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The Choice of Biofuels to Mitigate Greenhouse Gas Emissions

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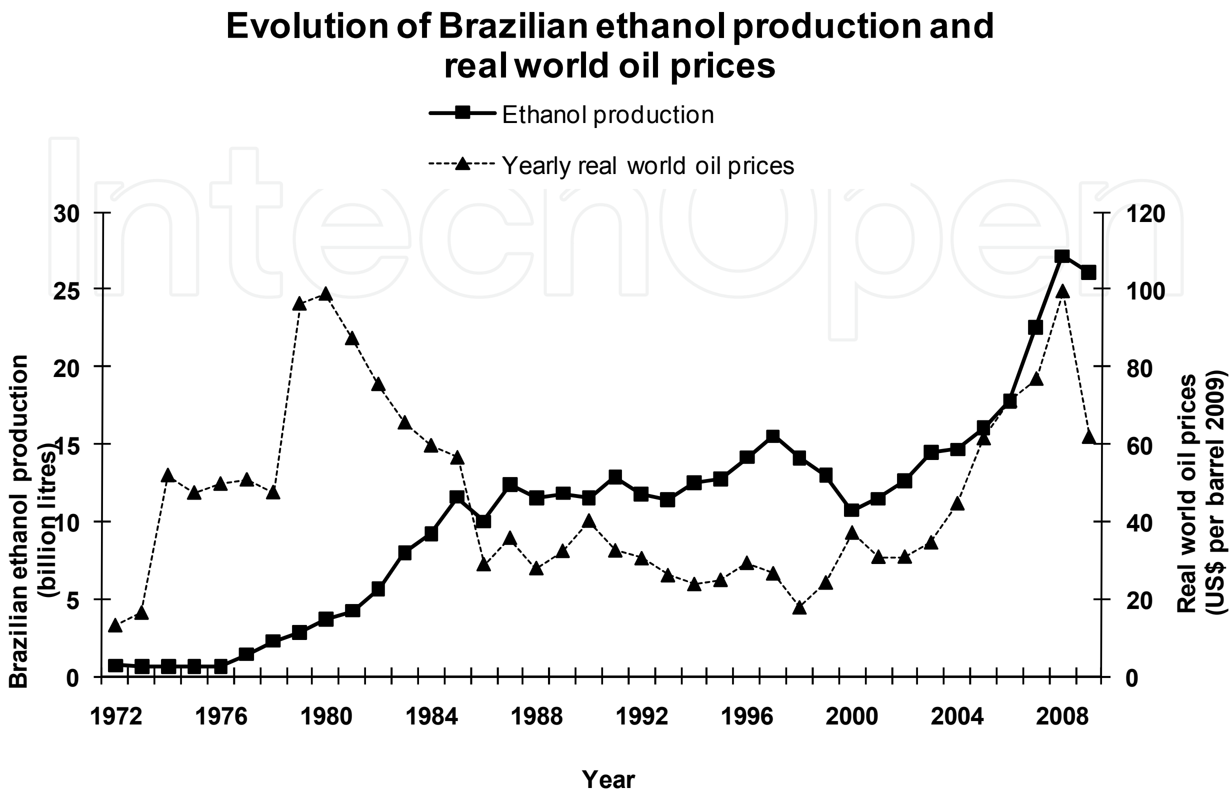
1. Introduction

The tentatives to use biofuels can be traced back to the years around 1900 when Henry Ford and Rudolf Diesel used ethanol and vegetable oil in their Otto cycle and Diesel cycle engines, respectively. With the introduction of oil in the energy scenario as a very cheap option, the interest in biofuels dwindled down rapidly and the transport sector was fully dominated by gasoline and diesel. However, the idea did not die and biofuels came and went a few times; in the mid 1920s ethanol fuel was used in Brazil and in 1931 a Federal Law mandated the blending of 5% ethanol in all imported gasoline used in the country. Since then, several biofuels options have been produced and tentatively used in some countries: ethanol, methanol, higher alcohols, vegetable oils, fat acid methyl/ethyl esters, biogas and dimethyl ether (DME) just to mention the main ones.

The driving forces behind the use of biofuels are many, but can be separated in four groups: environmental benefits (local and global), high oil prices, energy security and support to local agriculture. Different countries in different times were drawn by different motivations that changed in time in each case. Looking into the main biofuel programs today it can be seen that USA alcohol program was originally intended to mitigate local pollution problems due to vehicle tail pipe emissions but today is driven by the support to local agriculture, energy security and only very recently, with the Energy Independence and Security Act of 2007 (EISA 2007), it has shown some interest in global warming mitigation, with the introduction of minimum greenhouse gas (GHG) emission reduction limits for different alternative of biofuels (Renewable Fuel Standard – RFS2); ethanol dominates the first generation technologies (1G) with biodiesel playing a minor but important role. The Brazilian Alcohol Program launched in 1975 was aimed at reducing the oil imports (due to high oil prices and energy security), but also at improving the sugarcane industry conditions, badly hit by the low sugar prices and overproduction; after the decline in oil prices in the mid 1980s the focus became the reduction of local pollution in the large cities resulting from vehicle tail pipe emissions; more recently, in 2004,the National Biodiesel Production and Use Program was initiated in Brazil with a strong focus on social inclusion and support to small producers, but also with the justification to eliminate diesel imports. Some countries in the European Union (EU), notably Germany, introduced biodiesel to support local agriculture with surplus production problems, however, the Renewable Energy Directive (RED) introduced in April 2009 and the revision of Fuel Quality Directive (FQD) present some sustainability requirements, including GHG emission reduction minimum threshold values, tightening along the time, and fuel quality standards. Since the motivations are many and variable in time, with the changes in context both in local and global scale, it is critically important that a biofuels program, to be launched by any country, should have very clear objectives and a long term view to reduce the risk of supporting inadequate alternatives that will prove unsustainable, or at least inefficient, in the future.

