Biofuels Potential in Latin America and the Caribbean: Quantitative Considerations and Policy Implications for the Agricultural Sector

Carlos E. Ludena[1]
Carlos Razo[2]
Alberto Saucedo[3]

Agricultural Development Unit
Division of Production, Productivity, and Management
Economic Commission for Latin America and the Caribbean
United Nations

Av. Dag Hammarskjöld 3477, Vitacura
Casilla 179-D
Santiago de Chile, Chile
Phone: (56 2) 210-2000
Fax: (56 2) 208-0252

[1]Email: carlosludena@yahoo.com
[2]Email: carlos.razo@cepal.org
[3]Email: lsaucedo77@yahoo.com

Selected paper prepared for presentation at the American Association of Agricultural Economics Annual Meeting, Portland, OR, July 29-August 1, 2007

The authors wish to thank the staff and consultants of the Agricultural development Unit of the UN-Economic Commission for Latin America and the Caribbean, namely Sofia Astete, Soledad Parada and Martine Dirven for their substantive inputs and useful comments on previous drafts, and Josefina Hepp and Alejandra Vildósola for the research assistance.

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Rising oil prices has led to increased interest to replace domestic demand for liquid fuels for transport (petrol and diesel) with biofuel production (ethanol and biodiesel). One of the pioneers in biofuel production is Brazil, which since the 1970s has established a government program that promotes the production and consumption of ethanol. Currently, Brazil is the leading producer of ethanol in the world and has started also programs for biodiesel production based on soybeans, oil palm and other crops. Other countries in Latin America and the Caribbean have also expressed interest in biofuel production, and have started programs, and in some cases the legislation that promotes biofuel production. However, most of the analysis of biofuel crops has been focused in the major countries such as Brazil and Argentina. As most countries in the region embark in biofuel projects and establish national policies on biofuels, there is a need for a roadmap that looks into the technical considerations that biofuel production will require. Most government policies are driven by politics, and in some cases such as the discussion of food production versus biofuel production, there should be technical analysis of increased production of biofuels. For those reasons, this study offers the first complete assessment of the potential of biofuels in Latin America and the Caribbean for 28 countries in the region, based on 12 agricultural and forestry crops. We first identify the biofuel production potential based on current surplus production, as a catalyst of biofuel production in the region. We then estimate the land requirements based on a 5% replacement of domestic liquid fuel demand, and the suitable available area in each country for such replacement. We also project biofuel production and available land area needed to meet food and nutrition targets for countries in the region to 2025. The results of this study show that the crops with the largest potential in Latin America and the Caribbean are sugar canes and cassava. Based on current production levels the conversion of sugarcane into bioethanol could surpass the 5% mix in more than half of the domestic markets of the countries surveyed. For biodiesel, countries with current surplus production that could be transformed to biodiesel and exceed the 5% mix include Argentina, Bolivia, Paraguay, Costa Rica and Honduras. For land, Latin America, particularly South America may have enough suitable land for production of biofuels, specially sugar cane, soybeans and oil palm, the main crops identified in this study. As for food supply and security and the future production of biofuels to 2025, we find that for major food exporters, there is enough land for both food and energy crop production. However, there are some smaller countries, especially in Central America and the Caribbean that may have to decide whether to import food and produce energy from crops. In term of the effect on prices, we find that increased biofuel production may have important price effects the effect may depend we analyze energy crops, traditional crops or by-products of biofuel production. Finally, in terms of the impact on agricultural structure and land ownership, the most significant structural changes consist in a higher concentration in production and tenure as well as the establishment of new kind of actors and norms. Policies and institutions should be established that enables small producers to take advantage of increased biofuel production, so they can benefit in terms of employment, income, as means for poverty reduction in rural areas of Latin America and the Caribbean.

JEL Classification: Q42, Q48, Q11, Q15
Key words: Biofuels, land availability, price effect, agricultural structure, Latin America, Caribbean.

Introduction

Latin America has land as well as the climate conditions needed for the production of energy crops, and therefore the potential to satisfy a large part of the global demand for biofuels. For those reasons, increased demand for biofuels is an opportunity, as well as a challenge, for the agricultural sector in the region. Beyond the environmental benefits of the use of biofuels, the increased global demand for this energy source represents potentially, a source of income and employment, especially in rural areas where a large share of the population lives under the poverty line.

However, it is important to consider that production of biofuels might mean the expansion of the production frontier, which imposes a serious challenge to the agricultural sectors of countries in the region. Additionally, increased biofuel production might have impacts on market structure, a shift from traditional crops, increased input and output prices, among others. For these reasons, it is important to evaluate the potential in Latin America for production of biofuels, in such a way that policies can be implemented to reduce the negative effects and guarantee a sustainable production of biofuels in Latin America.

On the other hand, most of the focus of biofuels in Latin America and the Caribbean has been on Brazil and Argentina, the two countries with the largest potential locally and globally. However, most Latin American countries have started considering the production of biofuels for their own domestic markets, as well as for exports to the global market. For most Latin American countries, which are net fuel importers, the implementation of a biofuel program is a valid alternative that could save hundreds of million of dollars per year in oil imports for these small economies.

This study estimates the potential of biofuel production for 28 countries in Latin America and the Caribbean. We consider the impact on domestic production, as well as the land requirements needed to replace 5% of fuel for transport in the domestic market by either bioethanol, in the case of petrol, and biodiesel, in the case of diesel. We then focus on land requirements to the year 2025 for biofuel production, taking into consideration food production and security for every country in the region.

This article has been prepared as a guide and road map for policy makers in the agricultural sector of Latin American countries, on the type of issues and considerations that should be taken on implementing such programs.

The paper is organized as follows. First, we briefly review the literature on the potential of biofuels for transport for Latin America and the Caribbean as a whole. Second, we describe the four quantitative estimates of the potential of biofuels and its impact on land use, input use, and food security. We then discuss the potential impact of increased biofuel production in the region on prices, and the expected impact on agricultural structure in Latin America. Finally, we close with some conclusions and policy implications for the region.

Potential of Biofuels Production in Latin America and the Caribbean

Most of the studies at a global level mention the large potential of biomass as an energy source in Latin America and the Caribbean. Berndes et al. (2003) in his revision of seventeen studies about the future of biomass as an energy source finds that ranges are wide due to uncertainty in land availability and yield levels for biofuel crops in the future. The same is for the future availability of wood fuel and agriculture and forestry residues.

Smeets et al. (2007) estimates that biomass energy potential for the year 2050 in Latin America and the Caribbean, based on surplus agricultural land, could vary between 47 and 221 EJ per year, depending on production systems. These values represent between 17% and 26% of world biomass energy potential, more than any other region in the world, except for Sub-Saharan Africa (subject to the type of production system).

The previous values are estimates of the energy potential of biomass, for electricity production as well as for liquid fuels for transport. According to the IEA (2004), the transport sector represents 27% of secondary energy world consumption (and 21% of primary), which is supplied almost entirely by oil. Due to increased automobile stock, these percentages could increase to 29-32% by 2050.

De Vries et al. (2007), estimate that the potential of biofuels for transport in the year 2000 as 30-40 EJ per year. The authors estimate that by the year 2050, the potential could expand between 75 and 300 EJ per year, based of the four scenarios of the Intergovernmental Group on Climate Change (IPCC). Also, Smeets et al. (2007), considers that Latin America is one the regions with most potential in the World. In a scenario with high growth and high technology, the potential is more than 65 EJ per year, which is more than 20% of total world production of 300 EJ per year.

Comparing the potential of fuels for transport with global demand in the year 2050 (80-250 EJ per year), de Vries et al. (20007) estimate that it could cover 100% of total demand in three out of four scenarios, if all the land considered able/disposable for biomass plantations could be used for biofuels production. Additionally, Smeets et al. (2007) estimates that for Latin America and the Caribbean in particular, bioenergy (not only for liquid fuels), could cover in more than 100% the energy demand, with ranges between 120% and 580%.

Of this technical potential, it is important to determine the real economic potential for production. De Vries et al. (2007) mentions that the production cost of biofuels in the year 2000 was between $10 and more than $20 per GJ of energy. In the short term, cost could be reduced substantially by the year 2050, increasing the economic potential of biofuels. De Vries et al. estimate that under certain circumstances, more than 25% of global potential in 2050 could be costs lower that $12 per GJ. For Latin America, this percentage would be more than 70% of total supply in 2050, making it attractive exports of biofuels from this region.

However, de Vries et al. (2007) mentions that the potential of Latin America and other tropical regions could be reduced in more than 80% under circumstances with high population growth and a lower growth in crop yields, due to pressure in food demand and land for food production. This denotes the relationship between biofuels production with other factors, which we will discuss later in this paper.

In this paper, we consider the potential of biofuels in Latin America and the Caribbean from different points of view, starting with current surplus production, estimates of agricultural frontier expansion to areas less suitable for crop production, considerations of food security, impact on prices and on the structure of agricultural production in Latin America and the Caribbean.

Methodology: Quantitative Assessment of Biofuels in Latin America and the Caribbean

The quantitative estimates in this paper are used as indicators of the potential of biofuels in Latin America. We divide them in two parts. First, we estimate quantitatively the current potential of biofuels in the region using current production and cropland area. Second, we estimate the potential to the year 2025, assuring food production and security and well as meeting targets of malnourishment reduction.

Current biofuel potential in the region is first estimated using an indicator of the potential mixture of biofuels in the domestic liquid fuels market (petrol and diesel) for each country. These estimates are based on surplus production for countries in the region, that is, crop supply that after meeting local demand is exported or warehoused[1].

$$MI_j = \sum_i^k \left(\frac{Q_{ij} \times y_i}{FD_j} \right) \qquad (1)$$

where MI_j is the mixture index of ethanol (biodiesel) in the local petrol (diesel) market of country j, expressed as a percentage; Q_{ij} is the average net production surplus (in tonnes) of energy crop i in country j during the period 2000-2003; y_i is the yield of ethanol or biodiesel of

[1] Net production surplus = Domestic Production + (Imports – Exports) + Stock change

energy crop i in liters per tonne. In this case, we assume that this yield is common for all countries in the region given the available information. However, there are ethanol and biodiesel yields that are country specific given crop varieties, processing technologies and other factors that may increase this yield for specific countries. The product of Q_{ij} and y_i is equal to the sum of total potential ethanol (biodiesel) production from energy crop i to k. FD_j is the local liquid fuel demand (in liters) in country j during 2000-2003. The production data is from FAOSTAT, the yield data is taken from Table A1, Table A2 and Table A3, and fuel demand data is from the UN's 2003 Energy Statistics Yearbook (2006).

In this case these estimates show as if all net production of the studied energy crops is used for liquid fuel production. The Mixture Index (MI) shows the current technical potential, but does not reflect the economically viable production of biofuels. That is, the MI is a catalyst for the current potential of the region and certain countries to meet country level demand for liquid fuels.

These estimates are only for those countries with production surplus of energy crops, according the food balance sheets from FAO. That is, in those countries where production surpasses local demand and that are currently exported or warehoused.[2] Based on these results we estimated the technical potential of biofuel production and the potential mix, for ethanol and biodiesel, in current demand of gas and diesel for each country for the years 2000-2003.

[2] We do not consider in this first analysis the energy difference between diesel and biodiesel (Kojijama y Johnson, 2005, pp 84), and we assume that for food balances before 2003 there was no crop production for biodiesel.

These estimates are attractive in the sense that only considers surplus production, avoiding possible direct competition of biofuels production with food and animal feed production. However, it does not consider the possible expansion of the agricultural frontier to new areas or the possible switch between with traditional crops, which are important factors in biofuel production.

Biofuel production may impact on input demand, especially on those inputs considered scarce. One of those inputs is land. It is expected that increased demand of biofuels will have impact of land demand. There would be either land switch from one crop to another or expansion of the agricultural frontier into new cropland.

