

**“An Allocation Methodology to Assess GHG Emissions Associated with Land Use Change”
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SUMMARY

The objective of this project is to contribute to the advance of discussions regarding ILUC measuring methodologies, developing an analysis routine based on a cause and effect approach based on allocation criteria of land use change. It is important to note that this approach is in fact a set of alternative LUC and ILUC evaluation methodologies different than the economic models which work with future projections of land use change based on demand shocks. Therefore, given that there is no well-defined body of analytical procedures, this work proposes a cause-descriptive approach which is consistent with the current Brazilian situation, both from both the dynamics of a general agricultural and cattle raising production point of view to one of ethanol sugarcane in particular, concerning also the availability of data on the change in land usage in Brazil already gathered and organized by ICONE.

The approach proposed here is an allocation methodology where the substitution of productive activities (and natural vegetation by productive activities) is calculated from absolute variations observed over a determined period of time. The positive variations are allocated to the negative variations based on assumptions regarding LUC. The allocation assumptions, mainly in the case of natural vegetation substitution, were calibrated by physical data obtained by satellite imaging.

Therefore, the coefficients of competition and advance at the border were calculated by the combination of secondary data gathered mostly at the *Produção Agrícola Municipal* (PAM-Municipal Agricultural Production) of the IBGE, and remote sensor primary data gathered by the Instituto Nacional de Pesquisas Espaciais – INPE – and the Laboratório de Processamento de Imagens e Geoprocessamento – LAPIG, of the Universidade Federal de Goiás). The period of analysis selected was from 2005 to 2008, when ethanol production grew from 16 to 27 billion liters per year.

Substitution matrices were calculated, in absolute and relative terms, for each region of Brazil (South, Southeast, Center-West Cerrado, Northern Amazon, Coastal Northeast and Northeast Cerrado). Such matrices illustrate the direct replacement of soil usage and indicate that from the total expansion of sugarcane (2.4 million de hectares), only 9.7 thousand ha of native vegetation were directly converted. The matrices of direct substitution were used to calculate indirect substitution matrixes which show there was a total of 181 thousand ha of native vegetation indirectly converted by the advance of sugarcane – which represents around 8% of the total growth of the culture. Direct and indirect conversions, combined with the other changes in land use were responsible for total emissions of 2.4 million tons of equivalent carbon dioxide. Considering the energy production increase in the period, a direct and indirect emission factor (LUC +ILUC factor) of 7.63 g CO₂.eq/MJ was estimated.

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Such an emission factor is significantly lower than other estimates, which indicates that the greenhouse gas emissions of (direct and indirect) changes in land use may be overestimated. The present study is the first experience of determinist methodology (or by allocation) specific to the Brazilian reality and contributes to the theoretical and methodological development of the ILUC biofuel concept.

1. Land use change and biofuels – current context and study objectives

The concept of Greenhouse Gas emissions (GHG) caused by Land Use Change (LUC) and Indirect Land Use Change (ILUC) due to the expansion of the use of agricultural based biofuels came to the world's attention starting 2008. Some studies show that the incorporation of emissions coming from ILUC may cancel out the climatic benefits of biofuels (FARGIONE *et al.*, 2008; SEARCHINGER *et al.*, 2008). The effects of sugarcane expansion on the direct land use change has already been analyzed both by the use of satellite imaging as well as by secondary data, showing that this crop increases area over pastures and other crops with insignificant effects on native vegetation (NASSAR *et al.*, 2008). On the other hand the development of methodologies for estimating indirect land use change (ILUC) and the impact on total biofuel GHG emissions is still under discussion in academic and political circles. The basic idea behind the indirect land use change concept is that, upon expanding into pastures and other crops, biofuels cause these other uses to expand into the agricultural frontier, causing deforestation and, consequently, the generation of additional GHG emissions.

Approaches used to estimate the ILUC of biofuel expansion can be divided into three groups. Firstly, economic models projecting agricultural markets are used to estimate the effect of a demand shock for biofuels regarding the base scenario and therefore land use change is estimated at the margin. Both general equilibrium as well as partial equilibrium models are used toward this objective; in this last group the Brazilian Land Use Model - BLUM developed by ICONE needs to be highlighted. The comparison between methodologies currently in use, including the different economic models used by the California Air Resource Board (CARB), by the American Environmental Protection Agency (EPA) and by the European Commission (EC), was drawn up under section 4.5 of chapter OE4 of the "Sugarcane Ethanol Production Sustainability Study" report, coordinated by UNICAMP, FUNCAMP and CGEE.

The second approach used refers to allocation methodologies based on historical data, also known deterministic or causal-descriptive methodologies. The approach of economic modeling also uses historical allocation patterns to calibrate the models and, in most cases, patterns by satellite observation. The American government's EPA report, for example, used the allocation pattern estimated by Winrock International (HARRIS *et al.*, 2009). The study, conducted by IFPRI which estimated a marginal ILUC of 18 g CO₂eq /MJ for sugarcane ethanol, using the MIRAGE general equilibrium model, also used the Winrock allocation pattern (AL-RIFFAI *et al.*, 2010). While data obtained through satellite images can be very precise in measuring direct land use change, for estimating indirect land use change, such data are not the best answer. Cause-effect logic should be defined based on both satellite images as well as other basic assumptions to be able to reproduce the complex dynamics involved in the ILUC concept. The study of Econometrics and Greenergy using this approach estimates a total emission factor (LUC + ILUC) at the margin for sugarcane ethanol for the period from 2000 to 2005 of 45 g CO₂eq /MJ (TIPPER *et al.*, 2009). However, this study is too simplistic in the way it distributes the total emissions of world deforestation among several drivers and biofuels, apart from presenting significant conceptual errors.

