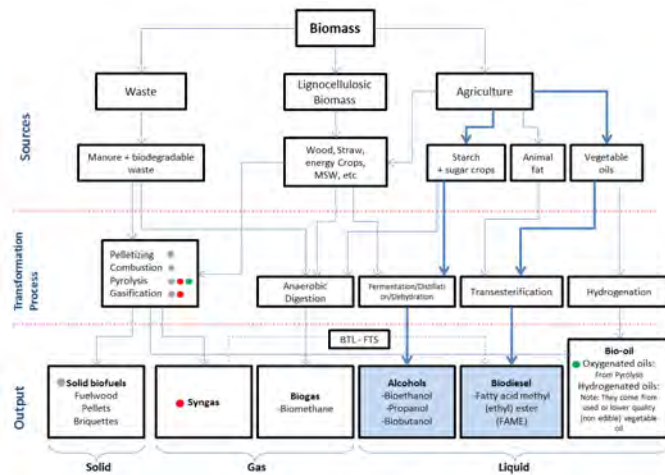
⁶In a broad sense fuel is any material capable of storing potential energy and that usually releases such energy as heat. Having said that some other bioenergy products (such as firewood or methane) can be considered themselves as fuels. However the literature has coined the term biofuels mostly for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

Types of biofuels (by natural physical state)

Biofuel can be classified by their natural physical state, i.e. solid, liquid and gas (as shown in figure I.4). Solid biofuels come from non-standardized material, like: branches, dung, irregular firewood, bark, among others; and are exposed to mechanical processes to transform them into regular shapes such as pellets or briquettes, making storage, commercialization and use less problematic. There is also the possibility to put biomass through torrefaction (pyrolysis), which involves exposing the material to temperatures between 200 and 300°C in the absence of oxygen.

Two main products are obtained: a solid material called biochar, and a gas called syngas or synthesis gas. Biochar can be used as a more concentrated firewood, but it has greater positive effect if it is used in agricultural practices, creating a negative net effect in terms of carbon emissions to the atmosphere, i.e. absorbing carbon instead of emitting it (J. Mathews, 2008a). In the case of syngas, it can be used directly as fuel or it can be used as source material to produce gasoline and diesel (through the Fischer–Tropsch process) (A. Demirbas, 2007).

Figure I.4. Route from biomass to biofuels



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

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

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

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

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

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

It is also possible to employ residual oil from frying processes, or wastes from oily animal fodder. However, the commercial experience with this product is not as wide as the FAME one (Evans, 2007), nor as homogenous in terms of product quality. It is also possible to use non-edible oily seeds such as *Jatropha Curcas*, which is not very demanding in terms of soil conditions, so it can be planted in degraded or marginal lands. From now on in this document, the term biofuel will make reference to any liquid fuel produced from biomass and used for transportation purposes. On that basis, it is possible to go deeper in to the classification of biofuels:

Types of biofuels (by technology generation)

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

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

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

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

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

Second generation biofuels (2GBf): they emerged as a response to the most critical issue faced by 1GBf: the fuel vs. food dilemma. Lignocellulose sources are the base for 2GBf, so more materials can be employed as mentioned before. The yield that can be obtained with 2GBf exceeds regular feedstock results by a factor between 2 and 5, and the requirements of agrochemicals is less intensive in comparison with 1GBf (Hill,

2007). Biodiesel production uses *Jatropha*, Castor oil and some bushes such as *Pongamia Pinnata* and *Callophyllum Inophyllum*. Lignin sources are also useful if they go through the Fischer Tropsch Synthesis. 2GBf can be obtained by using two paths:

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

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

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

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

Fourth generation biofuels (4GBf): Given the recent emergence of 4GBf, their literature references are ambiguous. On one hand they are presented as organisms genetically modified, in order to raise cellulose content and with low lignin content.