Our second index looks into land requirements for specific replacement of a fraction of domestic liquid fuel demand with biofuels. We first estimate the amount of land area needed to produce a specific mixture of biofuel on the total demand of domestic liquid fuel, defined as:

$$CLB_{ij} = FD_j \times z_{ij} \times y_i \times \alpha \qquad (2)$$

where z_{ij} is average yield of energy crop *i* in country *j* (in tonnes per hectare) in 2000-2003, and α is the percentage replacement of domestic fuel demand (in percentage). In our calculations we chose a replacement rate of 5%. That is, 95% petrol (diesel) and 5% ethanol (biodiesel), E5 and B5, respectively. This is a conservative estimate and reflects current legislation being set as policy incentives in the region.

Once we have estimated the land needed for biofuel production, we can estimate the land requirement index (LRI_{ij}) for energy crop *i* in country *j* defined as:

$$LRI_{ij} = \frac{CLB_{ij}}{CL_{ij}} \tag{3}$$

where; CL_{ij} is the average area harvested of energy crop i in country j during 200-2003 (in hectares). The land requirement index takes into account the current demand of liquid fuels (petrol and diesel), as well as the current area under cropland of every energy crop in each country.

The land requirement index is basically the area of new cropland needed for biofuel production to replace 5% of total liquid fuel domestic demand (E5 for ethanol or B5 for biodiesel) relative to the current area harvested. That is, it can be interpreted as the number of times current cropland in crop i has to expand to meet the replacement rate.

These estimates show another aspect of biofuel production, in this case, the need for new land, current but also potential land. First, it allows us to know if there is enough current land under production to satisfy domestic demand for a 5% mix, and second, if there is not enough land, it estimates how much land would be needed relative to current land under production to reach a 5% mix. In this case we assume that such expansion or change in land use, without taking into account area needed for food production.

This index is crop specific, that is, it assumes that a single crop (i.e. sugar cane) replaces by itself 5% of domestic liquid fuel consumption. For that reason, the results for each crop are mutually exclusive from one another, because it assumes the land expansion of a single crop at a time.

Potential agricultural frontier expansion and suitable land availability

The previous two indexes analyzed the potential of biofuels based on net production surplus and land requirements for each country. However, this analysis does not take into account the agro-climatic conditions for such an expansion. We define another index to complement the previous analysis and to incorporate the potential expansion areas for biofuels according to soil, weather, and other physical factors that are included in the concept of agro-ecologic zone.

An agro-ecologic zone (AEZ) is the characterization of a geographic area based on soil type, soil fertility, rain regime, temperature, elevation and drainage. The concept of AEZ allows quantifying crop potential of specific crops in different regions. It also allows to determine all agricultural land use options under specific management conditions and input level, and to quantify the amount of land that can be cultivated under a specific crop. The suitable available area (AA) for crop *i* in country *j* (in thousand of hectares) is defined as:

$$AA_{ij} = SA_{ij} - CL_{ij} \tag{4}$$

where SA_{ij} is the area of land very suitable or suitable for crop production of energy crop *i* in country *j* (in thousand of hectares), and CL_{ij} is the current area harvested of energy crop *i* in country *j* (in thousand of hectares).

The data for this index is the result of the analysis and estimates of FAO and IIASA (International Institute for Applied Systems Analysis), published by Fischer et al. (2002). To estimate the available cropland we consider suitable and very suitable (S+VS) areas by country for each crop in this study, considering that these areas will have the higher susceptibility to be used by a specific crop. It is worth noticing that these estimates include crop potential for each crop under rain fed conditions (does not include irrigation)[3] and an intermediate input level[4]. However, these estimates do not allow us to know whether there is crop replacement or expansion into new cropland areas, issues that we consider in the following sections.

Now, using the available area, we can estimate the suitability of producing biofuels to meet a specific mixture of domestic liquid fuel demand. This suitability we have called the Potential Expansion Index (PEI) which is estimated as

$$PEI_{ij} = AA_{ij} - CLB_{ij} \quad (5)$$

This index denotes the amount of land available to produce, in our estimates, a 5% mixture of biofuels in the domestic demand of liquid fuels. This index is important since it allows knowing how much land is currently available for biofuel production after securing domestic food production. This is a key factor in the current discussion of biofuel production and how much it affects food production.

Biofuel production and food security in Latin America to 2025

As discussed before, one of the main concerns of biofuel production is its competition with food production. Such competition could negatively affect production of food for human consumption as well as for animal feed. One of the main objectives of a biofuel program, is to minimize the effect that the potential production of biofuels on the domestic food and feed markets. For that reason we try to determine the geographic and technical potential of biofuels to the year 2025,

[3] The agricultural potential under irrigation assumes that good quality water resources are available and that water infrastructure is in place. That is, identifies areas where weather and soil conditions allow cropping under irrigation.
[4] Fischer et al. (2002, p. 76-80) defines a low input level where there are no chemical use and there is a limited use of organic fertilizers, limited or zero use of biocides and long periods of no land use. A high input level is defined as use of fertilizers, pest management and short no-use periods. Table 5.10 in Fischer et al. (2002) shows potential yield under intermediate and high input levels for different crops in various climatic regions.

taking into consideration malnourishment reduction targets and food security for each country in the region.

Before we continue, we define the different types of potential production of energy crops, using the definitions from Van Wijk and Coelingh (1993) and the World Energy Council (1994), we define the geographic and technical potential as:

- Theoretical potential (disposable) is the maximum limit of primary biomass i.e. the net primary biomass productivity obtained from total planet surface from photosynthesis.
- Geographic potential is the theoretical potential of disposable land for biomass production used for energy production.
- Technical potential is equivalent to the geographic potential less losses of primary biomass conversion into secondary energy carries. This potential is defined by the efficiency of conversion technologies.
- Economic potential is equal to the technical potential that can be obtained at profitable levels.
- Implementation potential is defined as the maximum amount of the economic potential that could be done within a determined time frame, taking into consideration restrictions and institutional incentives.

In this study we omit the economic potential and the implementation potential due to data limitations, and focus on the analysis of the geographic and technical potential for 31 countries in Latin America and the Caribbean.

Disposable area for energy crops

In order to estimate both the geographic and technical potential, we first determined the available area for energy crops that first cover the nutritional needs and objectives of malnourishment reduction in countries in Latin America. We use the same methodology from Marrison and Larson (1996), modified the particular needs of Latin America and the Caribbean, with a time frame from 2002-2025. These authors focus on population growth and per capita calorie intake as main drivers of future food demand. These factors will determine the amount of land needed to meet future food demand, and therefore, the available area for energy crops.

To determine the future the available area, we first estimate a multiplier of food supply (MFS), in this case, cereals[5]. The MFS takes into account population growth as well as the nutritional needs of each country in the region. The MFS is defined as:

$$MFS = \left(\frac{P_{2025}}{P_{2002}}\right) \cdot \left(1 + \ln\left(\frac{\beta_{2002-2004}}{2}\right)\right) \quad (6)$$

The left hand side is a population growth term and the right hand side is an undernourishment term (β is the malnourishment rate in 2002-2004). The population growth term is the ratio between the population of Latin America in the year 2025 (considering constant fertility) and the population in 2002. Countries with higher MFS, indicates that they should increase domestic food production or net imports.

The undernourishment component has been modified from Marrison and Larson. In their study, they assume that the minimum calorie needs will be met by 2025. In the case of Latin America,

[5] According to Marrison and Larson, cereals constitute 92% of total trade of cereals, oilseeds and vegetables. However, it overestimates imports by omitting products such as cassava.

by the year 2002, minimum dietary energy requirements have been met for all countries in the region (which makes the nutrition component equal to 1, and therefore, meaningless. For that reason, we decided to use a different indicator of hunger and malnourishment. In this case we assume that by the year 2025, all countries in Latin America and the Caribbean will reduce the prevalence of undernourishment to 2% of total population, similar to values in developed countries[6]. These values have been normalized using a logarithmic scale, to correct for dimensionality issues in the estimates.

The future level of net imports will determine what part of the MFS should be supplied by domestic production. Similar to Marrison and Larson we consider three possible scenarios:

1. The first scenario assumes that net imports are fixed at 2002 levels. The domestic multiplication of food production (MFP) is:

$$MFP_{fix.imp} = \left\{ MFS \left(\frac{Q_D + M}{Q_D} \right)_{2002} \right\} - \left(\frac{M}{Q_D} \right)_{2002} \tag{7}$$

where Q_D is domestic production and M is the level of imports.

2. Second, we assume that net imports are zero:

$$MFP_{no.imp} = MFS \left(\frac{Q_D + M}{Q_D} \right)_{2002} \tag{8}$$

3. Finally, we assume that net imports increase, but stayed fixed as a percentage of total calories supplied in 2002:

[6] According to FAO data, the countries with the highest percentages of undernourishment (>20%) in the region are Bolivia, Dominican Republic, Guatemala, Haiti, Honduras, Nicaragua y Panama.

$$MFP_{\% fix.imp} = MFS \tag{9}$$

For equation (7), we observe that countries that depend on food imports should increase significantly their domestic production. That is the case of some Caribbean islands such as Antigua and Barbuda, Bahamas, Barbados, Dominica, Grenada, Jamaica, and Trinidad and Tobago. Saint Kitts and Nevis, and Saint Lucia are an extreme case because they do not report any cereal production.

Domestic food production could increase by more intensive land use or increased crop yields. To estimate how much current cropland use must increase we estimated yield increases to 2025 of nine cereal crops by country (barley, corn, millet, wheat, rice, oats, rye, sorghum, and other cereals). According to our results, on average, cereal crops will increase their yield in the region by 20% between 2002 and 2025 (i.e. 0.87% per year). FAO projections estimate that cereals, in developing countries, will increase their productivity by 38% between 1999 and 2030 (i.e. 1.22% per year). We can observe that our estimations are conservative.

The total cropland required in 2025 (CLR_{2025}), assuming a yield increase of 20% between 2002 and 2025, can be derived from cropland (CL) in 2002:

$$CLR_{2025} = \left(\frac{CL_{2002}}{1 + \%\Delta Yield_{2002-2025}} \right) \cdot MFP_{fixed.imp} \tag{10}$$

We assume that energy crops do not use cropland, forestry areas or wilderness areas[7]. For that reason land for energy crops is taken from areas classified as pastures and "other"[8]. Assuming

[7] According to the World Resources Institute, wilderness areas are defined as areas that do not show evidence of development (settlements, roads, buildings, airports, railroads, pipelines, power lines and reservoirs). Wilderness does include desert areas.

that none of 2002 cropland is classified as wilderness and that wilderness areas are equally distributed among forests, pastures and "other" land, a wilderness factor is defined and used to estimate the fraction on non-cropland area potentially available for use as new cropland, for biomass plantations, or other uses. The wilderness factor, WF, is defined as the proportion of non-cropland that is wilderness:

$$WF = \frac{Wilderness_{2002}}{\left(Pasture_{2002} + Forest_{2002} + "Other"_{2002}\right)} \tag{11}$$

The available area (AA) for conversion to new cropland or to biomass energy plantations is

$$AA_{2002} = \left(1 - WF\right) \cdot \left(Pastures_{2002} + "Other"_{2002}\right) \tag{12}$$

This assumes that natural forest and wilderness are not available for conversion. Countries in South America and Mexico have the largest quantity of available area, from 10 million hectares in Ecuador to 174 million hectares in Brazil.