Another methodology based on land allocation was developed considering as a basis a global allocation pattern of agricultural uses (FRITSCHÉ *et al.*, 2010). Based on this assumption the proportion of land use among each crop which is traded on the global market was considered a proxy of the average potential of emissions associated with ILUC. Within this logic, Brazil contributed with about 22% of the total land used for exported commodities. The area for sugarcane ethanol in Brazil therefore, will contribute in this proportion to the global emissions factor. To define the direct substitution pattern of sugarcane in the

country, Fritche *et al.* (2010) say to use the allocation pattern described by Lapola *et al.* (2010), even though this is not explicit in the study.

Another initiative to develop a causal-descriptive methodology is being coordinated by E4Tech, at the request of the British government with the participation of several researchers and stakeholders². Preliminary results show an ILUC emission factor for sugarcane ethanol in the range of 13 to 19 g CO₂eq/MJ, depending on the hypotheses which are presumed.

The third approach for dealing with ILUC is called the precautionary approach, having as its principle that since the ILUC effect for biofuels is potentially high, it should be ensured that biofuels are cultivated in areas with a low chance of causing ILUC. An example of the usage of this approach is the “Responsible Cultivation Areas Methodology” under development by Ecofys. The debate by the Roundtable on Sustainable Biofuels (RSB) is also on this track. However, more – and better – estimates of the effects of land use change are still needed before assuming that such an effect is high and that, for this reason, LUC should be avoided in the meantime. Considering that these analyses are relatively recent, a lot of progress can be made from now on.

Therefore, despite the approach of allocation conceptually having the advantage of being more transparent and apparently more intuitive than the economic modeling, it still needs further study and public debate to instate itself as an acceptable methodology. Apart from this, the problems associated with this methodology, such as the establishment of the allocation based on much aggregated land usage data, are similar to the deficiencies observed in the economic models.

The current work intends to fill this gap, developing a causal allocation methodology based on the best historical data available in Brazil to determine an emission factor associated with land use change, caused by the expansion of ethanol in the country. Therefore an important advantage of the hereby proposed methodology is the fact that it is presented in a transparent manner, on spreadsheets which contain all the steps carried out for the calculation of the effect of expansion from a productive use in the conversion of native vegetation, accounting therefore, for LUC and ILUC. Apart from this, the methodology applied in this study establishes the allocation at the level of IBGE microregions, minimizing the errors associated with the choices of allocation criteria.

Although conceptually simple, the methodology is complex in at least four ways. Firstly, the assembly of the database needed to evaluate the historical standards is extremely labor-intensive and will be described in item 2. Establishing the relationship of cause and effect – which will be fundamental in carrying out the allocation of the agricultural and cattle raising activities at the border – is another complex point which requires a great deal of theoretical and conceptual discussion. It is also necessary to incorporate the effects of productivity gains from the different productive activities and the consequences of these in competition for land. Finally, it is necessary to define a proper analysis of a geographical unit, small enough to capture the competition between the different uses of land, but which holds all the reliable data. The IBGE data for microregions is more consistent and less subject to errors than the data collected by municipalities. The manner in which these four points are dealt with defines the quality of the results and the discussion concerning them collaborates to develop the ILUC concept, still very recent in scientific terms.

The specific objectives of this study are:

1. To define an historical pattern of substitution among the several agricultural uses in Brazil and their advancement on native vegetation;
2. To estimate the indirect effect of land use change caused by the expansion of sugarcane for ethanol;

² More information on such initiatives is available at: <http://www.ilucstudy.com/index.htm>.

3. To estimate a direct and indirect emission factor of land use change caused by the expansion of sugarcane ethanol (LUC + ILUC factor).