This is the case of some tropical Eucalyptus and Dahuria Larch. The main feature of these species is that they exclude carbon, turning into carbon negative biofuels (BioPact, 2007; J. Mathews, 2008a). It has been argued that energy content can be enhanced with 4GBf in comparison with 2GBf, reaching calorific values close to regular fossil fuels (Mannan, 2009).

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

Frequently, many authors combine 3GBf and 4GBf under 2GBf, therefore, it is not common to find much information about them. Their study and implementation are conceptually interesting, however, they need more time to reach a mature commercialization within the LAC region. For instance calculations have been made where is implied that some particular biofuels (methanol, ethanol, hydrogen and synthetic FT diesel) could cost between EUR 16–22 per GJ (with prices of 2006), however projections to 2030 indicate that through technology and a biomass supply cost of EUR 3 GJ such costs could drop up to EUR 9–13 per GJ⁷ (Hamelinck & Faaij, 2006). Thus, there are potential savings in production cost between 18% and almost 60%, which is very attractive to the industry.

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

1.2 SUSTAINABLE DEVELOPMENT AND ENERGY

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

⁷In some regions such as the former URSS and LAC region is possible to drop down such cost up to EUR 7-II per GJHHV.

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

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

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

1.2.1 Biomass production and sustainability

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

Important consequences are linked with a non–responsible biomass production system. Environmental results could be: devegetation, soil degradation, deforestation, erosion,

loss of biological diversity and climate change. In addition socioeconomic results could include: possible reduction of agricultural yields in some areas, uneven land distribution and forced displacement of local populations among others (Chum et al., 2011).

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

However, global warming, high pollution and fossil fuel's non-renewable nature have presented biomass as an appealing option in the current energy scenario. The photosynthetic process has an superb capacity for capturing energy. Through early studies (Miller, Mintzer et al. 1986) it has been shown that every year plants accumulate up to 10 times as much energy as the world uses. In using plants to produce energy important goals can be achieved: withdrawing the remarkable reliance on oil, moving back or even changing trends on pollution levels through carbon sequestration (wastes exchange⁸), and providing foundations for development and growth through rural development and creation of export industries.

This excitement comes with both high controversy and concern: a constant increase in food prices⁹, indirect effects such as tropical deforestation and GHG emissions generating a carbon debit due to inadequate land use¹⁰, this could be direct or collateral effects that endanger sustainability aims. Pros and cons around biofuels demand urgent attention: thus both sustainability balance and goals are top priorities on the global agenda.

1.3 LIFE CYCLE ASSESSMENT (LCA) IMPORTANCE

Measuring and monitoring sustainability is a key factor if new alternatives are to be implemented it is important to bear in mind that turning biomass into energy brings along input and output flows that may have impacts on the environment. Assessing Sustainable Development Production as a whole is, by definition, particularly hard, so indicators have been designed to reflect the desired “triple P” criterion. Some assessment methods applied to agricultural cases (Doherty & Rydberg, 2002) could

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

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

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

include, Cost Benefit Analysis (CBA), Ecological Footprint (EF), Energy Analysis (EMA), assessment of Ecological Integrity/index of Biotic Integrity (IBI), Positional Analysis (PA). However, none are complete or sufficiently integrated. (Fehér & L ydia, 2005).

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

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

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

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

Most of the LCA bioenergy analyses have been carried out in developed countries. Just recently a considerable amount of publications have shown productive systems in

developing countries, particularly in Southeast Asia. There is not abundant research for biofuels by using LCA studies in Africa and South America (Cherubini & Strømman, 2011). There is comparative analysis of the Colombian and Brazilian case via LCA study, however details of the study are not provided in the publication (Yáñez Angarita, Silva Lora, da Costa, & Torres, 2009). As part of this thesis, within the Chapter 8 will be presented a complete LCA for sugarcane based ethanol and palm oil, where it will compare results with those presented by Yáñez et.al.¹¹. To end the current chapter an insight of the Colombian bioenergy panorama is presented in brief.