Besides meeting the objectives of the main driving forces, the biofuel alternative to be sustainable and come to represent a meaningful positive impact on the performance of the transport sector it must have some characteristics such as environmental benefits (both local and global), be able to be produced in large quantities without negatively impacting food and feed production, have a good positive energy balance and, last but not least, be competitive in the long run with fossil fuels and other renewable energy alternatives. Although there were many alternatives studied and developed in the past decades, today ethanol and biodiesel from first generation technologies (1G) dominate the biofuels scene and the escalating oil prices have demonstrated to be a very strong driver, as can be seen in Figure 1 for the case of Brazil. The low oil prices between 1986 and 2001 are responsible for the stagnation of the ethanol use in Brazil and the escalating oil prices after 2002 (that peaked above US$ 140/barrel in 2008) can be blamed for the very fast growth in biofuels production and use in the world seen after 2004, when the global biofuel production increased from 32 billion liters (30 billion liters of ethanol and 2 billion liters of biodiesel) in 2004 to 93 billion liters (76 billion liters of ethanol and 17 billion liters of biodiesel) in 2009 (REN21, 2010); fortunately the major players have noticed the danger of embarking in wrong options and introduced legislations establishing some requirements to differentiate the alternatives in terms of feedstocks, local producing conditions, processing paths and, most importantly, GHG emission reduction potential.

The global energy market is several times larger than the agricultural commodities market and, therefore, the question is how much the world in general, and each country in particular, can or should produce before the demand for natural resources for biofuels becomes a problem. The International Energy Agency (IEA, 2009) forecasts in the Low Carbon Scenario (Scenario 450, to keep the temperature increase at no more than 2 ºC above the pre-industrial age values) that biofuels will represent some 11% of world transport fuel consumption by 2030; this means around 278 Mtoe of biofuels by 2030. Second generation technologies (2G) will start to be significant around 2020 and will dominate after 2030. IEA also points out that, although 2G technologies will dominate after 2030, sugarcane ethanol will be the only 1G biofuel to survive in the long term (IEA, 2008). In comparison the Reference Scenario estimates the biofuels global production in 2030 as 132 Mtoe representing 4% of the transport fuel demand. To play an important role in GHG mitigation, biofuels should come to represent at least 10% in the world transport fuel pool, with 20% representing a more ambitious, but probably achievable, target for the long term. Setting a tentative target the question now is if can we do it, in terms of resources availability, investments required and how much would cost with respect to GHG mitigation effect (US$/t$CO_2$). It is quite clear that the options should be carefully chosen and that only a handful of countries can play a significant role in this endeavor; this does not rule out the use of biofuel alternatives for niche and specific applications and the participation of several countries in the global biofuel production.



Source: BP, 2009 and EIA, 2010 (oil prices); Energy Research Company (EPE, 2010) and Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA, 2009) (Brazilian ethanol production)

Fig. 1. Evolution of Brazilian ethanol production and real world oil prices

Therefore, the aim of this chapter is to analyze several options of the most promising biofuels in terms of GHG mitigation potential, taking into consideration the demand for natural resources, GHG emission reduction, and technology availability in time.
The state of the art of lifecycle analysis (LCA) methodology to estimate de GHG emissions in the production chain of the biofuels are evaluated based on a selected literature review, aiming at the identification of the key issues in terms of reliability and reproducibility of the results, unresolved problems and comparing the biofuel alternatives with respect to their GHG emission reduction potential. The two major legislations related to biofuels (European Renewable Energy Directive and US Renewable Fuel Standard) are analyzed to identify the main points relative to GHG emission reduction requirements and the listed default values for the various alternatives; this is a key issue in this chapter as it offers a good indication on which ones are likely to survive in the long run.
Considered by many to be the most important unresolved problem, the determination of the GHG emissions derived from land use changes, both direct and indirect (LUC and ILUC), the theme is discussed based on the most recent works in this area that are or have already been submitted to public consultation process. The impacts estimated are analyzed to supplement the data presented in the previous section, indicating that they can be significant and that more work is certainly required to improve the confidence of the results to an acceptable level and to bring them to a broader range.

The land requirement to produce biofuels is discussed with respect to the potential availability, possible long term biofuels targets and the importance on the sustainability; it is stressed the importance of biofuel yields in all aspects of sustainability.
To be able to produce practical data, the work will concentrate in a case study, taking sugarcane ethanol produced in Brazil as an alternative to displace significant amounts of gasoline worldwide as transport fuel. In this way, the impacts of resource demand, energy balance and GHG lifecycle analysis, including LUC and ILUC effects, can be assessed. The introduction of 2G technologies after 2020 using the sugarcane fiber as feedstock is also investigated as well as the introduction of improvements in the 1G technology of sugarcane ethanol production in the future.

2. Characteristics of biofuels

There are some important characteristics of the biofuels that indicate how well they will perform in terms of meeting the objectives of mitigating the GHG emissions, improving energy security and strengthening the rural economy, without causing meaningful negative impacts on the local environment, food/feed production and prices, biodiversity, social-economic conditions of the local community and, probably the most important of all, be economically viable in the long term without subsidies. For the sake of maintaining the focus on the main issues, only the aspects of GHG mitigation potential and land demand will be considered.