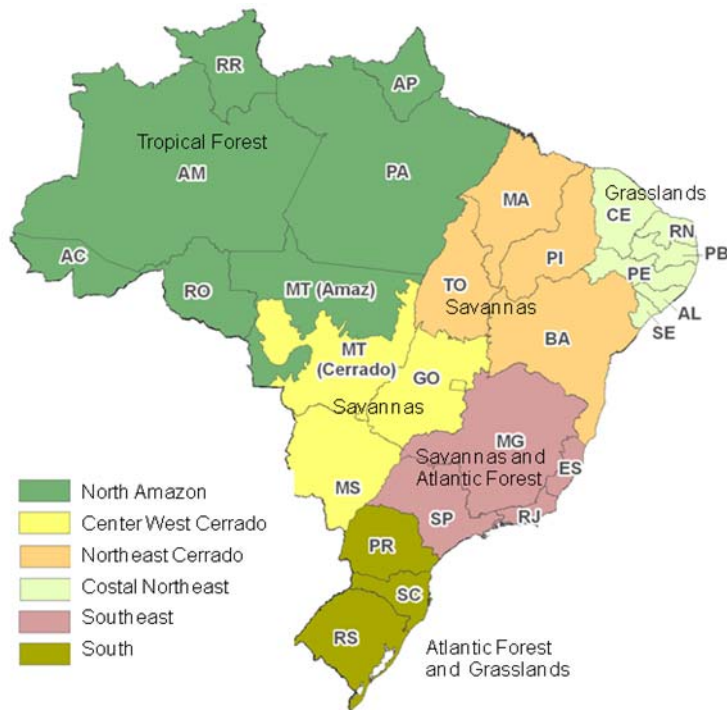
The definition of the historical pattern of land use change is carried out highlighting those crops which use more land in the country, whether they be pasture, sugarcane, soybeans, corn, cotton, rice, dry beans, or planted forest, apart from the sum of permanent crops, other annual crops, and areas of native vegetation. Thus, a pattern of substitution was defined among the eleven detailed land uses. This substitution represents the direct competition between the productive uses and the advance of these over native vegetation, which presented in relative terms represents the substitution and expansion coefficients, respectively. Both coefficients were calculated based on the pattern observed in the past, i.e. on the evolution of the area used for each use of land. This means it is a coefficient which evaluates the substitution of the area of a productive activity or of natural vegetation given the variation of a unit of area of another productive activity.

With the intention of providing greater transparency to the current study, all calculations carried out throughout all the methodological stages were undertaken with software of ample access (Excel 2007) and are in files attached to this report. Apart from the possibility of checking and processing the database, the attached file allows for sensibility analyses of the parameters and basic assumptions adopted.

2. Descriptive analysis of land use data in Brazil

All data and analyses in this study will be presented by the BLUM regions which are: South and Southeast (identical to the official political divisions); Center-West Cerrado (excluded is the Mato Grosso, which is in the Amazon); Northern Amazon; Northeast Coast; the states of Maranhão, Piauí, Tocantins (MAPITO) and Bahia making up the Northeast Cerrado Region (Figure 1). These regions were defined considering the dynamics of the local agriculture, as well as the Brazilian biomes. The State of Mato Grosso is the only one divided into two regions and the criteria to divide it is the IBGE listing of municipalities in the Amazon and Cerrado biomes. The municipalities located at the borders, that is, having areas within the two biomes, were arbitrarily divided down the middle. Thus, all data for these municipalities are divided by half and these municipalities appear twice in the database, one in each region.

Figure 1: BLUM Brazilian regions



Source: ICONE.

The period of analysis chosen was from 2005 to 2008. This period was selected as it represented a large increase in ethanol production and area planted with sugarcane. In this period the area planted with sugarcane grew about 2.4 million ha and the production of ethanol went from 16 to 27 billion liters per year (Table 1). It is worth mentioning that, since Cerrado conversion data has been available since 2002, the same analysis was undertaken for the period 2002 and 2008, enabling the analysis of the sensibility of the results obtained. However, due to the expansion of ethanol production having occurred from 2005 onward, it was opted to calculate the ILUC factor only for the period from 2005-2008.

Table 1: Ethanol total production according to BLUM regions, 2002, 2005 and 2008 (million liters)

	2002	2005	2008	Variation 02-08	Variation 05-08
South	987	1.043	2.055	1.068	1.012
Southeast	8.638	11.315	19.292	10.654	7.978
Center-West Cerrado	1.221	1.634	3.309	2.088	1.675
North Amazon	336	409	505	169	96
Northeast Coast	1.277	1.264	1.981	704	716
Northeast Cerrado	164	281	370	206	89
Brazil	12.623	15.947	27.513	14.890	11.566

Source: UNICA. Arranged by: ICONE.

As previously highlighted, the proposed methodology is based on a database with the best available data regarding land use in Brazil. The ICONE experience in gathering data for the BLUM database has a lot of synergy with the analyses hereby developed, showing that only the use of IBGE data, estimated on the scale of political-administrative units of the country is not robust enough to deal with land use analysis. Several motives explain the need for complementing the data. Firstly, there is no time series for pastures, given that it is only published in the Agricultural Census, available for only a few years (1996 and 2006 are the last years). The Census' own information, 159 million ha in 2006 is subject to strong uncertainty,

especially because it differs significantly when compared to estimates obtained by remote sensing³. Apart from this, the best native vegetation and/or deforestation data is also taken from remote sensing. Therefore, the combination of a good IBGE database on the area of agricultural crops should be combined with the georeferenced data, greatly improving the quality of the final information.

The data referring to agricultural crops were gathered from the Produção Agrícola Municipal – (Municipal Agricultural Production - PAM) of the IBGE and were categorized as follows:

- sugarcane,
- soybean,
- first harvest corn⁴,
- cotton,
- rice,
- first harvest dry bean,
- total of permanent crops,
- total other annual crops, except winter crops⁵.