1.4 COLOMBIA: COUNTRY, ENERGY NEEDS, AND BIOENERGY INDUSTRY

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

1.4.1 General Information

Colombia is a country located in north-western South America with a population of over 45 million people evenly distributed by gender (See Table I.1). It is possible to establish a density of approximately $38/km^2$ (Crossing information with Table I.2).

Table I.1. Colombian Population Distribution Estimated for 2006 and 2013

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

Its territory (more than 114 million hectares) places it as the fourth largest nation in South America. More than 70% of the population is located in urban centers which are

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

spread throughout the highlands of the Andes Mountains. However, Colombia also encompasses tropical grassland, Amazon rainforest, and both Caribbean and Pacific coastlines. In 2005, when bioenergy projects started in Colombia, more than half of its land was covered by forest, about 38% of the available land was suitable for agriculture, but was already predominantly used for livestock (above 90%), leaving only a small area for growing crops (see Table I.2). That opens the door today to create a new scheme of intensive agriculture/ergoculture¹² and to restructure land activity distribution.

Table I.2. Colombia Land distribution 2006 and 2011

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

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

FAOSTAT 2013

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

Table I.3. South American socioeconomic facts

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

World Economic Database, January 2014

Due to its high population (second in the South American region), its GDP per capita in Colombia is below average in South America (See Table I.3). A similar situation occurs

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

¹³Data from IDB (Inter-American Development Bank) databases:

http://www.iadb.org/countries/indicators.cfm?id_country=CO&lang=en

in Brazil according to the ranking; however, its GDP per capita is over the average in the region by far, showing a big gap in productivity, dividing these countries into two groups:

- High productivity (Venezuela, Chile, Uruguay, Argentina and Brazil)
- Low productivity (Colombia, Peru, Ecuador, Paraguay and Bolivia)¹⁴

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

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

It is fair to say that Colombia now has a better security situation which has brought investment confidence. Since 2002, under president Alvaro Uribe's administration, a new government plan started called "Democratic Security", characterized by providing an enforcement of the public force (Manson, 2003)¹⁵, hence creating a trust climate and boosting direct foreign investment. But it is undeniable there still exists the effects of a 40-year-old civil conflict with the presence of guerrillas, paramilitaries, and drug dealers creating political instability, and generating grim effects such as forced displacement and irrational use of land. However, a high environmental price has been paid by Colombia in order to adopt the current development model. The uncontrolled growth of every city has left a huge legacy of environmental problems: atmospheric and noise pollution, and

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

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

traffic congestion are endemic. Generalized respiratory issues and control policies are a consequence of that, diminishing the productivity in some cities¹⁶. Aquatic ecosystems, especially rivers close to development cores are extremely polluted.

Additionally coffee plantations, the traditional crop in Colombia with around 590 thousand hectares cultivated today¹⁷, require intensive use of pesticides and fertilizers, and are highly demanding of lighting conditions, which means large scale clearances of shade trees, resulting in degradation of soil quality. Deforestation is massive and largely uncontrolled and is the outcome of undesired migration processes, thus increasing the desertification progression in the Andean ecosystem (O'Brien, 1997). Profits have been plunging and most of the added value is captured by international coffee processor, and benefits for small farmers are appalling.