2.1 GHG mitigation potential

The technical and scientific literature is rich in articles and reports dealing with biofuels GHG Life Cycle Analysis (LCA). Larson (2006) reviewed more than 30 publications on this subject covering a broad spectrum of biofuels such as first generation (1G) ethanol, biodiesel, pure vegetable oil, esters, ethers from different feedstocks and second generation (2G) ones including lignocellulosic ethanol and ETBE, Fischer-Tropsch diesel and dimethyl ether (DME) from crop residues and woody crops and grasses; a wide variation in the results was observed in terms of net energy balances and GHG mitigation potentials, even for the same type of biofuel. The reasons for this high uncertainty were attributed to possible range of the input values and variability of the assumptions related to GHG included, N_2O emissions, soil carbon dynamics and allocation method used to give credit to co-products. All but two of the works reviewed were related to developed countries conditions and the two exceptions referred to Brazil and India. In this work it is stressed the importance to refer the GHG emissions and net energy balances to the land used in the feedstock production (tonnes of CO_2eq/ha) and not only to the energy content of the biofuel (gCO_2eq/MJ). Another review of biofuels energy balances and GHG LCA covering 30 relevant papers and reports (Manichetti and Otto, 2008), screened from a set of 60 works, has also indicated a wide variation in the results for the different types of biofuels and feedstocks, even among analyses of the same biofuel and feedstock. First generation (1G) ethanol from maize, wheat, sugarcane and sugar beet and biodiesel from rapeseed, soy beans, sunflower and palm oil, as well as second generation (2G) cellulosic ethanol and Biomass to Liquid (BtL) biofuels, were included in the works reviewed. The agricultural phase is appointed as responsible for most of the GHG emissions and for the adverse local environmental impacts, while the processing phase had the largest contribution to energy use, with the exception of sugarcane ethanol. The main uncertainties are related to N_2O emissions, due to its complex process and dependence on site specificities, agricultural inputs and co-products allocation methodology with its many alternatives. The emissions due to land use change, both direct and indirect (LUC and ILUC), were not included in the analyses but their importance was emphasized. Among other causes of uncertainties and variation in the results it was mentioned the temporal, geographical and technological representativeness of the life cycle inventory data, derived mainly from the use of different data sources for the same unit process. The use of best values or average values for a specific production path, differences in yields and inputs have a strong impact on the final results. The integration of different inputs to produce different products (the biorefinery concept) and the technological evolution impacts were suggested as topic to be considered in future work in this area. Once again, the data and results were mainly related to developed countries pointing to the necessity to know better the performance of biofuels in terms of GHG LCA and energy balance in developing countries.

There are many more publications dealing with this theme, but they generally lead to the same conclusions of the two works discussed above:

- To be able to compare biofuels in terms of energy balance and GHG emissions, more precise procedures and methods need to be developed and reliable data from the same or similar sources should be used. System boundaries, GHG species considered, co-product impact allocation methods, yields and inputs data, non energy GHG emissions calculation procedures and assumptions are the key issues.
- The agricultural phase is the key area in terms of GHG emissions; non energy related GHG emissions, such as soil emissions due to fertilizer use and soil carbon stock dynamics, result from very complex processes that depend on the local soil and climate conditions and agricultural practices and even the past history of land use.
- The processing path is very important in terms of energy balance, especially for ethanol, and can be critical also with respect to GHG emissions if high carbon footprint fuels (such as coal) are chosen.
- Land use change derived emissions, both direct and indirect (LUC and ILUC), need to be considered, but the methodology and tools necessary for this task are not yet established properly; the dynamics of LUC and ILUC evaluated using econometric models need to evolve a lot more to be widely accepted, and soil emission data from world wide data basis that does take into account the local conditions in many countries and regions need to be produced and properly organized.

Recently, two major biofuels programs were launched supported by specific legislation in USA (Renewable Fuel Standard – RFS2, defined in the Energy Independence and Security Act of 2007) and in the EU (the 10% share of renewable energy in transport by 2020 mandated by the Directive 2009/28/EC Of the European Parliament and of the Council of 23 April 2009). Both legislations establish requirements to qualify the biofuels to be counted to meet the targets and the potential GHG emission reduction is a key parameter in this qualification process.

The EU Directive requires a minimum threshold limit for GHG emission reduction compared with the replaced fossil fuel of 35% starting in 2013 (biofuels produced in new installations are already required to meet this limit); this limit will be increased to 50% by 2017 and to 60% by 2018 (in this last case it applies to biofuels produced in new plants). Second generation biofuels (2G) and those produced from wastes and residues will count twice toward the targets; biofuels produced from feedstocks cultivated in restored degraded land will receive a bonus of 29 gCO_2eq/MJ to be discounted from the biofuel LCA emissions. To facilitate the qualification of the biofuels according to this criterion the rules to calculate the GHG impacts of biofuels are presented in the Directive (Annex V) and default values (without LUC and ILUC effects) are included to be optionally used instead of values obtained from a formal calculation procedure. Table 1 presents some of these typical and default values for different biofuels and production pathway.

Biofuel production pathway	Typical GHG emission saving (%)	Default GHG emission saving (%)
Wheat ethanol (lignite as process fuel in CHP plant)	32	16
Wheat ethanol (natural gas as process fuel in CHP plant)	53	47
Wheat ethanol (straw as process fuel in CHP plant)	69	69
Corn ethanol , Community produced (NG in CHP plant)	56	49
Sugar beet ethanol	61	52
Sugarcane ethanol	71	71
Rapeseed biodiesel	45	38
Sunflower biodiesel	58	51
Soybean biodiesel	40	31
Palm oil biodiesel (process not specified)	36	19
Waste vegetable oil or animal oil	88	83
Pure vegetable oil from rapeseed	58	57
Wheat straw ethanol (2G)	87	85
Farmed wood ethanol (2G)	76	70
Waste wood Fischer-Tropsch diesel (2G)	95	95
Farmed wood Fischer-Tropsch diesel (2G)	93	93

Source: Directive 2009/28/EC

Table 1. Typical and default values for GHG emission reduction for biofuels not including LUC/ILUC derived emissions

From the Table 1 above some conclusions can be drawn:

- The GHG emission reduction performances of the biofuels are very much dependent on the feedstock and production pathway, especially on the process fuel used.
- Waste materials, either as feedstock or process fuel, offer superior performance in terms of GHG abatement potential.
- Second generation biofuels (2G) promise the highest GHG emission reductions but the production technologies have yet to be demonstrated at commercial scale.
- Among the first generation alternatives (1G), sugarcane ethanol has the highest impact on GHG emission reduction, even considering the emissions derived from the transport of the biofuel from the producing country to EU.
- Some biofuel alternatives will not meet the Directive GHG emission reduction threshold limits, but nevertheless are widely used today and their productions are still expanding.
- The inclusion of the GHG emissions derived from LUC and ILUC will bring several biofuel alternatives, that seems to meet the Directive limits, to the non attainment area, especially those that exhibit lower yields such as grain ethanol and oil seed biodiesel (except palm oil).