The fraction of available area required for new cropland (NCF) is:

$$NCF_{2002-2025} = \frac{\left(CLR_{2025} - CL_{2002}\right)}{AA_{2002}} \tag{13}$$

Caribbean countries show a high dependency on food imports, and for that reason that in scenarios 1 and 2 (mainly) *NCF* is relatively high. It ranges from 11 times the *AA* in Dominican Republic to 536 times in Jamaica (results not shown here). That is not the case in South

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[8] Includes uncultivated land, grassland not used for pasture, built-on areas, wetlands, wastelands and roads. Desert is also included as part of "other". Such desert areas are discounted from our analysis by excluding such wilderness areas for biomass production.

American countries, where they require just a fraction of *AA*, being the lowest Uruguay and Argentina (with negative percentages, that is, there is more than enough agricultural land) and the largest Venezuela (71%).

Finally, the available area for energy crops, the biomass energy crop area (*BECA*) is estimated as

$$BECA_{2025} = \gamma \cdot \left(AA_{2002}\right) \cdot \left(1 - NCF_{2002\,-\,2025}\right) \tag{14}$$

where *NCF* is the fraction of available area (*AA*) used for new cropland in 2025, and γ is the fraction of available non-cropland that is assumed to be used for energy crops. In this case we assume 10% of total area used for energy crops, same as Marrison and Larson (1996).

<u>Geographic and Technical Potential</u>

The geographic potential is defined as the quantity of primary biomass (i.e. not derived from residues by directly from the energy crop) produced for energy purposes in disposable land areas. These land areas are those left after demand for food, feed, and forestry products has been met, corrected for biodiversity losses, pastures for animals and areas not physically suitable for energy crops. Hoogwijk (2004) determines the geographic potential for country *i* according to the following formula:

$$G_i = \sum_{i=1}^{n} A_i a_i Y_i MF \tag{15}$$

where A_i represents the total area; a_i is the soil exclusion factor for reasons previously described; Y_i is crop yield under rain-fed conditions, and *MF* is a management factor that represents the knowledge in crop management as well as technology advancements.

To estimate the geographic potential we used the methodology from Marrison and Larson (1996), where they determine the disposable land for energy crop production (i.e. $A_i \cdot a_i$ in equation (15)) once food security needs of the region have been taken into account. Crop productivity (Y_i) was estimated using crop time series from FAO (1961-2004) projected to 2025[9]. The value of *MF* was taken from 2025 projections of the IMAGE 2.2 model for agricultural and forestry crops (Hoogwijk, 2004). We estimated the potential for 12 energy crops, using the three scenarios previously described.

The IMAGE 2.2 is a model used to evaluate changes in the environment. This model includes four scenarios according to the "special report of Emission Scenarios" by the Intergovernmental Panel on Climate Change (IPCC). These scenarios reflect two large dimensions: the degree of globalization versus the degree of regionalization and the degree of orientation into an economic-material path relative to the ecological-social path. These dimensions affect projections on variables such as population growth, GDP, social behavior (i.e. diet, self-sufficiency rate, etc.) and technological change.

For comparison purposes, we use in the estimation of the geographic potential, the yields of different energy crops obtained from scenarios A1B and B1 to the year 2025 (see description in Appendix 1). We consider these two scenarios, because they better describe the current trends: globalization and the search for energy sources that are neutral to the environment.

There are two types of primary biomass: energy crops and residues. Energy crops are those planted for energy production and can be classified in three categories (Hoogwijk, 2004): a)

[9] As an adjustment mechanism we used 5% confidence intervals.

Crops that contain sugar (sugar cane, sugar beet), starch (cassava) and oil (soybeans, sunflower, canola), b) short cycle forestry crops (willow, eucalyptus) and c) herbaceous crops (switch grass, miscanthus). Our study focuses on energy crops plus a forestry crop (Eucalyptus).

To determine biomass productivity from forestry crops, we take as reference Carpentieri et al. (1993), that determine based on the experience of Brazilian commercial plantations of eucalyptus, that biomass yields (dry tonnes / Ha / year) for eucalyptus is determined by the following equation:

$$Yield = (0.016 * Precipitation) - 1.05 \qquad (16)$$

This equation is based on the relationship where the annual average rainfall has a high correlation with eucalyptus yields of commercial plantations. We use eucalyptus as a proxy for this potential since it is a specie able to grow in tropical and sub-tropical areas, and that can be used for other forestry species for biomass production.

Finally, to estimate the *technical potential* we consider two main components: crop yield and the technical coefficient of transformation (efficiency). The differences shown for the same crop between each region are given only by differences in yield projections to 2025 (our own and taken from IMAGE 2.2), since the transformation efficiency is assumed the same for all countries. The estimates of the technical potential are derived from the geographic potential using the transformation efficiency coefficients. We used transformation coefficients in Tables A1-A3, and assume that by 2025 there is the same efficiency level in the extraction of biodiesel and ethanol. According to Hoogwijk (2004), there is an increase in conversion technology of ethanol from 40% in 2000 to 55% in 2050. Based on these projections, the technical potential (2025) for diesel is 171 lt / dry tonne and 391 lt / dry tonne for ethanol.

Results: The potential of bioethanol and biodiesel production in Latin America and the Caribbean

Mixture Index (MI): Potential production of ethanol and biodiesel

We begin our discussion of the quantitative estimation for potential production of biofuels (bioetanol and biodiesel) for countries in Latin America and the Caribbean with the Mixture Index (MI). Table 1 shows the results for the (MI) for ethanol and Table 2 shows the results for biodiesel.

In the case of ethanol, the main crop used as source of is sugar cane in almost all countries of Latin America and the Caribbean. Surplus availability for most countries is common for sugar cane and constitutes for most countries the main source for ethanol. Potential for ethanol production based on cereals such as corn, wheat and sorghum are mainly concentrated in Argentina. This shows the competitive advantage of Argentina to produce ethanol based on these types of cereals. Overall, all surplus producers can produce a total of almost 20 billion liters of ethanol per year, which corresponds to 58% from sugar cane, 22% from corn and 18% from wheat. This is equivalent to a regional mix of local fuel demand of 26 percent. That is, current surplus production of energy crops for ethanol production could cover one quarter to total fuel demand in the region.

The country with the largest technical potential based on surplus production is Argentina, which can produce a mix that could cover more than double (204%) the current demand of petrol. However, we should note that these crops are less efficient and more costly that sugar cane in conversion to ethanol. Paraguay also has large surplus of corn, which would allow them to reach a mixture of 68%. Bolivia and Colombia could use mostly sugar surplus reaching gas mix of 4% and 12%, respectively.

In the case of Brazil, the estimated production potential of bioethanol is 43%. We should clarify that that this estimate does not include current bioethanol production, which represents 8.9% of gas consumption in Brazil (ANP 2004 and Abegás 2004).[10] That is, there is already established ethanol production from sugar cane in Brazil, which is considered as part of internal demand for sugar cane, which would result in a higher percentage mix than estimated in Table 1. As it is well know, Brazil started an ethanol production program based on sugar cane in the 70's through the National Program for Alcohol (PROALCOL). Now, this country has almost 3 million hectares for bioethanol production, which places it as the first exporter of ethanol in the world.

In Central America, almost all countries can reach a mix higher than 5%, only from their sugar surplus. Guatemala is the country with the higher mix (76%), followed by Nicaragua, El Salvador and Belize. In the case of Costa Rica, cassava surplus is equivalent to that of sugar cane, placing that country to produce from each of these two crops, a mix of 10% each.

Caribbean countries have mainly sugar cane surplus, and in less proportion from cassava. All countries, except for Saint Vincent and the Grenadines (0.1%), can produce bioethanol with mix

[10] This is equivalent to 3% of total consumption of liquid fuels in Brazil.

for local gas market equal or larger than 5%. Cuba has the largest potential because it can produce more than three times its local consumption of gas, mainly due to its large surplus of sugar cane (second only to Brazil) and its low gas demand.

For biodiesel, the crop with the largest potential is soybeans (Table 2), which represents 79% of total biodiesel production, followed by sunflower (17%) and oil palm (4%). However, we can observe that soybean production is concentrated in four countries at the south of Latin America: Argentina, Brazil, Bolivia and Paraguay, with Argentina concentrating most of soybean and sunflower production. Meanwhile, oil palm is more predominant at the north of South America and Central America. In general, the technical potential of biodiesel can reach 11% of all diesel demand in the region.

Argentina, Bolivia, Brazil, Paraguay, Costa Rica and Honduras show large surplus that allows them to have mix of 5% or higher. Argentina, with its production of soybean and sunflower, could reach a mix level of 47%, while Bolivia and Paraguay with biodiesel production from soybean mainly, could reach a mix of 27% and 15%, respectively. Meanwhile countries which could base their production of biodiesel in oil palm, could reach mix between 1% and 11%. In general, most countries do not reach a 5% mix. For that reason, if they would like to implement a biofuel program, they should expand land under energy crops. This can cause pressure on the environment, food production, etc.

These first estimates analyze the potential of biofuels only using production surplus, and serve as a first approximation of country potential and crop selection or a mix of crops best suited for each country. However, it is necessary to account for other aspects, such as soil and climate limitations in each country, production costs and impact on country welfare. These factors are considered in the following estimates.

Land Requirement Index (LRI): The need for land to replace 5% of liquid fuels

Table 3 and Table 4 show the area required in each country and for each crop to obtain a 5% mix (for bioethanol and biodiesel), and how many times the current area planted would need to expand, as estimated through the land requirement index (LRI). As explained in the methodology, the expansion areas calculated consider each crop as the only source of biofuels necessary to reach the 5% mix, that is, each column for each country is mutually exclusive. There is no estimate of the optimal crop areas necessary to obtain a 5% mix. The selection of an optimal combination of crops is a specific issue for each country and is subject to suitable land availability for each crop, production, costs, and the different types of policies and incentives adopted by each country.

For ethanol production, the principal crop is sugar cane (Table 3) as seen in the precious results of Table 1. Because this crop is widely cultivated in Latin America and the Caribbean and has high yields of bioethanol per unit of land, the land requirement index (LRI) for this crop to reach a 5% mix (E5) is small (0.01 times for Cuba and 4 times for Dominica), assuming that all crop production would be used for ethanol production.[11] Compared to sugar cane, sugar beet is only cultivated in only 3 out of 31 countries in the study. Chile is the country that needs less

[11] The Ministry of Agriculture of Ecuador (2001) reports reach a mix of E20, it would require to increase sugar cane production in 55,600 hectares, install two sugar cane plants (and their corresponding alcohol plants) with a capacity of 15,000 tons/day each, which means an investment of US$ 550 millions.

expansion of its current cultivated area (LRI = 1) and Venezuela would require the largest expansion (LRI = 327).

For wheat, Venezuela would require a very large expansion (4,245 times) relative to current cultivated area. However, other countries including Argentina, Bolivia, Brazil, Chile, Paraguay, Peru, Uruguay and Mexico would only need to expand the cultivated areas between 0.04 and 1 times. In absolute terms, the highest land requirements for biofuel production (CLB) would be Venezuela with 4 million hectares and Brazil with 1.3 million hectares. Corn is a widely cultivated crop in the region. Expansion requirements would range from 0.03 times in Argentina, to 108 times in Antigua and Barbuda. Most important cropland area expansions (in thousand of hectares) would be in Mexico (1,397), Brazil (662), Venezuela (411) and Colombia (349).

Cassava is a crop that is planted in almost all countries of the study, except Chile and Uruguay. The largest area expansion (in thousands of hectares) would be in Mexico (367), Brazil (223), Venezuela (158) and Colombia (101). South American countries would not require significant current area expansion, ranging from 0.01 and 4 times. In Central America, Belize would require to expand crop area 20 times, Mexico 227 times and in the Caribbean, Bahamas 157 times and Antigua and Barbuda 154 times. Sorghum requires large expansion areas in Mexico (1.3 million hectares) and Brazil (1.2 million hectares). In terms of expansion, Peru (1610 times), Cuba (398 times) and Ecuador (29 times) would require the largest increments relative to current area cultivated.