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

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

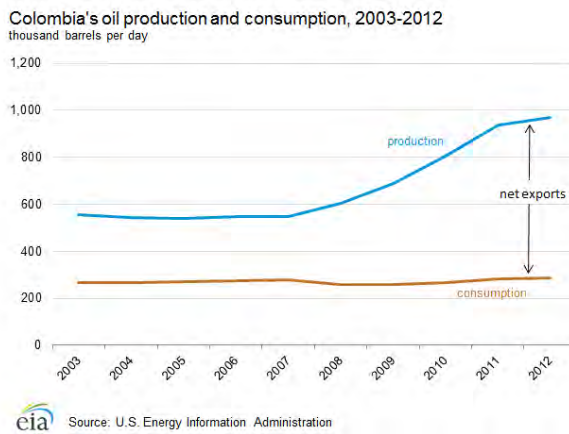
¹⁶Daily respiratory hospital admission is highly correlated with air pollutant emissions. The result of this is: on one hand frequent work absence and on the other hand creation of taxes for emissions, restrictions over the use of vehicles, among others (Lozano 2004). In recent years Bogota, Pereira, Cali and Medellin have implemented restriction of the use of vehicles only during peak hours with effective results. Other cities are planning to follow that example. However, since the beginning of 2012 the Mayor of Bogota, Samuel Moreno, has imposed a very controversial full "No drive day" during two weekdays (taking turns according with the license plates on private vehicles), generating slowdown in business and creating analogous effects experienced by Mexico City, where a similar program appeared to have induced the purchase of a second vehicle, often older and more polluted. This law is under revision by city council in order to whether cancel or continue.

¹⁷FAO Data base <http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#anchor>

1.4.2 Energy Information

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

Figure I.5. Colombia's Oil production and consumption



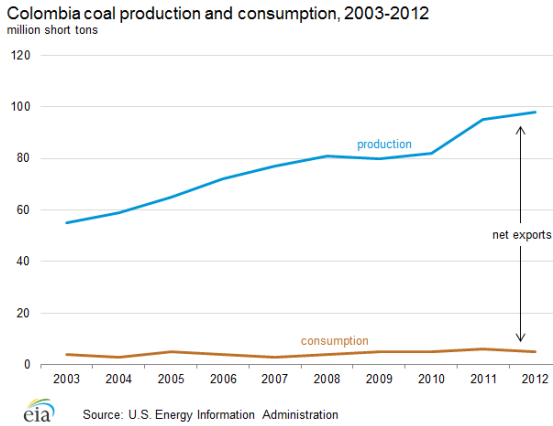
As the security situation is being improved, the number of attacks against Colombia's energy infrastructure has dropped, but even today occasional sabotage is done by insurgent groups to the country's pipelines and power lines (EIA, 2009a). According to Oil and Gas Journal (O&GJ) cited in EIA, Colombia had 1.36 billion barrels of proven crude oil reserves (as of 2009), the fifth—largest in South America. Production though, is at risk, attributed to lack of confirmed new oil reserves and uncertainty associated to investment flows for exploration and drilling activities (See Figure I.5).

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

Colombia counts on a diversity of energy choices, but none of them are absolutely sustainable in the long run. The country is running out of oil, hydro is highly threatened by possible droughts, and coal's share in internal industry is not heavy, not to

mention high pollution contributions; hence investment in new alternatives, such as bioenergy, must be considered and welcomed, after proper studies and commitments to sustainable production standards.

Figure I.6. Colombia's Coal production and consumption



1.4.3 Biofuels in Colombia

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

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

Research and Development (R&D)

Colombia has been following the path of biofuels research for almost 30 years and it has accumulated several research groups that are working in several areas, including:

basic research, agricultural projects, product transformation, biotechnology, engine applications and environmental impacts.

It is remarkable the interest of research groups born from private initiative, directly linked with agribusiness chains: CENICAÑA¹⁸ for instance is the Colombian Sugarcane Research Centre, it was funded in 1977 and it is sponsored directly by ASOCAÑA¹⁹ (established in 1959). The same happened with CENIPALMA (Colombian Research Centre for palm oil), which works since 1991 under supervision of FEDEPALMA²⁰, which in turn was created in 1962. Despite this, research centers are not specifically designed for supporting the biofuel industry, their efforts are focused on these products because they concentrate R&D to point out efficient crop methods and biological varieties that increase yields per hectare.

Other independent R&D centers are also present around the Bioenergy industry. That is the case of CIAT²¹ International Research Center for Tropical Agriculture. This center is leading cassava-based ethanol production in the LAC region, a pilot plant was recently built as is explained in appendix 9.I.