All this data was gathered by microregion for the years 2002, 2005 and 2008 and organized on an Excel spreadsheet. Microregions, with a total of 558, are geographic units in which more than five thousand Brazilian municipalities are aggregated, and the use of such a scale facilitates the manipulation of data and offers an adequate level of detail. Data for planted forest (pinus and eucaliptus) in Brazil were estimated from the total area occupied by such forest published by the Associação Brasileira de Produtores de Florestas Plantadas (Brazilian Association of Planted Forest Producers) – ABRAF (ABRAF, 2009). The total area of planted forest was distributed over the microregions using data from forest production from the IBGE survey Produção da Extração Vegetal e da Silvicultura (Production of Vegetation Extraction and Silviculture) IBGE⁶. This area stock data was subtracted (2008 stock minus 2005 stock) to obtain the flow for the period⁷.

Data referring to the loss of native vegetation was gathered for three biomes – Amazon, Cerrado and Atlantic forest – and is already flow data, as it represents the difference of native vegetation coverage over two years. For the analysis hereby proposed the accumulated deforested data for the years 2005, 2006 and 2007 was used, which also represents the flow for three periods. We understand that the occupation of deforested areas by crops and/or pastures occurs mainly in the year following the deforestation, as shown by Morton *et al.* (2006) and confirmed by informal talks with specialists in agricultural frontier regions (Figure 2). Obviously the occupation of new areas depends on a series of factors related mainly to the climate and market. However, it was necessary to define a hypothesis relative to this issue in order to choose the analyzed deforestation periods.

³ Although the comparison between remote sensing data are not clearly presented in the final report, such analysis was made under the theme “Land Use, Changes in the Land Use and Forests” in the context of the Low Carbon Study in Brazil (GOUVELLO, 2010).

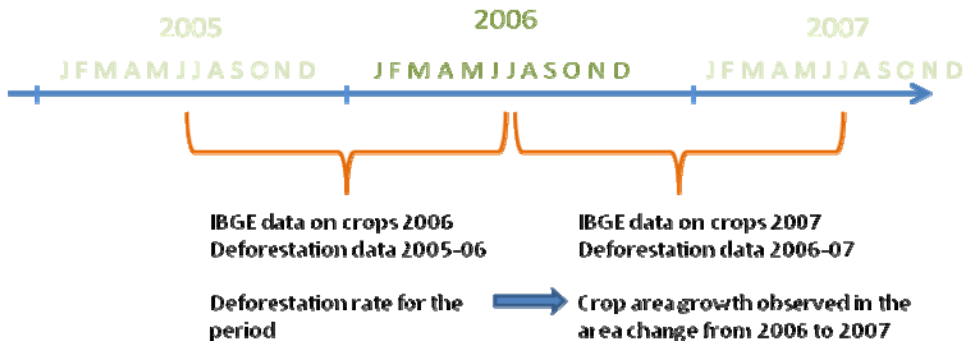
⁴ As the first corn harvest data are not available for the year 2002, it was estimated based on data for corn in 2002 and total share of second harvest of corn of corn in 2003.

⁵ **Data** was considered for the following winter crops: peanuts, barley, rye, wheat, triticale, oats, flax and mauve, and corn and beans from second and third harvest.

⁶ The estimates of planted forest area by microregion used here are the same from the BLUM database and used in the Low Carbon Study for Brazil (Gouvello, 2010).

⁷ Land use is considered a “stock” variable whereas change in land use is understood as “flow” variable. One flow variable can be calculated by subtracting two stock variables

Figure 2: Land use substitution rationality and secondary data used



Therefore, this work presumes that the deforestation observed in a determined period will cause an increase in the following year’s agricultural area. Both deforestation and crops data refer to the period from August to July of the following year, i.e. the data from the IBGE for the year 2006 refers to the area planted in the second semester of 2005 and harvested in the first half of 2006.

Analysing the growth of the total agricultural area in the country between 2002 and 2008, we realize there was strong growth, especially between 2002 and 2005, for soybean crops (7 million ha), rice (800 thousand ha) and planted forests (1 million ha). The growth of the sugarcane area is concentrated in the period between 2005 and 2008, when the other crops were largely stable or showed a decrease in area (Table 2).

Table 2: Area used by crops and commercial forest in Brazil, 2002, 2005 and 2008 (thousand ha).

	2002	2005	2008	02-08	05-08
Sugarcane	5.207	5.815	8.211	3.004	2.396
Soybean	16.376	23.427	21.064	4.688	-2.363
Corn	9.693	9.024	9.652	-41	628
Cotton	764	1.266	1.067	303	-199
Rice	3.172	3.999	2.869	-303	-1.130
Dry beans	2.984	2.225	2.229	-754	4
Commercial forest	4.214	5.242	5.887	1.672	645
Perennial crops	6.424	6.252	6.496	72	243
Other temporary crops	3.286	4.053	4.129	843	76
Total	49.711	61.303	61.603	11.892	300

Sources: IBGE and ABRAF. Arranged by: ICONE.