In the USA, the Renewable Fuel Standard (RFS2) has taken a slightly different approach in the sense that it established four different types of biofuels with different GHG emission reduction threshold values, minimum volume to be used in 2022 and phase in time schedule: renewable fuel (essentially corn starch ethanol), cellulosic biofuels, biomass based biodiesel (excludes vegetable oil and animal fat co-processed with petroleum) and other advanced biofuels (including co-processed biodiesel). The minimum annual volumes in 2022 and minimum threshold limits for the life cycle GHG emission reduction compared with the fossil fuel displaced are: corn starch ethanol – maximum volume of 15 billion gallons (56.8 billion liters) to be reached in 2015 and minimum GHG emissions reduction of 20% (for the new plants); cellulosic biofuels – 16 billion gallons (60.6 billion liters) and minimum GHG emission reduction of 60%; biomass-based biodiesel – 1 billion gallons (3.8 billion liters) and minimum GHG emission reduction of 50%; and other advanced biofuels – 4 billion gallons (15.1 billion liters) and GHG emission reduction of 50% (EPA, 2010).

Likewise the EU Directive, EPA presents default values for lifecycle GHG emissions reduction for different biofuels and production pathway; in the EPA case the LUC and ILUC derived emissions are included. Some of these default values are shown in Table 2.

Here also, there are significant differences among biofuels production pathways and fuel used in the process. When the LUC and ILUC effects are included, corn ethanol does not qualify as an advanced biofuel even in the case where biomass is used as fuel; with natural gas as the fuel it barely qualifies as a renewable biofuel and with coal fueled plants there is practically no GHG emission reduction in the lifecycle. Sugarcane ethanol qualifies nicely as an advanced biofuel even in the case where the residues are not collected and used; when this is done, there is a considerable benefit for GHG emission reduction. Second generation ethanol offer a considerable advantage in terms of GHG reductions. The values above 100% are the result of co-product credits allocated in favor of the biofuel.

Biofuel	Production pathway	GHG emission reduction (%)
Corn ethanol	Dry mill with NG	21
Corn ethanol	Dry mill with coal	1
Corn ethanol	Dry mill with biomass	38
Sugarcane ethanol	No residue collection	61
Sugarcane ethanol	With residues collection and surplus power generation	91
Cellulosic ethanol	Switchgrass – biochemical	110
Cellulosic ethanol	Switchgrass – thermochemical	72
Cellulosic ethanol	Corn stover – biochemical	129
Cellulosic ethanol	Corn stover – thermochemical	92
Corn butanol	Dry mill with NG	31
Soy bean biodiesel	FAME	57
Waste grease biodiesel	FAME	86

Source: EPA, 2010

Table 2. Lifecycle GHG emissions reduction default values for different biofuels and production pathways in 2022 (LUC and ILUC derived GHG emissions are included)

In a quick comparison between the two major pieces of biofuels legislation some observations can be made:

- The amount of biofuels required in the next 10 years will be considerable, but looking only at the additional volumes needed above today's production the goals seem achievable in the total. However, the expectations on second generation (2G) biofuels may not materialize in such a short time. The USA ethanol and biodiesel productions in 2009 were 41 billion liters and 2.1 billion liters, respectively, and in EU these volumes were 3.6 and 8.9, respectively (REN21, 2010).
- The installed capacity in USA was already 12 billion gallons/year of ethanol (EPA, 2010). In the EU, the 10% renewable energy participation in transport is estimated to be divided in 5.6% for biofuels (in 2008 biofuels already represented 3.3% of transport fuel use) and 4.4% for other renewable alternatives, mainly electricity, what will demand a significant improvement in the electric vehicle (EV) technologies to reduce the costs from the present values.
- The threshold limit of 50% for the GHG emission reduction, including the LUC/ILUC impacts, will not be easily satisfied by most grain ethanol and oil seed biodiesel with pathways using fossil fuels. Biomass fuel will help to improve the GHG performance of the biofuels, but it is constrained by cost and availability in large scale and there will be competition for feedstock for 2G plants. Sugarcane has a tremendous benefit in this respect since there are large amounts of residues in the distillery (bagasse that is the residue from the juice extraction operation) quite enough to supply all the energy needed to operate the distillery and to generate surplus electricity for sale; with the collection of the agricultural residues (trash: sugarcane tops and leaves) and the surplus bagasse it is possible to have a 2G plant operating integrated with the 1G distillery with synergies that will result in lower investment and operating costs as well as higher GHG emission reduction.

- Some type of biofuel sustainability certification criteria will be formally introduced in the two regions including other aspects beyond GHG emission reduction capabilities such as local environmental impact (air, soil and water), protection of biodiversity, avoided use of land with high carbon stock, social impacts and others.