Some research projects are starting to be directed exclusively to bioenergy production. The Biotechnology Institute belonging to Universidad Nacional²² just discovered a bacteria that is capable of eating glycerin (co-product of bio-diesel and highly contaminating if it is not treated adequately) transforming this substance for further processing (La Rotta, 2009).

In order to enhance sustainable production of biofuels and to promote strategic lines for innovation and scientific research in Colombia US\$ 1,180,000 was planned to invest from 2008 to 2012 (MEN, 2008; Rojas R, 2008). These funds were supposed to come from “Inter–Americas Development Bank” (IDB) giving more than 40% of the total investment. The “Knowledge Partnership Korea Fund for Technology and Innovation²³” contributed US\$350,000, and the rest being donated by “Instituto

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

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

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

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

²²The biggest public university in Colombia

²³This contribution from the Korean government is part of a big help (US\$ 50 million) to Latin American countries in order to strengthen their science and technology capacity. The inclusion of Korean

Colombiano para el Desarrollo de la Ciencia y la Tecnología”, “Francisco José de Caldas” (COLCIENCIAS)²⁴ (MEN, 2008). So far, there has been no report on the public light regarding this particular initiative.

Legal Framework

Regardless of longstanding interest in bioenergy/biofuels research, legislation around biofuels in Colombia only started some years ago with Ley 693 de 2001²⁵. In this law the regulation indicates that gasoline and diesel must be blended with ethanol. Despite the advanced condition of the market at that, the standards were not clearly established. With a later resolution in 2003 this situation improved, by recognizing the importance of biofuels and the necessity to expand the supply. Initially it demanded that cities with a population over 500,000 should mix regular gasoline with ethanol in a proportion of 10±5% to create what is known, nowadays, as regular oxygenated gasoline. Mandatory use started in September 2005. Some tax-exemptions in the commercialization chain were released to boost the production, and the prices would be controlled by the Government through the Ministry of Mines and Energy²⁶.

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

Partnership was announced by Ciro de Falco, IDB Executive Vice-President in his opening speech for the Global Forum: Building Science, Technology, and Innovation Capacity for Sustainable Growth and Poverty reduction (January 2007).

²⁴Colombian Institute for Science and Technology Development.

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

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

Investment

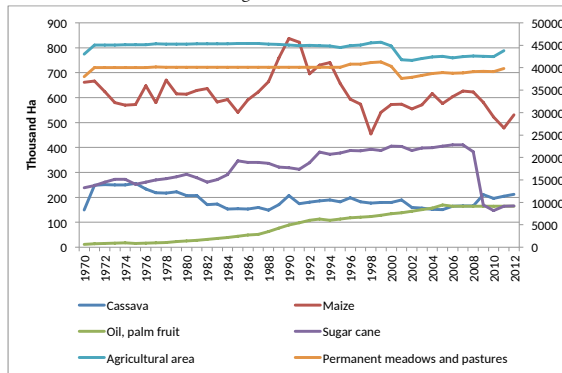
In 2006, a consortium of Colombian companies announced that they would build three ethanol plants in the country, with a total production capacity of 5,600 bbl/d, however, that has not happened. Contrary to coffee, biofuels have to be processed domestically, so the export of unprocessed commodities can be avoided (J. A. Mathews, 2008), generating local development. These plants mainly target export markets, but will also sell some of their production domestically. ECOPETROL formed a joint venture in 2007 with local palm oil producers to build a biodiesel plant in the city of Barrancabermeja, with a capacity of 2,000 bbl/d. ECOPETROL aimed to blend most of the plant's output with conventional diesel fuel produced by its refinery in the city (EIA, 2009a).