Productivities were also estimated from area and production data of Municipal Agricultural Production (PAM) of the IBGE (Table 3). Considering that agricultural productivity is defined as the production divided by the area (in tons per hectare), such data were obtained from the IBGE and used to estimate the productivity gain according to the following formula:

$$\text{Productivity gain} = (Y_{2008} / Y_{2005}) - 1$$

Where Y_{2008} is the crop productivity in 2008 and Y_{2005} is the crop productivity in 2005.

Table 3: Selected crops and pasture: productivity gain, 2005 to 2008.

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Peren. crops	Other temp.	Pasture
South	20%	74%	85%	87%	18%	56%	9%	50%	23%	9%
Southeast	4%	18%	14%	51%	4%	13%	9%	26%	239%	23%
Center-West										
Cerrado	12%	18%	48%	20%	21%	-21%	9%	-2%	10%	19%
North Amazon	18%	4%	94%	12%	-3%	5%	9%	3%	106%	35%
Northeast Coast	11%	1%	100%	25%	14%	29%	9%	33%	-12%	0%
Northeast Cerrado	-9%	11%	19%	21%	13%	-10%	9%	11%	-7%	34%

Sources: IBGE and ABRAF. Arranged by: ICONE.

For crops with more than one harvest per year, the total harvest production was divided by the area destined for crops in the first harvest of the year. Therefore, as in the case of corn, the production from the first harvest and the corn production from the second harvest were added and divided by the corn area of the first harvest. This is explained by the fact that the growth of the second harvest means a land yield increase, the focus of this study. The estimated productivity gain for permanent crops was carried out considering the weighted average per area from the productivity gain of the three main crops of each region. For planted forests the Annual Average Increment was used (IMA, the Portuguese acronym), which represents the wood volume increased by year (ABRAF, 2009).

The productivity gain for cattle raising was estimated in terms of beef production per ha, as available from IBGE data. Considering that this activity occupies large areas of land in Brazil and that it is the one with the greatest capacity for intensifying production, the final results are quite sensitive to the estimate of the cattle raising gain.

The period between 2002 and 2007 can be divided into two periods with different trends in terms of deforestation and agricultural growth. The deforestation observed in the Amazon, Cerrado and Atlantic Rainforests was concentrated in the period from 2002 to 2005, which may be related to the strong growth of crops at the time. During this period in these three biomes there was more than 8.7 million ha of deforestation, reaching nearly 3 million ha per year. In the period from 2005 to 2007, total deforestation was 5.8 million ha, or about 2 million ha per year (Table 4).

Table 4: Accumulated deforestation observed for the periods from 2002 to 2007 and from 2005 to 2007 for the Cerrado, Amazon and Atlantic Forest biomes.

Region	Accumulated Deforestation 2002 to 2007				Accumulated Deforestation 2005 to 2007			
	Cerrado	Amazon Forest	Atlantic Forest	Total	Cerrado	Amazon Forest	Atlantic Forest	Total
South	1	0	84	85	1	0	41	41
Southeast	293	0	63	356	151	0	37	188
Center-West Cerrado	1,327	873	10	2,210	491	281	3	775
North Amazon	313	9,477	0	9,790	94	3,886	0	3,980
Northeast Coast	0	0	0	0	0	0	0	0
Northeast Cerrado	1,427	742	0	2,169	541	317	0	858
Brazil	3,361	11,092	158	14,611	1,278	4,484	81	5,843

Sources: INPE and LAPEG-UFG. Arranged by: ICONE.

Deforestation data was obtained from three separate sources. For the Amazon we have used PRODES data gathered by INPE – National Institute for Space Research. As deforestation rates are only published by states, those rates were distributed among municipalities in accordance with the data of the extent of

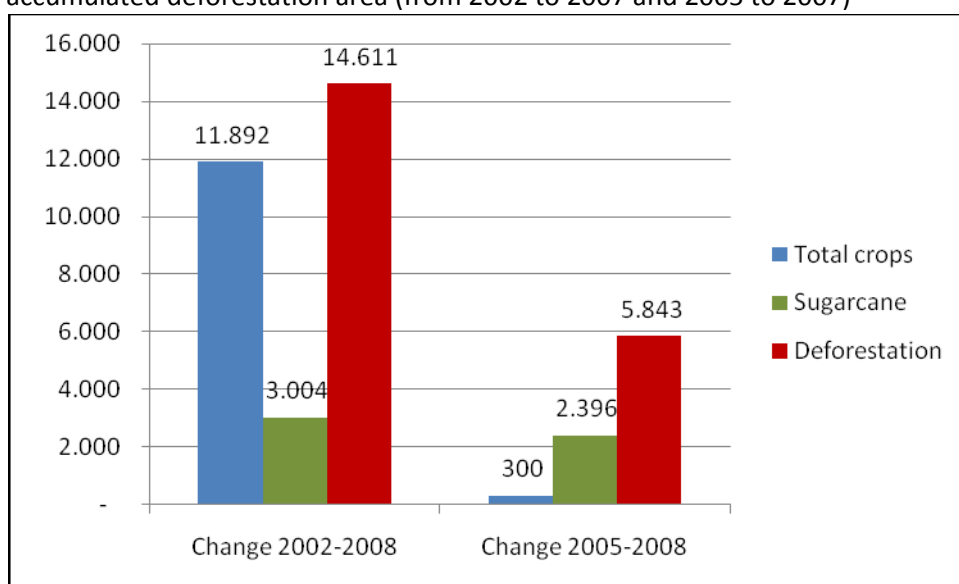
deforestation published by municipalities. The difference between the deforestation rate and the extension of deforestation refers to the fact that the latter comprises only the observed deforestation, while the deforestation rate is calculated considering the observed deforestation and the areas which could not be observed due to clouds⁸. The deforestation rates estimated by municipality were therefore aggregated for the microregions.