For biodiesel production based on oil palm (Table 4), Brazil (10 times) and Mexico (11 times) would be the two countries that would require the largest area to reach a B5. For soybeans, countries with the largest need for expansion of current area would be Panama, Venezuela, and Peru. Meanwhile, traditional soybean producers such as Argentina, Bolivia, Brazil and Paraguay would diminish a fraction or their current area under soybeans.

For sunflower, Mexico (3,866) and Ecuador (1.732 times) would require the largest expansion in the region, and Argentina the smallest (0.31 times). For castor oil, although Brazil requires in absolute terms 1.5 times the area of Mexico to satisfy domestic diesel consumption (4 vs. 6 million hectares), the area of Brazil would only need to expand 39 times, while the area of Mexico would need to expand 2,025 times. Haiti requires 31 times the current surface up to 70 thousand hectares. Finally, Paraguay would require expanding current area only 12 times.

Cotton is a widely cultivated crop in the region. In South America, Brazil is the country with the largest absolute area to reach B5 at 5.4 million hectares. However, Venezuela (330 times), Ecuador (269 times) and Colombia (20 times) would require the largest area expansion in the region. In Central America, Costa Rica would need the largest expansion (1,303 times) and Nicaragua the smallest (68 times), while Mexico would only need to expand their area 37 times. Finally, in the Caribbean, the largest expansion would correspond to San Christopher and Nieves and the smallest to Haiti (99 times).

For canola, which is a crop of template weather, it is cultivated by only a few countries in the region. In absolute terms (millions of hectares) Brazil with 2.6 and Mexico with 1.8 would require the largest expansion, and Chile is the country that would require to expand the least the current area under production (16 times), being that crop of great potential for biodiesel production in that country. Finally, in the case of jatropha, there are no data on current area under production from FAO. However we assume a yield of 4 tonnes/Ha. to estimate the area needed to reach a mix of B5. Same as for other crops, Brazil is the country that would require the largest expansion (1.2 million has), followed by Mexico (549 thousand has.) and Argentina (347 thousand has).

Potential Expansion Index (PEI): Potential land use of biofuel crops

Before we present the estimates for the Potential Expansion Index (PEI), we show the results of the suitable available area (AA) for each energy crop (Table 5). Same as previous estimates, these results are mutually exclusive, that is, only take into account crop potential as if it would be planted exclusively. For example, in the case of sugar beet the two countries with largest available area are Brazil, Uruguay, and Argentina. However, these areas are currently used by soybeans, corn and wheat.

We can observe that for the majority of crops there is a potential to expand the agricultural frontier. For example, in the case of oil palm in Central America (in concordance with the announcements of governments in this region to use oil palm as a biodiesel source), there is potential to plant in the case of Nicaragua 768,000 additional hectares from the 2,000 hectares already planted. For that reason, the announcement to plant 200,000 hectares of oil palm in Nicaragua is within the range from the agro-ecologic and climatic point of view.

Taking into account the previous estimates of cropland area for biofuels (CLB) to obtain a mix of E5 or B5, and the available area (AA), we estimate the Potential Expansion Index (PEI) (Table 6). We can observe that the region with the largest is South America. Sugar cane is the crop with the largest potential in the entire region, except for Chile where there is no much land suitable for sugar cane production. All other countries have suitable areas that could provide with land for sugar cane production for ethanol. For sugar beet, and given the assumptions described in the previous section, this is cultivated in areas not suitable for this crop (denoted by negative areas in Table 6 in Chile, Ecuador, Mexico and Venezuela). That is, that given the assumptions in this section, there is not enough land for ethanol production.

Wheat is planted in almost all of South America. Only Colombia, Guatemala, Honduras and Venezuela do not have surplus land to produce a mix of E5. For corn, most South American countries have enough available land for ethanol production. An exception is Colombia, which does not count with surplus land for bioethanol production and shows negative areas. This means that current production is planted (under the conditions previously described) in land not suitable for this crop. In Central America and the Caribbean only Nicaragua and Cuba have surplus land suitable for ethanol production. From all crops, cassava has the largest area available in Latin America being this area enough for a mix of 5%. The only exceptions are Argentina, Belize and Jamaica.

In the case of biodiesel we can see that for oil palm in South America there is enough land for expansion, because there is only need for 632,000 hectares out of the 78.2 million hectares available for this crop. All Central American countries and Mexico could expand oil palm production without any trouble, while for Caribbean countries there is enough land for Cuba, Haiti, Jamaica and Dominican Republic.

For soybeans, Argentina is the country with the largest area available (22.7 million hectares) versus the required area (1 million hectares). However, for Brazil, Colombia, Paraguay and Peru there are not enough suitable areas to reach the 5% mix. This may cause the need to use current production under the risk to put pressure on market prices (domestic and international). In the case of Mexico and Central America, Mexico has the largest available land with 6.7 million hectares, while there are expansion limitations in Belize, Guatemala and Panama. In the Caribbean there is large land availability in Cuba, Haiti and Dominican Republic.

For sunflower seed, countries with the largest expansion availability are Argentina (15 million hectares) and Uruguay (3 million hectares). While for Brazil, Chile, Ecuador, Paraguay, Venezuela and Mexico the current area does not meet the land requirements to reach a B5. Castor oil has expansion possibilities in Mexico, while for Brazil, Ecuador and Paraguay, expansion is limited. In the Caribbean, sunflower and castor oil are crops not suitable under the given conditions.

Biofuel production to 2025: Food security vs. Energy production

We begin our discussion of the projections results to 2025 by discussing the potential available land area (AA) for energy crops in 2025 as shown in Table 7. We have to remind that this area already accounts for food production and nutrition targets for these countries. We can observe that for Argentina, Paraguay and Uruguay, that are net exporters of cereals, the scenario 3 is the lowest, while for the rest of the countries in the region, it happens otherwise. We can observe that for the rest of the region, in the scenario where there are no imports (Scenario 2), the available area is lower due to increased domestic production (land competition) to meet demand. All countries in South America and Mexico have the largest potential for biofuel production. However, in all Caribbean countries, except for Cuba, there is no potential in scenarios 1 and 2. Only in scenario 3, Bahamas, Barbados, Saint Lucia, and Saint Kitts and Nevis show a small potential. In Central America, Belize has available area in all three scenarios while Costa Rica only has available area in Scenario 3, and the rest of Central American countries do not have available area for energy crops in any scenario.

Once we have estimated the available area (AA) for biomass production after meeting food and nutritional needs, we estimated the geographic and technical potential for each country in the region. The results of the technical potential (Table 8 and Table 9) are derived from the geographic potential (results not shown here) as described in the methodology section. The results in Table 8 and Table 9 only show the results of scenario 3 (fix % of imports), the scenario that allows the variability of imports, according to the food needs of each country. This allows that some countries in Central America and the Caribbean, which are highly dependent of cereal imports, can (at very modest levels) produce biofuels. The results of scenarios 1 and 2 are available upon request from the authors.

For ethanol production, Table 8 shows that the crop with the largest potential is sugar cane, followed by cassava. The region with the largest potential for ethanol is South America, except for sugar beet. For sugar cane, the technical potential for South America is 6 EJ. The IMAGE 2.2 scenarios A1B and B1 estimate the potential at 75% of our estimates. Cassava is the second crop, with 2 EJ. The IMAGE 2.2 scenarios estimate a larger potential for cassava at 5 EJ (233 G Lt). For corn, sorghum and wheat, the technical potential is between 1 and 2 EJ. Sugar beet shows the smallest potential with 0.4 EJ. For Mexico and Central America, the technical potential is much smaller. The main crops for these regions are sugar cane and cassava with approximately 1 EJ each.

Same as with ethanol, South America has the largest potential for biodiesel (Table 9). The main crop for both South America and Central America and Mexico is oil palm. In South America, the potential for oil palm is 4 EJ, followed by cotton seed, sunflower, and soybean with 1 EJ each. In Mexico and Central America, oil palm has the largest potential with 4 EJ, while all other crops have a potential of 1 EJ or lower.

Forestry Biomass Potential

The estimated technical potential of forestry biomass is shown in Table 10. These results show that from forestry biomass we could obtain in Latin America and the Caribbean between 13,389 and 16,723 PJ. The largest share of this potential corresponds to South American countries, especially Brazil, Argentina, Colombia and Peru. Outside this region, Mexico and Cuba show significant values.

Countries with the largest potential for ethanol from forestry biomass in liters are Brazil (94-110 G Lt), Argentina (44-52 G Lt), Colombia (27-41 G Lt), Peru (25-34 G Lt), Mexico (13-24 G Lt), Chile (14-15 G Lt) and Bolivia (10-14 G Lt) respectively for each scenario. Ecuador, Uruguay and Venezuela show smaller potential (3 to 16 G Lt), although relative to Central America and

Caribbean countries these value are significant. If we aggregate ethanol production for the region, we can observe that for scenario 1 (Fixed imports to the base year 2002), it is 3.4 times the average petrol regional consumption for 2000-2003 (Table 1), 3.2 times in scenario 2 (net imports equal to zero) and 4.0 times in scenario 3 (fixed % imports).

Due to current transformation technologies, the technical potential for synthetic diesel production is lower (in volume terms) relative to ethanol. However, the energy content of one liter of biodiesel (33.3 MJ/Lt. – Low Heating Value (LHV)) is 58% greater than the one of ethanol (21.1 MJ/Lt. – LHV). The estimated diesel production volumes, has Brazil (41-48 G Lt) and Argentina (19-23 G Lt) as the largest producers in the region. Diesel production in South America represents between 114-140 G Lt, for Central America 0.3-1.6 G Lt and for the Caribbean 1.2-1.7 G Lt. Comparing totals regional diesel production in the year 2025 to average diesel consumption for the period 200-2003, it is 1.2 times for scenario 1 and 2, and 1.5 times for scenario 3.

Impact on food, crop, and input prices

Biofuels production's pressure on animal staples and pastures production is an additional social cost that should be internalized in order to assess the real impact of an expansion of biofuels use and production. Increased biofuels demand implies, undoubtedly, a raise in energy crops demand. However, the impact and magnitude of this increased demand on energy and other crops' prices, is far from clear. The evaluation of the impact on prices requires a more detailed analysis which includes the market's characteristics (supply and demand) of each crop, as well as, the interaction with traditional crops markets.

The decision to use biomass for energy or food, in financial terms (bigger gross margin), depends on which has a lower opportunity cost. However, it is also important to consider the opportunity cost for society as a whole. While a positive effect can exist on the value chain and the producer may receive a higher income, food markets could experience a general price increase, which could lead to a decline in consumer's real income. This is a sensible situation mainly in developing countries, where low and middle income strata use a significant part of their income for food consumption.

Estimates from the Confederation of the Food and Drink industries of the EU (CIAA) show that rapeseed oil price has increased between 41 and 45% above average prices from 1996-2000 period. Moreover, it estimates that cereal prices will increase between 6 and 11% by 2010 and for oily crops between 5 and 15% (CIAA, 2006). Other potential negative effect from the expansion of biofuels production may be on food security, nutrition, environmental impact, etc.

<u>Induced effects on agricultural products' price</u>

The impact of biofuels demand on agricultural crops prices is difficult to measure, however some studies have tried to evaluate such an effect. Raneses et al. (1999) analyzed the possible impact that a rise in soybean based biodiesel demand has on the agricultural sector of the United States, and specifically, on production and prices of soy-oil, soybeans, soy meal and corn.[12]

[12] The authors assume that the increase in biofuels demand originates from increased use of biofuel in three sectors: Federal transport float, Mining and Maritime (mainly big boats used for recreation).