The IDB is also planning to finance a US\$20 million palm based biodiesel plant that will eventually produce up to 100,000 tons of fuel per year. Some exotic varieties such as *Jatropha* are attracting the attention of investors in Colombia, trying to replicate the successful African experience. In particular, Oilsourse Holding Group Inc. and Abundant Biofuels Corporation are eager to bid on Colombian soil with an estimation of US\$45 million. It brings an appealing chance to diversify feedstock in Colombia bioenergy plans and partially avoid the food vs. fuels discussion.

Regarding biofuels: what is produced in Colombia and how?

Figure I.7. Land indicators of selected Commodities

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



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

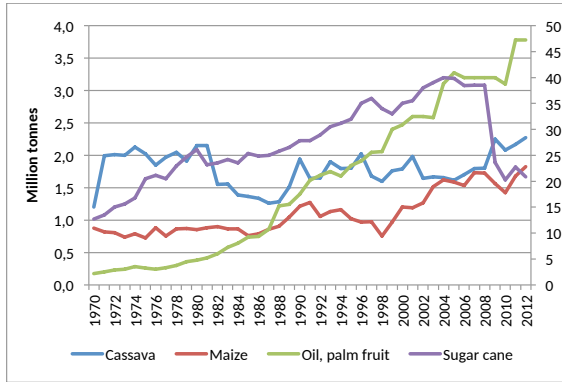
Nowadays in Colombia, there are different sources of alternative energy: wind power is generated on the North coast in the Jepirachi plant in the Department of La Guajira, several hydro dams are located throughout Colombia supplying most of the electricity to

the energy grid, and now it is the turn for bioenergy: today this South American country is producing ethanol and biodiesel, and there is a project for biogas.

Bioethanol

Bioethanol in Colombia is partially based on starch extracted from maize and cassava crops. Maize has the highest acreage among biofuel feedstock sources²⁷. Maize crop area has been fluctuating substantially in the last 2 decades, but the current level is slightly lower than 20 years ago, close to 0.6 million hectares (See figure I.7). Cassava is also a starch source and its area has practically remained constant from the early 1990's but has a remarkable production growth using the same area (its production has changed 66% in the analyzed period and the cultivated area has varied by 16%, see figure I.8).

Figure I.8. Production of selected Commodities in Colombia



Note: Sugarcane is measured in the secondary axis

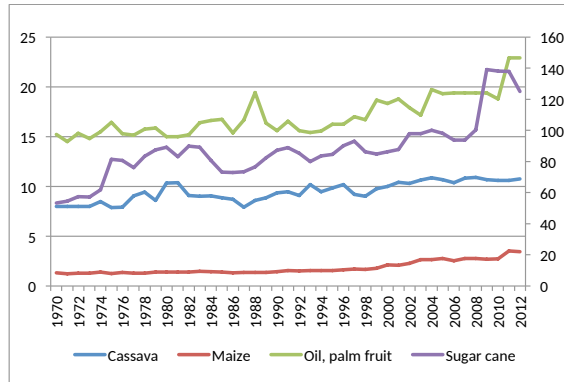
FAOSTAT | © FAO Statistics Division 2013 | 11 December 2013

Currently, most of the ethanol industry in Colombia is alcohol-based, hence sugarcane is the preferred input due to its high productivity²⁸, reaching levels of 90 ton/ha, which is approximately 8 times cassava productivity (See figure I.9). It is estimated that between 37,000 and 50,000 sugarcane hectares (8.2% and 11.1%) and 3000 cassava hectares (16%) are dedicated to producing ethanol (Rothkopf, 2007).

Figure I.9. Yield of selected commodities in Colombia (tonnes/ha)

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

²⁸Colombia is placed in world top 10 sugarcane producers.



Note: Sugarcane is measured in the secondary axis.

FAOSTAT | © FAO Statistics Division 2013 | 11 December 2013

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

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

Table I.4. Differences between Brazilian and Colombian ethanol industries

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

a: Toasa; b: Sugarcane.org (2014); c: Faostat; d: Chum et al. 2011;
e: Fedebiocombustibles website; f: (Barros, S. 2012); *: Calculated based on the source.