3. LUC/ILUC impacts

An important component of the total lifecycle emission of GHG of biofuel production/use chain is likely to come from the impacts of LUC and ILUC. To put the subject under a right perspective the differences between the two effects must be made clear: direct land use change is the change in land use that occurs within the system boundary when the feedstock is planted replacing an existing land use (pasture, other crop, forest, etc.); indirect land use change takes place when agricultural production displaced by the biofuel feedstock crop will take place in other area, or even in other country, in its turn, displacing an existing land use. This concept exists for many years but it came to the spotlights with two articles published in 2008 in *Science* (Searchinger and al. and Fargione and al., 2008); these articles had the merit to bring the concept to a broader discussion, but on the negative side they presented results for LUC/ILUC GHG emissions that were unreasonably high as a consequence of inadequate data and assumptions used (see Table 4 at the end of this section). It was a case similar to the famous publication of Thomas Malthus in 1798 *An Essay on the Principle of Population* where he predicted that the world population would starve in the future because it increased in a geometric rate while the food supply grows according to an arithmetic rate; his calculations were corrected, but his hypotheses were not, since he did not considered the agricultural yield growth and other technological improvements.

GHG emissions resulting from land use change are related to soil carbon stocks loss (or gain when the impact is positive) and N_2O soil emissions due to fertilizer decomposition, change in soil carbon stock, residues decomposition and other. There are emission factors suggested by the IPCC, but real values are difficult to estimate because they depend on soil and climate conditions, agricultural practices (type of fertilizer and way it is applied) and previous use of the soil, since soil carbon stocks change slowly. The modeling of land use change uses normally economic based model of the computable general equilibrium or partial equilibrium concepts, sometimes coupled with optimization models, but several other types of model are available for this application in spite the fact that they were developed for other uses and have to be adapted to analyze the land use dynamics (CBES, 2009). A literature review concerning the impact of land use change on greenhouse gas emissions from biofuels was prepared by the DG Energy for the European Commission (DG Energy, 2010) and has shown that, although scientific progress has been made, consensus is still far from being reached. Some of the critical issues identified are: land use data, a fundamental part of the LUC modeling, is very poor and unreliable; there are some confusion with respect to handling crop yields variation and multi-cropping intensity; elasticities between increase in demand and improving yields are difficult to quantify empirically; rotation of land in and out of crop production leads to erroneous classification of land use type; how the biofuel feedstock is determined and the co-products credits are allocated and the corresponding impacts on land demand are not clearly explained; and, last but not least, it is not only how much land will be converted that matters, but also what type of land since this has a strong implication on the emissions due to the fact the carbon stock (above and below the ground) vary with the type and location of soil and present land use.

In this last issue, it is critical the share of forest/woodland converted to crops, considering the high carbon stocks and the impacts on biodiversity and other environmental services. It was also observed from the review that carbon stocks had significant variation among the studies, even for the same type of land (sometimes by a factor of 15) and the dynamics of pasture use for livestock production is poorly understood.

Considering the complexity of the land use impacts and the lack of consensus on how they can be estimated, the US Department of Energy (USDOE) Biomass Program sponsored a workshop on May 11 to 14, 2009, with more than 50 experts from around the world, to review the state of science, identify opportunities for collaboration, prioritize the next steps for research and discuss the data needed in terms of availability and quality. The focus was selected to be the interface between land use changes and global economic models; the main finding was that there was a need to improve current generation of land use change models and the central limiting problems were the historical data on land use (not land cover) that are frequently nonexistent or available only in a very coarse scale, and the poor understanding of the driving factors of LUC. Initial land use change drivers (cultural, technical, biophysical, political, economic and demographic) usually change in time and location, a condition not handled by the models; data from different sources with varying quality and high level of aggregation just add more uncertainties to the modeling. Other important drivers are governance capacity, population growth, land tenure regimes, macroeconomic and trade policy, environmental policy, infrastructure, land suitability, domestic and international agricultural and energy markets, and climate conditions; it seems unlikely that a single model, or even a combination of different models, could handle quantitatively all these drivers and produce consistent and replicable results. The most recent important tentatives to estimate the LUC/ILUC impacts have used economic equilibrium models (general or partial equilibrium) oriented to agriculture associated with spatially explicit land use models and optimization models. A combination of models tends to increase the scope of the analyses, but bears the risk of increasing the uncertainties due to error propagation from one model to the other. A final conclusion of the workshop was that there was a strong agreement among the participants regarding the uncertainties surrounding current use of global economic models to project the land use change effects of biofuels.

Nevertheless, both the EISA and EU Renewable Energy Directive require that the ILUC impacts be included in the lifecycle analysis of GHG emissions of the biofuels, immediately in the case of EISA and in a near future in the EU Directive.

EPA was in charge of managing the EISA mandate and produced the necessary studies and analyses leading to the RFS2 Final Rule in terms of default values for different biofuels and production pathways shown in Table 2 above (EPA, 2010). The international ILUC GHG emission values for corn ethanol and sugarcane ethanol were established as 30.3 gCO_2eq/MJ and 3.8 gCO_2eq/MJ, respectively.

The European Commission has not come to a final decision about the values of GHG emissions resulting from ILUC effects from the production of biofuels, but several reports have been submitted to public consultation in 2010 (IFPRI, DG Energy, 2010 and JRC, 2010a and 2010b) covering several aspects of the problem. The work of the International Food Policy Research Institute (IFPRI, 2010), that seems to be the main document, used a modified version of the MIRAGE model (Modeling International Relationships in Applied General Equilibrium) to analyze the impact of the increase of biofuel consumption in the EU due to the requirements of the EU Renewable Energy and Fuel Quality Directives. The baseline was determined assuming the biofuel share in transport fuel in 2008 (3.3%) would remain constant from 2009 to

2020, and the Directive scenario assumes that in 2020 the first generation biofuel will represent 5.6% of the total transport fuel demand. The modeling considered that biofuels will compete in the international market considering three alternatives: same situation as today in terms of import duties and other barriers (Business as Usual Scenario), global free trade regime and free trade with the MERCOSUR. Some results are presented in Table 3 for the Business as Usual Scenario (BAU), without considering the peatland drainage for the production of palm oil, for the marginal (considers the effects of the new production of biofuels disregarding the past average values) Indirect Land Use and marginal Net Emission Reductions by the production and use of ethanol and biodiesel from different feedstocks.