Deforestation data for the Cerrado was obtained by the Laboratory for Image Processing and Geoprocessing of the University of Goiás – LAPIG/UFG). LAPIG made estimates of the deforested areas of the Cerrado in the environment of the Integrated System of Deforestation Alerts (SIAD- Sistema Integrado de Alertas de Desmatamento) using MODIS images interpretation (FERREIRA *et al.*, 2007)⁹. Such data was made available to ICONE by municipality and then aggregated by microregion.

Deforestation data for the Atlantic Rainforest is published in the Atlas of Remaining Forest of the Atlantic Forest (Atlas dos Remanescentes Florestais da Mata Atlântica) produced by INPE and SOS Mata Atlantica Foundation. In the Atlas, deforestation data by municipality is published for accumulated 5-year periods. This accumulated deforestation data was then transformed into annual deforestation data in order to be estimated for the period of the study.

Considering the description of the above data, it can be seen the most suitable period for analyzing the impact of sugarcane ethanol expansion on deforestation is from 2005 to 2008. This is due to the fact that the expressive growth of the sugarcane area and little growth in other crops can be observed in this period, as well as less accentuated annual deforestation rate than the peak observed in 2003 and 2004 (Graph 1).

Graph 1: Change in area for sugarcane and total crops (from 2002 to 2008 and from 2005 to 2008) and accumulated deforestation area (from 2002 to 2007 and 2005 to 2007)



Sources: IBGE, INPE and LAPIG-UFG. Arranged by: ICONE.

Regarding area for pastures, after some attempts at estimating for the years analyzed, we opted to consider it as residual, that is, it was considered that all the deforested area would be converted into crops or pasture. Therefore for each microregion pasture area was defined as being the difference between the deforestation and the total crop growth. Where crop growth is greater than the deforested area there has been a decrease in pasture as, in theory, crops have grown over this. According to such an assumption,

⁸ Detailed information on the methodologies for calculating the rate of deforestation and data by county can be found at PRODES: (<http://www.obt.inpe.br/prodes/>).

⁹ For further information about the SIAD check the LAPIG site: (<http://www.lapig.iesa.ufg.br/lapigsite/index.php>).

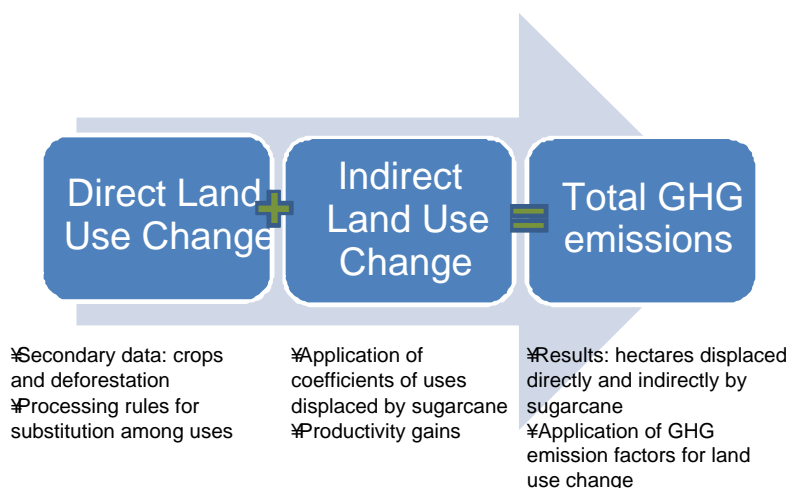
growth of 5.5 million ha in the country can be seen, concentrated in the North Amazon region, which presented an increase of 4.4 million. This is because the deforested area there was greater than the total growth of crops. An immediate result of this assumption is that agriculture (crops + pasture) always expands or maintains its total area and thus total agricultural area never declines. Associated with this result, a future improvement which should be made to the analysis hereby presented would be to include data on regeneration area. It is known that in the Amazon this amount is not irrelevant, indicating therefore that the coefficients of expansion presented in this study tend to be overestimated.

3. Methodological Proposal

The methodology of this project consists of three stages in order to achieve the three specific objectives (Figure 3):

- ✓ 1st stage: Estimating the substitution coefficients of productive uses and native vegetation – direct land use change (LUC);
- ✓ 2nd stage: Establishing the cause and effect relation between ethanol demand expansion and conversion of native vegetation – Indirect land use change (ILUC);
- ✓ 3rd stage: Measuring of total GHG emissions (LUC + ILUC) associated with the expansion of ethanol consumption.

Figure 3: Methodological framework of land use change based on allocation of uses.



Source: ICONE.