Processing technology to treat sugarcane in Colombia is being brought from India and it has some advantages, including: it produces a low volume of vinasse²⁹ and allows them to be further processed and deliver fertilizer to market. In addition ethanol plants in Colombia use about one-third of the water of Brazilian plants and about half of the energy (Toasa, 2009). However the sugarcane variety used in Colombia needs heavy irrigation which is avoided in Brazil.

Additionally, sugar mills in Colombia are energy self-sufficient, using burned bagasse as a power source. In fact, the energy produced is higher than the required amount for the factories, for that reason surplus is sold to the national energy grid³⁰.

In spite of counting with higher yields in terms of tons of sugarcane per ha, Colombia handles higher productions costs and prices, and this is mostly due to the fact that in Brazil alcohol industry has been from the mid 70's, whereas in Colombia is just starting to mature. Literature does not provide detailed reference regarding maize ethanol production, but there are some notes around exotic cassava production in the country (See appendix 9.I).

Biodiesel

Biodiesel production in Colombia is derived from palm oil³¹, because other oleaginous sources have been reduced and are not competitive (Honty & Gudynas, 2007). Contrarily, palm oil crop areas and production have increased rapidly (on average 13% and 11% respectively yearly, See charts 7 and 8).

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

Opportunities and threats

The Colombian bioenergy industry brings a dual challenge: On one hand, it has the chance to develop an enormous comparative advantage. To develop alternative energies that not just implies a decrease of oil imports but opens the possibility of a nascent exporting industry, beyond just agricultural commodities that have been usually commercialized as raw materials or as products that face high levels of competition in

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

³⁰Some incentives are being created in order to attract investors to create 230 MW. Nowadays the industry is able to produce 90MW. Expanding capacity requires about US\$100000 and government support.

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

international markets or with low added value (e.g. raw sugar, unrefined oil) (See appendix 9.2).

The boost of this industry can have collateral impacts on other social aspects, such as job creation and income distribution. The biofuels industry is manpower-intensive, so it can have a positive impact on the labor market. In 2004 the palm oil industry contributed to employment with the creation of more than 30,000 direct jobs and about 60,000 indirect ones (Fedepalma, 2004). Sugarcane, by 2008, provided 36,000 direct jobs and 216,000 indirect (Toasa, 2009). If more agribusiness projects are implemented in this industry, economic well-being can be boosted and social conditions as well. The implementation of biofuel regulations contributes to a positive environmental balance in major Colombian cities, expressly: with the use of biodiesel, pollution emitted by low quality diesel used in the nation will eventually diminish.

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

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

Colombia demonstrates a robust legal framework, showing a strong government commitment to the industry. Of course, it has paid off with almost twelve bioenergy functioning projects since law 693 was released in 2001. Investors and agribusiness sectors are encourage to keep working on and enhancing productive capacity.

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

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

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

According to the government, the formula used to calculate the price was designed to encourage ethanol suppliers and boost the quantities produced, in order to reach the proposed goals to cover most of the country, but it has recognized that some errors could have been made and should be corrected³⁴

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

³⁴Based on the resolution 181232 (29/07/2008), issued by the Ministry of Mines and Energy, the Sales Revenue for alcohol fuel producers ($IPAC(t)$) is defined by the following formula: $IPAC(t) = \max[COP\$4696.88, EqAC(t)1, EqAC(t)2]$ Where $IPAC(t)$ refers to the Sales Revenue for alcohol fuel producer, as the result of the sale of such product (expressed in gallons and in standard conditions, i.e. at a temperature of 60°F). COP\$4696.88: Expresses a minimum price per gallon and it has to be paid to the producers if some other conditions are not convenient. This value has to be adjusted by use of the price producer index (IPP) (70%), and the official exchange rate (TRM). The price is fixed and adjusted by technicians at the Ministry.