Biofuel	ILUC Emissions	Net Emissions Reductions (*)
Ethanol - sugar beet	16.1	-35.9
Ethanol - sugarcane	17.8	-54.0
Ethanol – maize	54.1	3.6
Ethanol - wheat	37.3	-7.0
Biodiesel – palm oil	46.4	-22.0
Biodiesel – rapeseed	53.0	8.8
Biodiesel – soy bean	74.5	24.1
Biodiesel - Sunflower	59.9	8.7

Source: IFPRI, 2010
(*) Negative values mean emission reduction with respect to the fossil fuel displaced

Table 3. Marginal indirect land use emissions and marginal net emission reductions from the production and use of biofuels (gCO_2eq/MJ, 20 years lifecycle)

Analyzing the data presented in Tables 2 and 3 for the first generation biofuels it can be concluded that:

- Only sugarcane ethanol qualifies as an advanced biofuel according to RFS2 rules (50% minimum emission reduction) and can meet the requirements of the EU Directive for 2017 (50% minimum emission reduction), and with a little improvement can meet also the 2018 requirement (60% minimum emission reduction).
- Palm oil biodiesel is the only alternative of this biofuel that can reduce the GHG emissions in the replacement of fossil diesel; however, it does not meet the emission reduction minimum threshold value of the EU Directive even for the initial value of 2013 (35%) for this value is only 24% (fossil fuel lifecycle emissions of 92 gCO_2eq/MJ).
- All other biodiesel alternatives will increase the GHG emission compared with mineral diesel.
- Maize ethanol is the worst alternative of this biofuel in terms of GHG emission reduction, and even increases slightly the emissions compared with fossil gasoline, for the European Union case.
- Sugar derived ethanol have a better GHG abatement performance than the grain ethanol alternatives, but sugar beet ethanol can meet only the 2013 requirement.
- Ethanol, in general, is a better option to reduce GHG emission in transport than biodiesel.

With that said, it remains the question why so many countries are persisting with the idea to develop programs to promote biofuels with such a poor performance in terms of GHG abatement potential (grain ethanol and oil seed biodiesel)? The possible explanation is the intention to help the local agricultural sector and to reduce a little the oil imports. Although there is a large amount of uncertainties in the LCA of GHG emissions of biofuels in general, and the LUC/ILUC derived emissions in particular, these results are at least a qualitative indication that biofuels are not equal. Table 4 presents results from different sources including the extremely high value from Searchinger and co-authors (Searchinger et al., 2008), that are out of the range of the results from the other studies by the California Air Resources Board (CARB), US Environmental Protection Agency (EPA) and International Food Policy Research Institute (IFPRI).

Reference	Maize ethanol	Soybean biodiesel
Searchinger et al., 2008	156	165-270
CARB, 2009	45	63
EPA, 2010	47	54
IFPRI, 2010	54	75

Source: EC, 2010

Table 4. Land use change GHG emissions results from different works (gCO_2eq/MJ)

3.1 Land requirement for biofuel production

It is interesting to start to look the land availability situation around the world today and in the future to have a clear picture of how much and where there is land availability for this purpose. The second step will be to look what are the possible targets for biofuel production in the long term.

Doornbosch and Steenblik (2007) have made a good assessment of the land use and availability worldwide based on the work developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied System Analysis (IIASA). The results indicate that around 440 million hectares (Mha) will be available by 2050 for rain-fed cultivation of energy crops. This figure considers that the land needed to feed the additional population (from 6.5 to 9 billion people), estimated in 200 Mha, 100 Mha to accommodated population growth (housing and infrastructure) and the preservation of forests is discounted from the total land available. Nearly all this land availability is concentrated in South and Central America and Africa, and is presently being used as grassland for livestock production; therefore, land use change will take place and pasture intensification will be needed, a fact that is already taking place in many regions in the world. It is important to notice that this 440 Mha represents less than 10% of the 5,000 Mha of land under management (1,500 Mha arable and 3,500 Mha grassland), but should be considered as an upper limit for land available for energy crops by 2050. Deforestation is a major concern, but the causes are very complex and poorly understood, varying in space and time, deserving the attention of the scientific community to develop science based cause-effect relationships; today, the problem is being treated more on the emotional and subjective basis. Nogueira, 2008, presented some data on deforestation rates in Brazil between 1988 and 2006 and the variation does not seem to correlate well with the increase in agricultural production. In summary, land for energy crops production is not unlimited and, therefore, the biofuel options that present higher yields have a clear advantage in this aspect. Table 5 presents the estimated yields of different biofuels/feedstocks where a wide variation can be observed, even for the same biofuel/feedstock produced in different regions.

Region-Biofuel	Feedstock	Yields 2005 (l/ha)	Yields 2050 (l/ha)
EU-ethanol	Wheat	2 500	3 420
EU-ethanol	Sugar beet	5 000	6 750
EU-biodiesel	Rapeseed	1 200	1 640
US/Canada-ethanol	Corn	3 000	4 040
US/Canada-biodiesel	Soybean/rapeseed	800	1 100
Brazil-ethanol	Sugarcane	6 800	9 160
Brazil-biodiesel	Soybean	700	1 100
Rest of world-ethanol	Sugarcane	5 500	8 480
Rest of world-ethanol	Grain	2 000	3 090
Rest of world-biodiesel	Oil palm	2 500	3 910
Rest of world-biodiesel	Soybean/rapeseed	1 000	1 570
World-ethanol	Ligno-cellulose	4 300	7 580
World-BtL biodiesel	Biomass	3 000	5 960