All calculations and databases used to compute the stages above are filed in an Excel file attached to this document and can be consulted when in doubt, or used for sensibility analysis to changes in adopted parameters and basic assumptions.

3.1. First stage: Estimating of substitution coefficients of productive uses and native vegetation – direct land use change (LUC)

The 1st Stage is divided into four steps:

- (i) Gathering and organizing of a secondary database for crops by IBGE microregion for the following classes of productive agriculture: soy, sugarcane, rice, cotton, first harvest corn, first harvest dry beans, planted forests, other temporary crops and permanent crops.
- (ii) Gathering and organizing of the database of deforestation for the Amazon and Cerrado biomes, which are the two regions with the greatest agricultural expansion, and the Atlantic Rainforest.

- (iii) Construction of a database with variation estimates of pastures and total area by microregion between the years 2005 and 2008. As previously explained it was assumed that the variation in pasture area is the difference between the deforested area in the period and total increase in the area of temporary and permanent crops.
- (iv) Once the database per microregion is assembled, the procedures for data processing to determine the substitution in uses and the conversion of vegetation in each microregion are determined.

The construction criterion of pasture area and total agricultural area leads to a limited universe of possible substitution among crops (net sum of all crops), pastures, and native vegetation. There are three possibilities, arranged into cases, with a data processing procedure adopted based on the assumption of proportionality for each one (Figure 4).

Figure 4: Adopted Cases and Procedures

Cases	Δ deforest.	Δ crops	Δ pasture	Adopted Procedure
Expansion of crops and pasture	(+)	(+)	(+)	Proportional allocation of crops and pastures over natural vegetation.
Crop expansion only	(+) or 0	(+)	(-)	Proportional allocation of crops over pastures and natural vegetation.
Pastures expansion only	(+) or 0	(-)	(+)	Proportional allocation of pastures over crops and natural vegetation.

Source: ICONE.

The case where there is expansion of the total area greater than the expansion of *just* the crops (therefore, expansion of pastures) is classified as “expansion of crops and pastures” and the procedure is that of proportional allocation of crops and pastures over native vegetation. When the expansion of crops is positive and greater than the expansion of the total area (therefore where there has been a reduction in pastures), the growth in crops was proportionally allocated to pastures and/or natural vegetation. In the case where there is a reduction in the crop area, the pasture expands proportionally over crops and native vegetation, if that is the case.

Another assumption is that the degree of substitution between crops is more intense than among crops and cattle raising. In other words, the expansion area of a specific crop “A” is allocated in the other crops which have reduced planted area in the same microregion and, once all the possibilities of allocation of crop “A” expansion have been exhausted to other crops, the remaining area of crop “A” is allocated proportionally between pasture and native vegetation, depending on the case. This hypothesis is sustained by the evidence of the need for rotation among annual crops, but also by the similarities among production technologies in different annual crops.

The final hypothesis is specific for sugarcane. Studies based on satellite images indicate that sugarcane does not directly displace native vegetation. More precisely, NASSAR *et al.* (2008) indicate that sugarcane grows directly over pastures and other crops in similar proportions (about 50% each), and does not directly convert native vegetation. Based on this evidence, it can be presumed that sugarcane has “priority” to be allocated in pasture and other crops area. Succinctly, the adopted data processing procedure was that of first allocating sugarcane expansion in equal proportion among crops and pastures, and not having “available” area in the microregion, the allocation of the remaining area would occur in the available category (crop or pasture) and, only in the last case, over natural vegetation (Figure 5).

The first three columns of Figure 5 are binary declarations (yes or no) which compare sugarcane expansion and other variables in each microregion. The first column shows whether or not the expansion of sugarcane fits into the total area released by crops and cattle raising. The second column reports whether or not half of the sugarcane expansion fits into the reduction of crop area. The third column shows whether or not half

of the sugarcane expansion fits into the reduction in crop area. According to this logic there are five possible combinations, which are the five rows of the figure (excluding the title rows).

The final three columns show the procedure adopted in each of the five cases. In the case where half of the sugarcane fits simultaneously into the pasture and crop reduction (first row), half of the sugarcane expansion is allocated to each one. If the expansion of sugarcane is less or equal to the total reduction of crops and pasture, but half of the expansion of sugarcane is greater than the reduction observed in the pasture (second row), everything that is possible is allocated in pastures (up to the total area released by pasture) and the rest in crops. The third row is similar to the second. In the fourth and fifth rows, if the expansion of sugarcane is greater than the total reduction of crops and pastures, everything possible is allocated into these two uses and the remainder into areas previously occupied by native vegetation.

Figure 5: Adopted procedures to allocate sugarcane area expansion.

Information about sugarcane area expansion			Decision on how to allocate sugarcane area expansion		
< reduction (crops + pastures)?	< 50% of pasture area reduction?	< 50% of crop area reduction?	Over pasture area	Over crop area	Over natural vegetation area
Yes	Yes	Yes	50% of sugarcane expansion	50% of sugarcane expansion	Zero
Yes	No	Yes	Equal to the reduction on pasture area	Sugarcane expansion minus the area released by pastures	Zero
Yes	Yes	No	Sugarcane expansion minus the area released by crops	Equal to the reduction on crop area	Zero
No	Yes	No	Equal to the reduction on pasture area	Equal to the reduction on crop area	Sugarcane expansion minus reduction on pasture and crop area
No	No	Yes			

Source: ICONE

The result of step (iv) is the areas substituted by each land use for each Brazilian microregion. In summary, the area of expansion of a determined crop is distributed to other uses which retreated in the same period.