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

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

Finally, multinationals are accused of hiring or creating paramilitary groups, with hidden government approval, with the intention of securing their investment and to cover it from possible attacks from insurgent groups such as FARC guerrilla or other criminal organizations. On the contrary, the military capacity of these paramilitary groups have been used against local small farmers in order to displace them and grab their land (See Appendix 9.3), and used against union leaders to control and scare the population.

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

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

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

However, according with FEDEBIOCOMBUSTIBLES, in Colombia the area used for both sugarcane and palm oil is less than 1% of the agricultural area within the national territory (21.46 million ha). In addition ethanol production use nearly 40.000 ha out of 223.905 that are employed for sugarcane plantations. In the production of biodiesel it is utilized an area of 160.000 ha out of 430.000 ha of palm oil crops (USCO, 2012)

gasoline. The whole formula can be seen in the reference.

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

Based in the aforementioned, there is little prospect of bioenergy crops in Colombia representing (under current conditions), a threat to food security.

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

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

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

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

1.5 CONCLUSIONS AND GENERAL COMMENTS

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

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

Hydro provides a good backup for electricity production, but transportation and other industrial needs are not within its scope. Not to mention the possible risk associated

with droughts. Developing an alternative, such as bioenergy/biofuels, brings opportunities and responsibilities. If land availability and institutional willingness are merged in a project of sustainable production of biofuels, undesirable consequences for population and the environment can be avoided, then, on the contrary Colombia can accompany, rather than compete, with other countries i.e. Brazil and become a key supplier of bioenergy in the future.

Sustainable certificates, hopefully under multilateral support, can help market forces to find a win-win solution for human kind and nature, but sustainable production conditions must be studied, exposed and implemented, as a policy in the short run, but preserved in the long run. Colombia has already started its biofuels industry, but, it is important to establish to what extent Colombian biofuel production can be considered sustainable, and what is its potential in a domestic market and also on a global scale.

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

In the environmental part is it mandatory to preserve biodiversity hotspots and maintain or improve conditions of natural resources. This implies good practices in land and water management and also positive responses in air quality assessments. In general this has to be achieved by reducing overuse of agrochemicals (fertilizers and pesticides), as well as by improving technological routes (which either enhance the performance of current feedstocks, or enable the use of new materials to be converted in bioenergy products), and by achieving attractive energy balances³⁵, like those reached by forefront bioenergy players. The GHG emissions must be reduced through the implementation of bioenergy for transportation, having into the account LUC effects.

In the social aspect, there is the need of improving housing, health and education conditions for the nearby population affected by the establishment and processing of energy crops. Processing companies need to be engaged with responsible practices, and by respecting labor laws and by working under fair production standards. Expansion

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

cannot lead to force displacement of vulnerable communities. Land distribution, proprietorship and use regarding bioenergy requires close up scrutiny to guarantee a complete sustainable biomass-based product.

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

However, in order to prove the aforementioned to be true, the upcoming chapters will try to answer several questions which are at the core of this thesis document³⁶. Those questions will be focused in the ongoing industry, i.e. first generation biofuels, based on sugarcane and palm oil mainly, due to the short and midterm conditions of investment in the Colombian bioenergy policy agenda.

Main questions:

1. The panorama for Colombia has already been presented in this chapter, but what are the current biofuel production conditions in other countries that can be considered similar and used as a reference, i.e. which countries from the LAC region? What issues emerge in producing and using biomass based fuels?
2. What are the environmental problems that are faced by a nation such as Colombia? What kind of relationship exists between them and biofuel production and implementation?
3. Within the domestic market, how are cost and price conformed? Which actors play a role along the production chain regarding price/cost formation?
4. How is the whole production chain from feedstock production to final consumer organized?

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

5. How sustainable are sugarcane based ethanol and palm oil based biodiesel under a LCA perspective?
6. To what extent is it possible to expand current energy crops in the Colombian context? Taking into account biophysical, legal, ecologic, and social restrictions explored formerly?

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