Table 11 shows the results of Raneses at al. (1999), which are divided in three important effects on: 1) inputs for biofuels production, 2) sub-products derived from biofuels production (soy meal) and 3) other crops, substitute for animal staples, in this case corn. In the case of inputs for biofuels production, soybeans and soy-oil, an increase in biodiesel demand induces a rise in demand of those products. The raise in biofuels demand results in a price increase for inputs, which provides incentives for their production. However, the increase in production is not enough to re-establish prices at their original level. Raneses et al. (1999) show that on the extreme case of high demand, prices could increase by 14.1% for soy-oil and 2.0% for soybeans.

In the case of by-products (soy meal) from biodiesel production, the effect on prices is the opposite to the case of inputs. The increase in biodiesel production increases the production of soy meal, thus, rising its supply and consequently soy meal prices fall. According to the model the reduction in price could reach 3.3% in the most extreme case.

As for the effect other crops, in this case corn, Table 11 shows that the effect on prices and production are lower and only evident in the cases of medium and high demand. The intuition of this result is the following: in the cases of medium and high demand, the rise of the soybeans price induces producers to substitute soybeans for corn, which generates a fall in aggregate corn production. Additionally, the demand for corn as animal staple diminishes as a result of the reduction of soy meal price, which in turn, reduces corn prices.[13]

[13] Reduction in soy meal price and consequently in corn price, could have implications in the cattle sector, because it reduces feeding costs which could lead to an increase in meat production.

De la Torre et al. (2003) analyzes the potential impact of energy crops production (switchgrass, poplar and willow tree) for ethanol production through cellulose, on production and prices of traditional crops in the United States, considering that some of the potential areas for energy crops are, also, areas for fiber and food crop production. The study considers two scenarios,[14] and shows (Table 12) that increased demand for energy crops not only results in an increase in prices of those crops, but also, in a price increase of other crops which compete for the same agricultural land. The production of bioenergy crops would compete for the use of soil with traditional crops, which could result in a price increase for all crops.

Rosegrant et al. (2006) estimates the impact of biofuels demand on world prices of energy crops. The authors considered price impacts under three different scenarios, and a summary of their result is presented in Table 13. The increase of future biofuels demand has a significant impact on crop prices, mainly under Scenario 1, where biofuels are obtained from traditional crops. However, the consideration of technology improvements that allow obtaining biofuels from cellulose (Scenario 2), reduces significantly the increase on prices. If this technology improvement is joined by crop's productivity changes (Scenario 3), the impact of biofuels on prices is even lower. This last scenario shows that the combination of investments in the biofuel industry and the agricultural sector can mitigate impacts on consumers.

[14] The study considers two scenarios: The first scenario assumes lower initial prices for each crop, lower use of fertilizers and chemicals and partial harvest of switchgrass area. The second scenario assumes higher prices, standard use of fertilizers and chemicals, and total harvest of the switchgrass area.

Koizumi (2003) analyzes the effect that a change in the proportion of the ethanol-petrol mix in Brazil could have on the domestic and world markets of ethanol and sugar.[15] The author shows that a rise in the proportion of the ethanol-petrol mixture in the Brazilian market, results in an increase of ethanol production for domestic consumption and a reduction of exports of this product, since it is expected that Brazil, as the rest of the countries, favors domestic demand. Consequently, despite increased world consumption and production of ethanol in the 2006-2010 period, there is a slight reduction in ethanol world trade. Ethanol world price, would rise between 0.91-1.14%

The increase in ethanol prices in the Brazilian market creates incentives for reduction in sugar production and an increase of ethanol production, which leads to a fall in sugar production between 0.3-2.5% during the 2006-2010 period. The contraction in sugar production in Brazil results on a price increase between 3.82-5.44% in the domestic market. Additionally, the reduction of sugar production in the Brazilian market could generate a reduction in the world production, between 0.0-0.2%, and in world exports between 0.0-0.3%. This may cause that sugar world price could increase between 0.34-2.23 %.

The OECD (2006) study on agricultural market impacts on future growth in the production of biofuels, shows similar effects as the previously presented studies. This study shows that the additional demand for energy crops, due to an increase in biofuels production, could significantly affect the markets of those products. It is expected that leading biofuels producers, like Brazil,

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[15] Since Brazil eradicated all intervention measures on the sugar market in the late 90's, the only control measure the government has on the sugar industry is setting the ethanol-petrol mixture proportion. Additionally, according to FAOSTAT, Brazil is the world leading producer of sugar cane, 37% of world production in 2004, therefore a change in its levels of production could have an impact in international markets.

USA, EU, and Canada, would reduce significantly their energy crops exports or increase their imports.

The stronger impact in international markets, according to the study, should be in the sugar price, which could increase 60% in comparison to the situation in which ethanol production is maintained at the 2004 levels. The other crops prices also tend to rise, although in a less dramatic manner, 4% in the case of cereals and up to 20% in the case of vegetable oils.

However, it's important to mention that the results of the OECD (2006) study contrast with the expectations of the OECD-FAO (2006) in relation to sugar prices. According to the later study, it is not expected that the developments in the ethanol Brazilian market, would significantly reduce sugar production or exports by 2015.[16] This result is more in line with the ones obtained in Koizumi (2003), where the impacts on sugar prices are relatively low.

On the other hand, the OECD-FAO (2006) finds similar results as the previous studies. An increase in biofuels production could result in a reduction of energy crops exports since exporting countries would use part of their surpluses for biodiesel or ethanol production, which could produce a rise in price of these crops.[17]

The impact of increased biofuel production on prices varies depending on the type of crop or product. That is, these impacts vary depending whether we are talking about bioenergy crops, traditional crops or by-products obtained from biofuels production. However, although the

[16] See, OECD-FAO Agricultural Outlook (2006), page 22
[17] See, OECD-FAO Agricultural Outlook (2006), page 22.

magnitude of prices' impact varies across the studies reviewed, the direction of the effects is the same. We can infer that the likely effects that increased biofuel demand may have on agricultural product prices in Latin America:

1) *Price increase of bioenergy crops*: An increase of biofuels production raises the demand and prices for energy crops. The increase in prices provides incentives for the production of those crops. However, the increase in production may not be sufficient to reestablish original prices. This result depends on each particular case and crop.
2) *Price increase of traditional crops*: The increase in production of bioenergy crops may shift land from traditional crops to energy crops. This implies a lower availability of land for traditional crops which could result in a fall of their production and thus, a price increase.
3) *Reduction of price of by-products of biofuels production*: The increase in biofuels production increases the production of by-products of the production process (e.g. soy meal) which results in an increase in supply and therefore a reduction of their prices.

In summary it is very likely that a strong and global expansion of biofuels production could have important effects in the agricultural sector. These effects may be evident through changes in demand, exports, prices, and in the allocation of land for energy and non-energy crops.

The cattle and wood industry would also be affected by the increase of biofuels production. The effect in the meat production industry could work through changes in animal staples prices. While the price of by-products from the biofuels production process (e.g. distilled grain or soy meal) decreases, others like corn increases. This results in price and supply changes for meat.[18] Besides, the increase in biofuels demand could lead to an expansion of the arable land, which could result in a reduction of forest areas.

Finally, it is important to mention that a generalized increase in crop prices could have an impact on income distribution. That is, the increase in crops prices could represent a transfer of income from consumers to producers and from urban to rural areas. This effect could be in line with some countries objective to improve income in rural areas.

Additional remarks on the potential effects on prices

It is important to consider some additional factors, which could have an impact in the results and conclusions previously presented. First, some countries in Latin America and the Caribbean have surplus production for some crops. In those cases, development of new markets like biofuels could help them absorb this surplus production, which could mitigate potential price increases (IEA, 2004).

The analysis and results shown here, with the exception of Rosegrant et al. (2006), do not consider the possibility of future production of biofuels through lignocelluloses. These developments could potentially reduce biofuels production costs and the requirement of land needed to satisfy demand (Hamelinck y Faaij, 2006). Therefore, the results of the studies and

[18] This effect is identified in recent projections from USDA (2007). In their document the price of chicken and pork meat increases in comparison with the price of beef meat since cattle can take better advantage of the increase in supply of distilled grain, a sub-product of ethanol, whose increase in supply would reduce its price. However, it is expected that corn prices, used as staple for chicken and pork should tend to increase.

conclusions presented here are not necessarily robust to the consideration of new technologies for biofuel production.

Most studies, with the exception of the OECD (2006), take the increase in biofuels demand as an exogenous variable and production costs to be independent from oil prices. The increase in oil price has two effects, which work in opposite directions, in the incentives to produce biofuels: a) An increase in oil price rises production costs in agriculture which could result in diminished production.[19] b) An increase in oil prices creates incentives to biofuel production, which stimulates demand for energy crops.

The possible increase and magnitude of biofuel production depends on which of the two effects is the dominant one. Additionally, the heterogeneity with which oil prices affect agricultural production costs alters the incentive for the production of each bioenergy crop, which in turn, could have an impact on crop prices.

Biofuels' expected impact on agricultural structure in Latin America

Increased biofuel production is likely to have important impact on different areas of the agricultural production structure in Latin America and the Caribbean. These impacts include economic, institutional, environmental, technological, socio-productive factors that can change and influence the agricultural production structure, with important and significant impacts on aspects such as food and feed production, land tenure, farm size, concentration of production geographically and by products, etc.

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[19] The effect of an increase in oil price is not homogeneous because there are crops that are more intensive in the use of energy.

The impact of biofuels in the agricultural structure is analyzed here and includes the impact of biofuels in the economic, environmental and technological-productive factors and on the socio-productive structure[20]. Figure 1 contains a schematic diagram of the relationship between different variables and their effect on each other. This figure allows to better understand the relationships between increased biofuel production and different economic, environmental, institutional, and other factors. Next, we discuss each of these factors in detail.

Economic Factors (boxes 2-6, Figure 1) include those that affect the biofuels' price and cost system and therefore have an impact on the incentive to produce or not produce biofuels. Expectations of increased biofuels demand (box 3) rise biofuel production (supply). A better capacity to use sub products (box 6) increases the profitability of biofuels and therefore their production incentive. Increased demand expectations (box 3) are reinforced by energy security and environmental policies, both in supplying biofuel countries as well as in bioenergy importing countries (box 7).

There are also effects of dual directions (both ways), such as the increase of biofuels and value chain production costs (box 2). That is, lower production costs increases the incentive for biofuel production and, at the same time, increased production can cause cost reductions in the value chain.

[20] Results of a series of workshops with experts of several disciplines, organized by the Agricultural Development Unit with the support of the Sustainable Development Division of ECLAC, December 2006 and January 2007.

Institutional Factors (boxes 7-13) are those public policy aspects that affect incentives for biofuels production and can mitigate their negative impacts. The energy security and environmental policies (box 7), can promote biofuels production as a way to solve pollutant emission problems and/or strengthen energy independence and security. Biofuels production also will respond to incentives, credits and infrastructure policies (box 11). Higher consolidation of the bioenergy sector and higher organization level of producers (box 8), might increase their supports and influence the policies of boxes 7 and 11. However, other public policies (box 9) such as the oriented towards strengthening food security could create incentives against biofuels production. For instance, a corn price subsidy can increase demand, and depending on the supply curve slope, a possible increase of corn price which should increase the opportunity cost of biofuel corn-based production.

The public sector has also instruments to mitigate the potential undesirable impacts of increased bioenergy crops such as a raise in the concentration of production (box 27) which leads to higher mechanization (box 21), loss of rural employment (box 23), or displacement of traditional crops to more fragile ecological areas (box 14). These instruments can start from specific policies, such as the policies to protect the most vulnerable agricultural sectors (box 12), followed by territorial regulation policies (box 13), to state policies on biofuels which includes social, economic, environmental and institutional factors (box 10). These various effects should be dealt with through integrated policies.