Source: IEA, 2008

Table 5. Biofuels yields for different feedstocks and production regions

Even considering that the effects of the co-products are not included in Table 5, it can be seen that there are significant differences among biofuels and feedstocks, and among different regions in the world, in terms of land requirement for biofuels production, that must be taken into consideration in deciding which alternatives should be implemented. Besides the competition with land for food/feed production, the biofuel yields affects heavily the LUC/ILUC derived GHG emissions, as seen in session 3 above, and have a significant impact on production costs (agricultural inputs and field operations are related to cropped area and not to crop production quantity) and biodiversity. Sugarcane appears again as the best option, now and in the future, and can compete in equal terms with second generation alternatives with respect to land demand, with the advantage that the technology is ready now and not in the future. The superiority of ethanol compared with biodiesel is also demonstrated and sugarcane ethanol is the winner; considering that sugarcane is produced in more than 100 countries it seems reasonable to expect that the dissemination of this biofuel alternative has some probability to succeed if the right approach and policies are used. Molasses, the byproduct of sugar production, seems to be the cheapest feedstock for bioethanol, although there are some uncertainty about its availability for this application since it is already widely used for several applications, such as, beverage production, cattle feed, other products from fermentation (lysine, glutamates, solvents, etc.).

4. Sugarcane ethanol: A case study for Brazil

It is interesting at this stage to use the information described in the previous section to make some simulations, using the Brazilian current and future conditions, to get a feeling of the impacts of the production and use of biofuels in general, and ethanol in particular, on the GHG emission reduction potential and land demand.

The Brazilian Government prepared and released the Agroecological Zoning (AEZ) of sugarcane (EMBRAPA, 2009) identifying 64.7 Mha of land available for rain-fed cultivation of sugarcane without significant impacts on food production, deforestation, biodiversity and protected areas. It is important to point out that these 64.7 Mha represent only 7.5% of the country's area, meaning that 92.5% of Brazil surface will not be used to produce sugarcane. A recent study by the Interdisciplinary Center of Energy Planning of the University of Campinas (Leite, 2009, Leite et al., 2009) tried to indentify the land demand and availability for the production of a volume of ethanol sufficient to displace 5% or 10% of the projected gasoline consumption in 2025; the socioeconomic impacts, necessity of investments in distilleries, cane fields and infrastructure were estimated. The assessment of the land needs for sugar production for internal and external markets was also included. These works will be the reference for resources demand calculations and technology improvements with impact on ethanol yields.

For the estimate of future biofuels consumption the values projected by IEA (IEA, 2009) for the Reference scenario for 2030 will be used instead of the original estimates made in the two works above (104 and 205 billion liters in 2025). That means 132 Mtoe of total biofuels of which ethanol represents 79%, resulting in an ethanol demand around 200 billion liters in 2030, comparable to the estimated value used in the studies by Leite and Leite et al., 2009.

To estimate the land required to produce that amount of first generation ethanol in 2030 it is necessary to estimate the yields for that date. Using IEA data as shown in Table 5 above, which represents 0.7%/year yield improvement for sugarcane ethanol, the yield in 2030 would be around 8 100 liters/ha, demanding some 25.7 Mha. These figures are very conservative since sugarcane yields have increased at a rate of approximately 1.6%/year in the recent past; Landell et al., a group of sugarcane breeders, have drawn a roadmap for sugarcane quality improvement resulting in average sucrose yield per hectare increasing at a rate a little above 1.4%/year starting from 12,150 kg/ha/yr in 2010; considering also gains in efficiency in the distillery leading to a global distillery efficiency of 90% by 2030, up from 85% in 2010, the resulting ethanol yield would be around 12,000 liters per hectare. The land required to produce the 200 billion liters in 2030 would be reduced to 17 Mha, representing only 26% of the 64.7 Mha indicated in the sugarcane AEZ and just a little more than 1% of the current world arable land (1 500 Mha).

The 200 billion liters of ethanol in 2030 would be displacing 134 billion liters of gasoline that would produce, using EPA data, some 400 million tonnes of CO_2. Using also the EPA estimate of 61% GHG emission reduction potential for the Brazilian ethanol indicated in Table 2 the GHG emission reduction would be 244 Mt CO_2eq (14.4 t CO_2eq/ha), or 3.5% of the total emissions in road transport estimated for that year (IEA, 2009). In the future, if the sugarcane residues (bagasse and straw) were better used in a 2G plant integrated with the 1G distillery an additional 3000 to 4000 liters of ethanol would be obtained (Leite et al., 2009), reducing the land demand to no more than 13 Mha and the saved GHG emissions would increase to 364 Mt CO_2eq or 5% of the road transport emissions.

Just to make a quick comparison with the alternative of US corn ethanol, using the IEA yields of 3 600 liters/ha (IEA, 2008) and the GHG emission reduction default value from EPA of 21% (EPA, 2010) the required area would be 55 Mha and the GHG emission savings of only 84 Mt CO_2eq, or just a little over 1% of the projected road transport emissions. It must be said that these estimates are good for qualitative comparison only, since there are many uncertainties that need to be resolved in the LCA GHG emissions of the biofuels production/use chain, specially related to the ILUC effects. Another point is that the ILUC derived emissions calculated by econometric models are not linear with respect to biofuel volume produced; therefore the use of EPA values for other volumes is a simplified approach.

More data on Brazilian sugarcane ethanol LCA GHG emissions can be found on Macedo et al, 2008 and Macedo and Seabra, 2008.

Other considerations concerning the sustainability of ethanol production in Brazil are not included here, but they can be found in several publications dealing specifically with this subject such as, Smeets et al., 2006, Macedo, 2007, Walter et al., 2008, Zuurbier and van de Vooren, 2008, Goldemberg et al., 2008, Oliveira, 2011.

5. Final comments

The presentation of a plentiful of data obtained from studies made by well recognized and reputable institutions and researchers had the aim of indicating significant differences among the biofuels alternatives considering only two of their main characteristics: GHG abatement potential and land demand. A third very important characteristic, the production cost, was not included in the effort to compare biofuels because it was outside of the scope of this chapter, but nonetheless it is the key characteristic for the long term survival of the biofuel option without subsidies.

GHG emission savings is a fundamental characteristic for attainment of the qualification status of the biofuel according to the two major legislations in effect today: the EU Renewable Energy Directive and the US Renewable Fuel Standard (RFS2), and therefore the LCA GHG emissions of a biofuel is a crucial characteristic to be taken into account in the process of selecting the best alternative. Needless to say that it should be the “go no go” test if the biofuel production and use is intended to mitigate the global warming effect when displacing fossil fuels. In spite all that, the methodology and procedures to perform the LCA of the GHG emissions in the production path still have several points that need improvements and definitions: climate active gases included, allocation methods to divide the LCA emissions among co-products, N_2O emissions, soil carbon dynamics and the indirect land use change impacts (ILUC). The soil emissions, one of the most complex point in the analyses, are highly dependent on the local conditions (climate, soil, agricultural practices, past history of land use) and there is an urgent need to improve and extend the few existing data bases on soil characteristics, land use past dynamics, agricultural practices (fertilizer use, tillage types, crop rotation, double cropping, etc.). Besides the improvement of the input data, the determination land use change indirect effects is another area that needs more research and development of the models to make them able to simulate the driving forces of land use (highly variable in time and space), the cause/effect relationship of crop dynamics (where the displaced crops really go and what caused the occupation of native vegetation), cattle grazing and many other things.

Land for agriculture is a finite resource and, therefore, the demand for biofuels production must be carefully considered and in this process the yields are the main point. Besides, the ILUC impact on the LCA GHG emissions are highly dependent on the land, as well as the production costs and energy demand are more related to the area cultivated than to the volume of feedstock produced (fertilizer, herbicide, land preparation, agriculture operations and land rental). This reasoning should lead to the selection of biofuels alternatives with higher yields, such as sugarcane and sugar beet ethanol and palm oil biodiesel, but the reality is quite different with the domination of ethanol from grains and biodiesel from rape seed. In 2008, according to UNEP, 2010, to world biofuel crop production used around 36 Mha, or 2.3% of the arable land, to produce 67 billion liters of ethanol and 12 billion liters of biodiesel (REN21, 2009). Using the yield values indicated in Table 5 and assuming all ethanol from US corn and all biodiesel from EU rapeseed the total area required would be 32 Mha, very close to UNEP value; in the case where all ethanol is produced from sugarcane in Brazil and all biodiesel from oil palm the total area required would be 15 Mha, or less than half of the previous case. The 36 Mha estimated by UNEP is an indication that very low yield options are being widely used around the world, in spite the dominance of USA and Brazil in ethanol and EU in biodiesel. In the IEA projections land demand projections for biofuels in 2050 an average value of 160 GJ/ha is used, including second generation biofuels; Leal, 2007, projected for 2020 the yield gains for Brazilian sugarcane ethanol to 7,900 l/ha for 1G ethanol and 11,700 l/ha (245 GJ/ha) for an integrated 1G and 2G production using sugarcane sugars (1G) and fibers (2G).

Other important characteristics were not included in the evaluations due to the limitation necessary to keep the chapter at a reasonable size and scope. It is important to point out that several other characteristics such as impacts on the local environment and biodiversity, as well as some of the main socioeconomic impacts are strongly related to the extension of the land required to produce the biofuel feedstocks. Therefore, biofuel yield, energy balance and GHG emission reduction potential are critical issues for most of the situations around the world, but there are some specific local conditions that take the priorities to other areas such as job creation, local energy supply and development and creation of outlet for some local production potential constrained by lack of market access due non existence of storage and distribution infrastructure. Different driving forces may lead to different optimal solutions.

The Brazilian experience with the efficient and economic production of sugarcane ethanol is available as a reference for countries interested to deploy a biofuel program, but it cannot be expected to be readily transferable to some of the more than 100 sugarcane producing countries due to significant differences in the local conditions, including technology access, land tenure issues, human resources, cultural aspects and strength of the different drivers.

In summary, to make sure that the negative impacts on land demand are minimized and the positive impacts on GHG emission reductions are maximized it is crucial to make the proper choices if biofuels are to play an important role in the future world energy scenario.

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Planet Earth 2011 - Global Warming Challenges and Opportunities for Policy and Practice
Edited by Prof. Elias Carayannis

ISBN 978-953-307-733-8
Hard cover, 646 pages
Publisher InTech
Published online 30, September, 2011
Published in print edition September, 2011

The failure of the UN climate change summit in Copenhagen in December 2009 to effectively reach a global agreement on emission reduction targets, led many within the developing world to view this as a reversal of the Kyoto Protocol and an attempt by the developed nations to shirk out of their responsibility for climate change. The issue of global warming has been at the top of the political agenda for a number of years and has become even more pressing with the rapid industrialization taking place in China and India. This book looks at the effects of climate change throughout different regions of the world and discusses to what extent cleantech and environmental initiatives such as the destruction of fluorinated greenhouse gases, biofuels, and the role of plant breeding and biotechnology. The book concludes with an insight into the socio-religious impact that global warming has, citing Christianity and Islam.

How to reference
In order to correctly reference this scholarly work, feel free to copy and paste the following:

Rogério Cezar de Cerqueira Leite, Manoel Regis Lima Verde Leal and Luîs Augusto Barbosa Cortez (2011). The Choice of Biofuels to Mitigate Greenhouse Gas Emissions, Planet Earth 2011 - Global Warming Challenges and Opportunities for Policy and Practice, Prof. Elias Carayannis (Ed.), ISBN: 978-953-307-733-8, InTech, Available from: http://www.intechopen.com/books/planet-earth-2011-global-warming-challenges-and-opportunities-for-policy-and-practice/the-choice-of-biofuels-to-mitigate-greenhouse-gas-emissions

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