Environmental Factors indirectly produced through productive and land tenure concentration (box 27), which moves other crops to more fragile areas, some of them with high ecological value (box 14). Thus, the expansion of the agricultural frontier, accelerated for higher cropland demand, leads to more pressure on natural resources and ecosystems (box 15). At the same time, ecosystems homogenization derived from monoculture, also increases these pressures (box 18). The expansion of energy crops (box 1) can lead to additional use of agrochemicals to improve yields and can also force direct pressure on natural resources and ecosystems by generating new sub products which not always are properly used or stored. Consequently, a more efficient use of sub products (box 6) could contribute to reduced environmental pressure.

Technology-Productive Structure Factors (boxes 16-22) are those factors that influence the technology and production techniques used, which have an impact on farmers productivity and production costs. The effect of these factors works indirectly. For instance, a higher investment in R&D (box 19) can cause increased productivity and crop yields (box 17) and facilitate the availability of scale differentiated technological packages (box 20). The increase in primary sector productivity can result in cost reductions of inputs for biofuels production (box 2).

In contrast, an increase in biofuels production (box 1) can have an impact on the size and access to biofuels processing plants (box 16) and result in a "one crop" territorial concentration (box 18), around those processing plants.

The emergence of a new kind of dealers, contracts, intermediaries and suppliers (box 22) specialized in bioenergy sector have a direct and indirect effect in the rise of energy crops, because they can contribute to reduce costs on the value chain of energy crops (box 2). Their appearance is also favored by expectations of increased biofuels demand (box 3), the organization level of producers (box 8), and by the same rise of energy crops (box 1).

Socio Productive Structure Factors (boxes 23-28) includes a change oriented attitude of producers (box 24) which directly impacts the increase of biofuels. Such attitude, is also favored by investment in innovation (box 19), incentives and credits policies (box 11), and by the same rise of biofuels which can generate a scaling effect. If there exists, additionally to incentives to reduce transaction cost and take advantage of economies of scale, a dynamism-flexibility on land markets (box 28), it is likely that efforts to reduce costs should lead to higher concentration of production/land tenure (box 27).

The impact of biofuels on net employment generation in rural areas (box 23) is not clear. The increase in biofuels demand increase inputs demand, among them, labor. However, the possibility of big scale production may increase mechanization (box 21) in previously labor intensive crops areas, which could have a negative impact on rural employment.

Finally, biofuels offer an opportunity for productive conversion, especially for small producers (box 25). However, there exist three conditions for this opportunity to occur: first, there should be technological packages adequate for small producers' needs (box 20); second, small producers should have easy access to biofuels processing plants (box 16); and third, there should be incentive, credit, and infrastructure policies (box 11), which at the same time, should be inspired by inclusive policies (box 12).

Conclusions

In this study we have estimated the potential of biofuel crops in Latin America and the Caribbean. It offers the first complete assessment of the potential of biofuels in Latin America and the Caribbean for each country. Generally, most of the analysis has been focused in the major countries such as Brazil and Argentina. However, as most countries in the region embark in biofuel projects and establish national policies on biofuels, there is a need for a roadmap that looks into the technical considerations that these types of projects need. Most government policies are driven by politics, and in many cases they skip their technical and economic implications.

What we find in this study is that the crop with major potential for the region, in general, for ethanol production is sugar cane. This crop is available in almost every country in the study, and technology transfer from countries with leading technologies as Brazil may become a way for smaller countries to launch their own ethanol programs as Brazil. Another crop with potential for ethanol production is cassava, which is also available in most countries of the region, and is something to look for in the future. For biodiesel production, we find that depending on the region, the crop with highest potential may be soybeans, at the South cone of the continent (Argentina, Paraguay, and Brazil), or oil palm, at the north of South America and in Central America and Mexico. These potential for both ethanol and biodiesel production are large in some countries and may become one of the main drivers of agricultural production in the future.

As for input use, our study focused on land requirements, and the limitations of available cropland and their suitability for energy crops production. We conclude that there is enough land available for biofuel production, especially in South America. Major crops such as sugar cane and oil palm have enough suitable land available for their production. Others, like sugar beet and corn, may not have enough suitable land available for some countries for future biofuel production.

As for food supply and security and the future production of biofuels to 2025, we find that for major food exporters, there is enough land for both food and energy crop production. However, there are some smaller countries, especially in Central America and the Caribbean, which are food importers, and may have to decide whether to import food and produce energy from crops, or the opposite. We also find that the energy potential, once we have secured food production that meet malnourishment reduction targets is large and may cover future demand for biofuels in the region. For energy production from forestry crops we find that there are also large potentials, especially in South America.

In terms of impacts in prices we find that an increase of biofuels production raises the demand and prices for energy crops, which may motivate farmers for their production. Increased energy crops may shift land from traditional crops, which implies lower availability of land for traditional crops that may cause a fall of their production and thus, a price increase. As for the effect on by-products of the production process (e.g. soy meal), increased energy crop production may increase supply of those by-products, which may reduce their prices, benefiting other sectors, such as the feed sector.

As for biofuels' expected impact on agricultural structure in Latin America we argue that the increase of energy crops causes important changes in the socio-productive agricultural structure. The most significant structural changes consist in a higher concentration in production and tenure as well as the establishment of new kind of actors and norms. There are also, impacts on employment, but is difficult to assess their direction.

There are also significant changes generated in the economic structure, mainly due to economies of scale, and increased pressure on natural resources and ecosystems. From the institutional point of view, there are opportunities to influence the increase of biofuels through economic factors such as relative prices and demand expectations. The R&D investments also affect economic factors that can lead to increased biofuel production (modifying costs in the value chain).

The institutional sphere also contributes to reduce negative impacts on socio-productive structure and the environment. At first, protecting and offering opportunities to small farmers, and later, through territorial regulation. It should be noticed that the protection of small farmers, through inclusive policies, can contribute to avoid pressures on the ecosystems.

In summary it is very likely that a strong and global expansion of biofuels production could have important effects in the agricultural sector in Latin America and the Caribbean. Some countries in this region are or may become important role players in the biofuels international market as major producers and exporters. The effects that this increased biofuel production may have may be evident through changes in demand, exports, prices, and in the allocation of land for energy and non-energy crops in the region.

As concluding comments, this paper offers policy makers with a detailed assessment of input requirements as well as a look into the implications on prices and food security. This is important for governments in Latin America, as they are considering the implementation of biofuel programs. Researchers in agricultural economics may find this research interesting because it will offer the considerations of actual policy alternatives for Latin America, which could offer lessons and could be used by other developing countries.

Policy makers will also benefit from the results and discussion of this paper, allowing them to have measures on how their policies affect farmers in developing countries. The outcome of this paper may influence what policies in Latin American governments might take towards agriculture and their role in biofuel production. Finally, we think that the discussion generated by this research will help people to better understand the implications that biofuel programs may have in developing countries' agricultural sectors.

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Table 1. Mixture Latin (MI) and potential ethanol production from net surplus production (in millions of liters) in Latin America and the Caribbean (2000 – 2003).

Country	Energy crop					Total Bioetanol	Petrol consumption (2000-03)	Mixture Index (%)
	Sugar cane	Wheat	Corn	Cassava	Sorghum			
Latin America	11,622	3,490	4,446	98	230	19,886	77,084	26
South America								
Argentina	153	3,490	4,290		203	8,136	3,988	204
Bolivia	28		0			28	691	4
Brazil	7,275			8	23	7,306	16,952	43*
Colombia	699					699	5,833	12
Ecuador	16			5		21	2,208	1
Paraguay	8		156	8		172	254	68
Uruguay					3	3	350	1
Venezuela					1	1	10,971	0.01
Mexico and Central America								
Mexico	160					160	29,039	0.6
Belize	77			0.005		77	196	39
Costa Rica	94			76		170	810	21
El Salvador	199					199	512	39
Guatemala	846			0.2		846	1,113	76
Honduras	59					59	448	13
Nicaragua	122			0.2		122	233	52
Panama	42			0.1		42	549	8
Caribbean								
Barbados	21					21	124	17
Cuba	1,685			0.01		1,685	566	298
Jamaica	33			0.03		33	693	5
Dominican Rep.	100			0.2		100	1,517	7
S. Kitts. & Nevis	5					5	12	44
S. Vic. & the G.				0.026		0	25	0.1

Source: Author's own calculations base on FAOSTAT, and Energy Statistical Yearbook (United Nations, 2006).
Note: * does not consider current ethanol production from sugar cane.

Table 2. Mixture Latin (MI) and potential biodiesel production from net surplus production (in millions of liters) in Latin America and the Caribbean (2000 – 2003).

Country	Energy crop						Total Biodiesel	Diesel consumption (2000-03)	Mixture Index (%)
	Oil Palm	Soybean	Sunflower	Castor	Cotton	Canola			
Latin America	296	5,906	1,248	9.2	58.1	1.03	7,519	68,374	11
South America									
Argentina		3,739	1,217		11	1	4,968	10,555	47
Bolivia		197	26				223	826	27
Brazil		1,831		8	45		1,885	38,098	5
Chile						0.03	0.03	4,869	0
Colombia	93						93	3,276	3
Ecuador	25			1			26	2,690	1
Paraguay	2	134	5		2		143	988	15
Peru					0.1		0.1	3,219	0
Central America and the Caribbean									
Costa Rica	86	5					91	804	11
Guatemala	34						34	1,107	3
Honduras	54						54	803	7
Panama	2						2	810	0
Haiti				0,2			0.2	329	0

Source: Author's own calculations base on FAOSTAT, and Energy Statistical Yearbook (United Nations, 2006).

Table 3. New area required for biofuel production (CLB) (thousand of hectares) and Land Requirement Index (LRI) for ethanol E5 mixture in Latin America and the Caribbean (2000-2003).

Country	Sugar Cane		Sugar beet		Wheat		Corn		Cassava		Sorghum	
	CLB	LRI	CLB	LRI	CLB	LRI	CLB	LRI	CLB	LRI	CLB	LRI
South America												
Argentina	36	0.1			237	0.04	86	0.03	71	4	113	0.2
Bolivia	9	0.1			103	1	39	0.1	11	0.3	37	1
Brazil	141	0.03			1,267	1	662	0.1	223	0.1	1,236	2
Chile			22	1	103	0.3	40	0.4				
Colombia	40	0.1			389	22	349	1	101	1	252	4
Ecuador	18	0.2	203	295	506	23	231	0,5	97	4	178	29
Paraguay	3	0.05			24	0.1	14	0.04	3	0.01	28	1
Peru	7	0.1			153	1	70	0.1	24	0.3	90	1,610
Uruguay	4	1			24	0,2	13	0.3			15	1
Venezuela	97	1	286	327	4,330	4,245	411	1	158	3	727	3
Mexico and Central America												
Mexico	236	0.4			831	1	1,397	0.2	367	227	1,271	1
Belize	3	0.1					10	1	3	20	8	3
Costa Rica	6	0.1					59	7	10	0.4		
El Salvador	4	0.06					28	0.1	7	5	42	0
Guatemala	7	0.04			79	17	79	0.1	67	11	128	3
Honduras	3	0.06			124	62	39	0.1	22	8	58	1
Nicaragua	2	0.04					22	0.1	4	0.5	16	0.3
Panama	6	0.2					54	1	8	4	26	25
Caribbean												
Antigua and Barbuda							3	108	2	154		
Bahamas	3	1					7	47	2	157		
Barbados	1	0.2					6	61	1	51		
Cuba	10	0.01					29	0.2	18	0.2	165	398
Dominica	1	4					3	22	1	6		
Grenada	0,5	3					5	15	1	35		
Haiti	2	0.1					25	0.1	6	0.1	30	0.2
Jamaica	8	0.2					75	54	7	8		
Dominican Rep.	24	0.2					149	6	38	2	107	32
Trinidad and Tobago	2	0.1					9	10	3	40		

Source: Authors calculation based on FAOSTAT.

Note: Each area was estimated as if each crop would be the only source of bioethanol to reach the 5% mix in domestic petrol consumption in each country.

Table 4. New area required for biofuel production (CLB) (thousand of hectares) and Land Requirement Index (LRI) for biodiesel B5mix in Latin America and the Caribbean (2000-2003).

Country	Oil Palm		Soybean		Sunflower		Castor		Cotton Seed		Canola		Jatropha
	CLB	LRI	CLB	LRI	CLB	LRI	CLB	LRI	CLB	LRI	CLB	LRI	CLB
South America													
Argentina	0		1,053	0.1	887	0.3	0		4,001	16	864	160	347
Bolivia			107	0.2	122	1			406	5			27
Brazil	475	10	3,707	0.2	3,332	67	6,202	39	5,456	7	2,660	93	1,252
Chile					471	132					194	16	160
Colombia	33	0.2	571	24					935	20			160
Ecuador	30	0.2	378	7	256	1,732	408	82	967	269			88
Paraguay	13	1	100	0.1	112	3	100	12	426	2			32
Peru	26	2	523	337					770	10			106
Uruguay			111	3	105	1							27
Venezuela	56	2	539	363	945	141			4,407	330			199
Mexico and Central America													
Mexico	137	11	2,959	45	3,189	3,866	4,049	2,025	2,488	37	1,805	555	549
Belize			15	25									3
Costa Rica	5	0.1							391	1,303			26
El Salvador			83	76					170	292			24
Guatemala	6	0.3	97	9					267	191			36
Honduras	5	0.1	109	111					197	190			26
Nicaragua	2	1	56	20					98	68			14
Panama	10	2	272	2,090									27
Caribbean													
Antigua and Barbuda									148	233			2
Bahamas													10
Barbados													3
Cuba													54
Dominica													0.5
Grenada									67	480			1
Haiti							70	31	354	99			11
Jamaica													15
Dominican Rep.	18	2											71
Trinidad and Tobago													9

Source: Authors calculations based on FAOSTAT.
Note 1: Each area was estimated as if each crop would be the only source of bioethanol to reach the 5% mix in domestic diesel consumption in each country.
Note 2: In the case of Jatropha there is no data on area cultivated.

Table 5. Suitable available area (AA) for crop production (thousand of hectares) in Latin America and the Caribbean (2000-2004):

Country	Corn	Wheat	Sorghum	Sugar Cane	Sugar Beet	Cassava	Soybean	Oil Palm	Sunflower	Canola
South America	57,028	55,758	42,238	70,545	39,896	105,695	33,993	87,444	19,447	48,498
Argentina	24,893	33,120	9,908	6,667	26,252	38	22,758	0	15,177	37,764
Bolivia	5,645	833	5,665	8,818	0	25,947	4,296	6,058	143	982
Brazil	13,320	5,306	19,866	29,751	3,464	46,202	814	45,526	420	830
Chile	128	489	35	0	-40	0	222	0	239	190
Colombia	-377	174	446	6,274	0	8,662	143	10,544	0	0
Ecuador	359	601	1,064	907	-1	499	476	1,070	19	214
Guyana	205	0	207	1,343	0	3,083	194	4,767	0	0
Paraguay	2,987	654	226	4,505	0	868	-925	798	-13	55
Peru	302	1,313	643	6,000	0	2,210	111	10,910	340	1,462
Suriname	0	0	0	1,960	0	1,232	0	4,411	0	0
Uruguay	5,710	13,153	-20	1,265	10,222	0	2,992	0	3,118	6,984
Venezuela	3,856	115	4,198	3,056	-1	16,953	2,913	3,358	4	16
Mexico and Central America	-1,658	3,654	6,183	7,683	0	9,616	7,683	3,779	1,507	4,300
Costa Rica	-8	0	0	127	0	191	0	221	0	0
El Salvador	12	0	107	-49	0	262	258	0	0	1
Guatemala	-563	-3	-38	1,264	0	922	13	808	0	0
Honduras	-151	40	79	432	0	718	173	421	0	98
Mexico	-1,121	3,604	5,601	3,461	0	5,444	6,682	1,482	1,507	4,189
Nicaragua	238	12	436	923	0	1,222	557	768	0	12
Panama	-65	0	-1	221	0	857	0	78	0	0
Caribbean	643	0	110	2,190	0	3,759	0	612	0	0
Bahamas	0	0	0	712	0	278	0	0	0	0
Cuba	871	0	170	1,022	0	2,968	868	217	0	0
Dominican Rep.	-1	0	21	371	0	393	24	294	0	0
Haiti	-226	0	-81	55	0	121	38	44	0	0
Jamaica	-1	0	0	31	0	-1	0	57	0	0

Source: Authors calculations based on FAOSTAT, Fischer et al. (2002) and Global agro-ecological assessment for agriculture in the twenty-first century CD-ROM FAO/IIASA, 2005.

Note 1: Estimates based on equation (4), as the difference between suitable area (SA) and current harvested area (CL).

Note 2: The negative sign denotes that current area surpasses the area of suitable and very suitable without irrigation and an intermediate input level.

Table 6. Potential Expansion Index (PEI) (1000 has) for a 5% mix of ethanol (E5) or biodiesel (B5)

Country	Sugar Cane	Sugar Beet	Wheat	Corn	Cassava	Oil Palm	Soybeans	Sunflower seed	Castor Oil
South America	66,879	39,380	48,870	54,693	100,675	86,809	26,278	12,502	39,569
Argentina	6,631	26,252	32,883	24,807	-33	0	21,705	14,290	37,764
Bolivia	8,809	0	730	5,606	25,936	6,058	4,189	21	982
Brazil	29,610	3,464	4,039	12,658	45,979	45,051	-2,893	-2,912	-5,372
Chile	0	-62	386	88	0	0	222	-232	190
Colombia	6,234	0	-215	-726	8,561	10,511	-428	0	0
Ecuador	889	-204	95	128	402	1,040	98	-237	-194
Paraguay	4,502	0	630	2,973	865	785	-1,025	-125	-45
Peru	5,993	0	1,160	232	2,186	10,884	-412	340	1,462
Uruguay	1,261	10,222	13,129	5,697	0	0	2,881	3,013	6,984
Venezuela	2,959	-287	-4,215	3,445	16,795	3,302	2,374	-941	16
Mexico and Central America	6,115	-328	2,575	-3,445	9,064	3,601	4,174	-865	559
Mexico	3,225	0	2,773	-2,518	5,077	1,345	3,723	-1,682	140
Belize	-3	0	0	-10	-3	0	-15	0	0
Costa Rica	121	0	0	-67	181	216	0	0	0
El Salvador	-53	0	0	-16	255	0	175	0	1
Guatemala	1,257	0	-82	-642	855	802	-84	0	0
Honduras	429	0	-84	-190	696	416	64	0	98
Nicaragua	921	0	12	216	1,218	766	501	0	12
Panama	215	0	0	-119	849	68	-272	0	0
Caribbean	2,136	0	0	320	3,671	594	930	0	-72
Bahamas	709	0	0	-7	276	0	0	0	0
Cuba	1,012	0	0	842	2,950	217	868	0	0
Haiti	347	0	0	-150	355	276	24	0	0
Jamaica	53	0	0	-251	115	44	38	0	-70
Dominican Rep.	23	0	0	-76	-8	57	0	0	0

Source: Authors calculations base on FAOSTAT, Fischer et al. (2002) and Global agro-ecological assessment for agriculture in the twenty-first century CD-ROM FAO/IIASA, 2005.
Note: Negative sign denotes that current cropland exceeds the land area suitable or very suitable without irrigation and with an intermediate input use.

Table 7. Available area (AA) for energy crops (in 1.000 Ha) in Latin America and the Caribbean in 2025

Countries	Scenario 1 Net Imports$_{2002}$	Scenario 2 Net Import = 0	Scenario 3 % Fixed Imp.
Latin America and the Caribbean	39,984	38,600	44,566
South America	35,585	35,595	38,178
Argentina	14,524	15,913	13,444
Bolivia	1,641	1,538	2,113
Brazil	9,285	8,772	10,294
Chile	1,608	1,528	1,697
Colombia	2,620	2,335	3,474
Ecuador	359	255	563
Paraguay	1,121	1,192	819
Peru	2,597	2,377	3,257
Uruguay	1,156	1,201	1,139
Venezuela	674	484	1,378
Mexico and Central America	4,041	3,005	5,909
Mexico	3,977	2,945	5,584
Belize	64	60	71
Costa Rica	0	0	163
Caribbean	358	0	479
Bahamas	0	0	12
Barbados	0	0	2
Cuba	358	0	464
Saint Lucia	0	0	1

Source: Authors calculations based on 10% of total available land area. Note: The following countries have values of zero or close to zero in all scenarios: El Salvador, Guatemala, Honduras, Nicaragua, Panama, Antigua and Barbuda, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Vincent and the Grenadines, and Trinidad and Tobago.

Table 8. Technical potential for ethanol production (EJ) in Latin America and the Caribbean in 2025 in Giga liters (G Lt.) and Exa Joules (EJ).

Region and crop	Projection 2025		Range 2025		A1 B	B1
	G Lt	EJ	G Lt	EJ	G Lt	G Lt
Latin America and the Caribbean	663	14	576-750	12-16	582	573
Sugar cane	305	6	267-342	6-7	190	180
Sugar beet	20	0.4	17-22	0.4-0.5	0	0
Wheat	49	1	40-57	1-1	42	41
Corn	89	2	78-100	2-2	76	76
Cassava	139	3	122-155	3-3	233	235
Sorghum	62	1	51-72	1-2	42	42
South America	566	12	490-642	10-14	523	517
Sugar cane	262	6	228-295	5-6	160	152
Sugar beet	20	0.4	17-22	0.4-0.5	0	0
Wheat	36	1	29-43	1-1	34	34
Corn	81	2	70-91	1-2	66	66
Cassava	114	2	101-128	2-3	227	228
Sorghum	53	1	44-63	1-1	36	36
Mexico and Central America	94	2	84-105	2-2	55	53
Sugar cane	41	1	38-45	1-1	27	26
Sugar beet	0	0	0-0	0-0	0	0
Wheat	13	0.3	11-14	0.2-0.3	8	7
Corn	8	0.2	7-9	0.2-0.2	9	9
Cassava	24	1	21-26	0.4-1	6	6
Sorghum	8	0.2	7-10	0.1-0.2	6	6
Caribbean	2	0.1	2-3	0.04-0.1	4	4
Sugar cane	1	0.03	1-2	0.03-0.03	2	2
Sugar beet	0	0	0-0	0-0	0	0
Wheat	0	0	0-0	0-0	0	0
Corn	0.4	0.01	0.3-1	0.01-0.01	1	1
Cassava	1	0.01	0.3-1	0.01-0.02	0.5	0.5
Sorghum	0.1	0.002	0.1-0.1	0.002-0.002	0.4	0.4

Source: Authors calculations based on Scenario 3 (Fixed % of imports)
Note: The energy content of ethanol is 21.1 MJ/Lt (low heating value).

Table 9. Technical potential for biodiesel production (EJ) in Latin America and the Caribbean in 2025 in Giga liters (G Lt.) and Exa Joules (EJ).

Region and crop	Projection 2025		Range 2025		A1 B	B1
	G Lt.	EJ	G Lt.	EJ	G Lt	G Lt
Latin America and the Caribbean	294	10	212-376	7-13	109	110
Oil Palm	181	6	120-242	4-8	0	0
Soybean	24	1	20-28	0.7-0.9	26	26
Sunflower	25	1	20-30	1-1	41	41
Cotton seed	35	1	30-39	1-1	0	0
Castor oil	2	0.1	2-3	0.1-0.1	0	0
Canola oil	27	1	20-34	1-1	42	42
South America	231	8	186-276	6-9	92	92
Oil Palm	133	4	105-161	3-5	0	0
Soybean	22	1	18-27	0.6-0.9	23	23
Sunflower	23	1	18-28	1-1	35	35
Cotton seed	27	1	24-31	1-1	0	0
Castor oil	2	0.1	2-2	0.1-0.1	0	0
Canola oil	24	1	19-28	1-1	34	34
Mexico and Central America	63	2	26-99	1-3	18	17
Oil Palm	48	2	15-82	0.5-3	0	0
Soybean	2	0.1	1-2	0.05-0.1	4	4
Sunflower	1	0.05	1-2	0.04-0.1	6	6
Cotton seed	7	0.2	6-8	0.2-0.3	0	0
Castor oil	1	0.02	0-1	0.02-0.02	0	0
Canola oil	4	0.1	2-5	0.1-0.2	8	8
Caribbean	0	0	0-0	0-0	0	0

Source: Authors calculations based on Scenario 3 (Fixed % of imports)
Note: The energy content of biodiesel is 33.3 MJ/Lt (low heating value).

Table 10. Energy potential (PJ) from forestry biomass in Latin America and the Caribbean in 2025

Country	Scenario 1 Imports$_{2002}$	Scenario 2 Net Imports = 0	Scenario 3 Fixed % Imp.
Latin America and the Caribbean	14,304	13,389	16,723
South America	13,252	12,710	15,114
Argentina	2,442	2,675	2,260
Bolivia	567	532	730
Brazil	5,100	4,818	5,654
Chile	750	712	791
Colombia	1,572	1,401	2,084
Ecuador	215	153	338
Paraguay	382	406	279
Peru	1,390	1,272	1,743
Uruguay	444	461	437
Venezuela	390	280	798
Mexico and Central America	907	679	1415
Mexico	873	647	1,226
Belize	34	32	37
Costa Rica	0	0	98
Panama	0	0	54
Caribbean	145	0	194
Bahamas	0	0	5
Barbados	0	0	1
Cuba	145	0	188

Source: Authors calculations.
Note 1: We used, following Marrison and Larson (1996), a biomass transformation factor into energy of 20 GJ/TM.
Note 2: The following countries have values of zero or close to zero in all scenarios: El Salvador, Guatemala, Honduras, Nicaragua, Antigua and Barbuda, Dominica, Dominican Rep., Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and Trinidad & Tobago.

Table 11. Effects of increase in biodiesel demand on prices and production (%)

Product	Biodiesel Demand Low	Medium	High
Production			
Soy-oil	0.3	0.8	1.6
Soybeans	0.1	0.2	0.4
Soy meal	0.3	0.8	1.6
Corn	0.0	-0.1	-0.2
Price			
Soy-oil	2.8	7.2	14.1
Soybeans	0.4	1.0	2.0
Soy meal	-0.7	-1.7	-3.3
Corn	0.0	-0.1	-0.1

Source: Raneses et al. (1999). Note: Percentages are an annual average impact of increased biodiesel use in the period 1996-2000

Table 12. Price increase of other crops (%) as a result of an increase in production of bioenergy crops

Crops	Scenario 1 Sustainable Exploitation	Scenario 2 Productive Operation
Switchgrass	10	10
Corn	4	9
Sorghum	5	14
Wheat	4	12
Soybean	5	10
Cotton	9	13
Rice	8	10

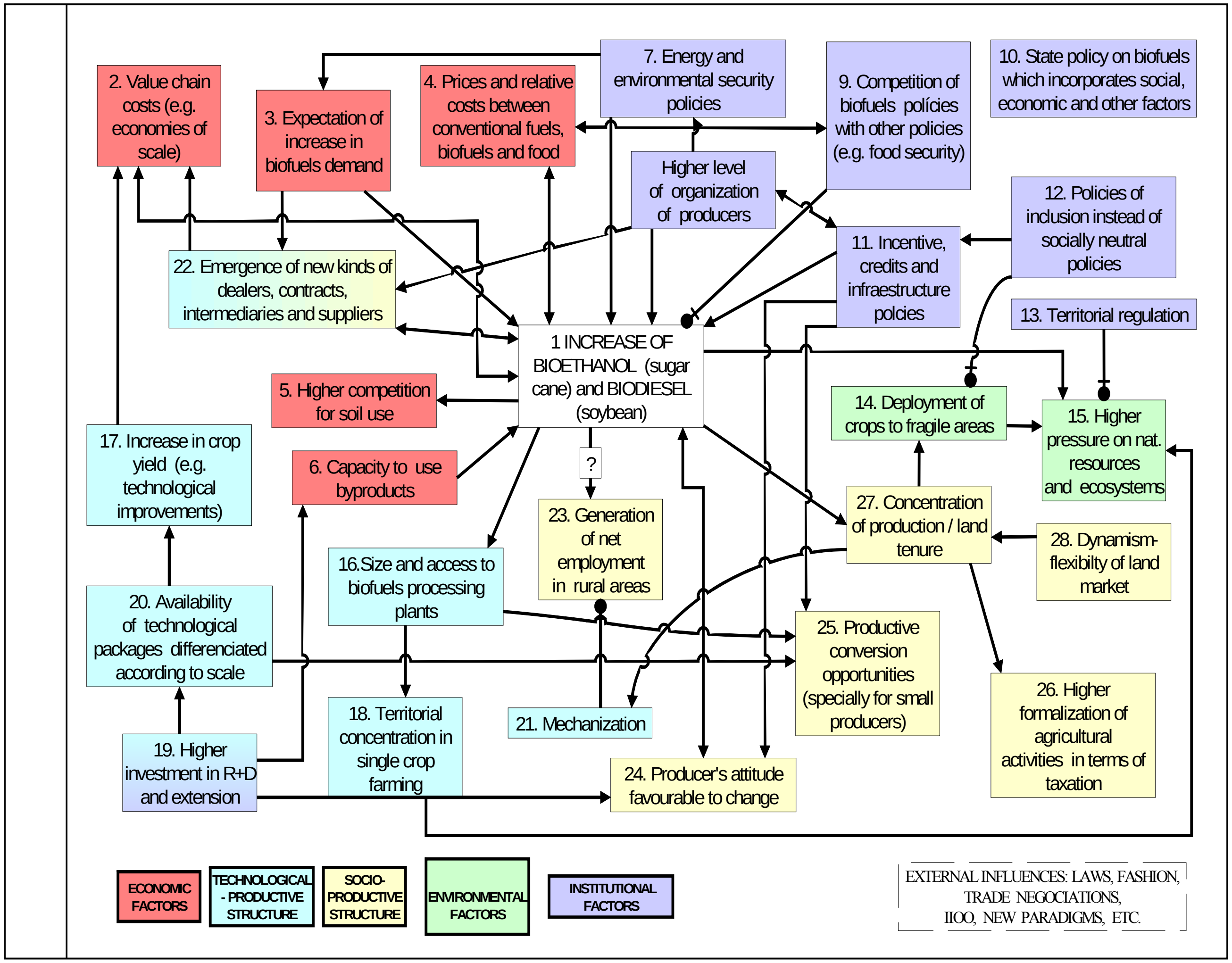
Source: De la Torre et al. (2003).
Note: Scenario 1 (Sustainable exploitation) assumes lower initial prices for each crop, lower use of fertilizers and chemicals and partial harvest of the switchgrass area. The second scenario (productive operation) assumes higher prices, standard use of fertilizers and chemicals, and total harvest of the switchgrass area.

Table 13. Estimated increase in world prices of crops (%)

Crop	Scenario 1: Traditional biofuels		Scenario 2: Cellulose biofuels	Scenario 3: Cellulose biofuels and productivity changes of crops
	2010	2020	2020	2020
Cassava	33	135	89	54
Corn	20	41	29	23
Oily crops	26	76	45	43
Sugar Beet	7	25	14	10
Sugar cane	26	66	49	43
Wheat	11	30	21	16

Source: Rosegrant et al. (2006). Note: Authors assume that biofuels represent 10% of liquid fuels in 2010, 15% in 2015 and 20% in 2020

Figure 1. Cause-effect relationships between biofuel crops (sugar cane and soybeans) and agricultural structure in Latin America and the Caribbean



Source: Biofuels Workshops, ECLAC's Agricultural Development Unit with support of the Sustainable Development Division, December 2006 and January 2007.
Note: Numbers in each box are used for reference in the text of the paper, and do not indicate a logic order. The arrows show, in general, positive monotonic relationships (if the cause variable increases or decreases, the effect variable changes in the same direction). The arrows with a dot indicate negative monotonic relationships (if the cause variable increases or decreases, the effect variable changes in the opposite direction). IIOO: International Organizations; R+D: Research and Development.

Table A1. Ethanol yield for sugar and starch crops

Product	Ethanol yield (Lt / TM)
Sugar cane	85
Sugar beet	98
Wheat	362
Corn	396
Cassava	280
Sorghum	359

Source: Authors calculations based on Kojima and Johnson (2005) and Smeets et al. (2005).

Table A2. Oil content and density by product

Products	% of oil	Density (kg/lt)
Peanut	46 – 48	0,91 - 0,92
Castor	40 – 48	0,97
Sunflower	32 – 40	0,92 - 0,93
Copra	62 – 68	
Oil palm (Carozo)	38 – 45	0,92 - 0,95
Oil palm	20 – 22	0,92 – 0,95
Sesame	50 – 56	0,92 – 0,93
Canola	38 – 45	0,91
Mustard	38 – 45	
Lint	40 – 50	
Cotton	18 – 22	0,92 - 0,93
Soybean	18 -22	0,92 - 0,93
Olive		0,91 - 0,92
Grape seed		0,92 - 0,94

Source: Authors calculations based on http://savoiapower.com/tinyES.html

Table A3. Theoretical quantity (without processing losses) of synthetic diesel for different types of biomass (gr / kg of biomass)

Biomass type	Diesel Production (with H_2O as agent)
Sugar cane residues	301,00
Sugar cane bagasse	274,26
Rice husk	294,56
Rice straw	301,56
Oil Palm fiber	373,24
Palm bunch, empty	154,14
Palm shell	331,52
Cassava roots	310,52
Gomero Wood	348,46
Eucalyptus	280,84
Palm tree	289,10

Source: Krongkaew et al. (2006)

Appendix 1. IMAGE 2.2 Scenarios

Scenario A1:
It describes a world with fast economic growth, low population growth and rapid introduction of new and more efficient technologies. The large topics are convergence among regions; capacity development and increased socio-cultural interactions, with a substantial reduction of regional differences in per capita income. Scenario A1 is divided at the same time in three subcategories that describe alternative directions in technological change of energy systems and the technological emphasis:

- A1F: Intensive in fossil fuels
- A1T: Non-fossil energy sources
- A1B: Balanced between all energy sources

Scenario A2:
It describes a heterogeneous world which main focus is self sufficiency and preservation of local identities. Fertility patterns across regions slowly converge, which results in rapid population growth. Economic development is regionally oriented and per capita economic growth and technological change are slower and more fragmented than in other scenarios.

Scenario B1:
This scenario assumes continuous globalization and economic growth, as well as a socio-environmental focus on life. It is interpreted as a balanced continuation of the modernization process. The path to follow is a government present at all levels and regulated market capitalism. It includes the strengthening of NGOs related to sustainability and equality topics. A modest and decent world: bureaucratic, regulated, but also seeking justice and sustainability.

Scenario B2:
It describes a world which emphasis is to seek local solutions for economic, social and environmental sustainability problems. Is a world with modest population growth, intermediate levels and a slower of economic development and, but more diverse technological change than in B1 and A1. This scenario is oriented towards environmental protection and social equity, focusing on local and regional levels.