(v) The fifth step consists of the aggregation of the substitutions obtained by microregion in matrices of direct area substitution by BLUM regions (South; Southeast; Center-West Cerrado; Northern Amazon; Coastal Northeast; Northeast Cerrado). Such aggregation is summarized in regional matrices of area substitution. This matrix is set up in such a way that the expansion of each hectare of each agricultural use will have its corresponding reduction in another agricultural use or conversion of natural vegetation.

(vi) The sixth and last step of stage one refers to the normalization of the matrix encountered in the previous item, in such a way as to enable the estimating of substitution coefficients of productive use and native vegetation. These will be used to calculate the effects on LUC and ILUC coming from the expansion of one additional hectare of sugarcane destined for ethanol consumption.

3.2. Second stage: Establishing the cause and effect relationship between ethanol demand expansion and conversion of native vegetation – indirect land use change (ILUC)

The matrices of coefficients defined in the first stage determine the direct substitution among the different land uses. In order to evaluate the indirect effect of the increase of sugarcane in land use it is necessary to calculate a second substitution stage. In other words, it is necessary to evaluate which changes occurred in land use caused by activities for which sugarcane was directly substituted.

The methodology adopted in this work attempts to track the direct and indirect substitutions (in area) caused by the expansion of sugarcane in the period from 2005 to 2008. The methodology starts from the direct matrix substitution among uses, identifying uses pushed aside by sugarcane. The direct substitution of native vegetation by sugarcane is accounted for in the LUC calculation of sugarcane. The other uses substituted by sugarcane also generate deforestation and GHG emissions, which is accounted for in the sugarcane ILUC.

If there were no productivity gain, each hectare displaced by sugarcane should be replaced and the ILUC would be equal to 1. However, the productivity gain that the other uses had during the period should be accounted for. The productivity gains are responsible for the fact that there is less production from a hectare in 2005 than in 2008, in such a way that a hectare pushed aside for sugarcane in 2005 corresponds to less than one hectare in 2008. Therefore, from the area moved aside by sugarcane in the period from 2005 to 2008 we should discount the productivity gain of this period, obtaining an area to be replaced in 2008 of less than the area moved aside by sugarcane in 2005.

Special attention should be given to cattle raising productivity, considering that this activity offers the greatest demand for land in Brazil and that it has the largest capacity for intensified production. Based on available IBGE data, land productivity gains were calculated in terms of meat production per hectare. To do this, we have considered the slaughter rate regionally (number of animals slaughtered in relation to total of bovine herd), the carcass weight (kilograms of beef produced per animal) and the stocking rate (number of animals per hectare). Milk production was only considered in the calculation referring to the stocking rate, as it is included in total herds and pastures. Productivity gains referring to milk production per animal per year, among others, were not considered in this calculation. Despite this tending to lead to underestimation of the productivity gain of cattle raising as a whole, we opted not to consider this factor due to the limitation of robust information.

Once the area of each of the other uses which should be replaced in 2008 is calculated, this replacement is allocated according to the expansion pattern of the crop estimated in the previous stage. The natural vegetation converted by activity *a* due to sugarcane expansion (ILUC_a) can be written as

$$ILUC_a = [x / (y+1)] * z$$

Where *x* is the direct substitution of activity *a* by sugarcane; *y* is the productivity gain of use *a* and *z* is the percentage which use *a* displaced natural vegetation.

The only restriction imposed on the above equation is that the ILUC_a should be lesser or equal to the displacement of *a* over natural vegetation in absolute values¹⁰. This restriction is imposed once the total displacement of *a* over natural vegetation due to the fact that sugarcane expansion is only a part of the total displacement of *a* over native vegetation. If the restriction is binding, the production of the product *a* displaced by sugarcane which was not replaced in the area of the same region should be reallocated to another region, by means of an increase in area or productivity gains.

¹⁰ The value of the displacement of *a* over the native vegetation in absolute values was estimated and reported in the matrix of direct substitution.

1) Activity definitions

For all definitions and calculations described below, the subscribed i and j represent the following land uses:

- 1 = Sugarcane;
- 2 = Soybeans;
- 3 = Corn;
- 4 = Cotton;
- 5 = Rice;
- 6 = Dry beans
- 7 = Planted forest;
- 8 = Permanents;
- 9 = Other temporaries;
- 10 = Pasture;
- 11 = Deforestation.

2) Matrix presentations and adopted operations

a. Direct substitution matrix - absolute values

Consider the squared matrix LUCabs, of an order of 11, which represents the direct substitution between land uses, of elements $a_{i,j}$, where i represents the use which is being substituted by use j .

Thus, the element $a_{1,3}$, for example, indicates the sugarcane area which is being substituted by corn.

The elements of the main diagonal represent the absolute increase of use j (in this case $i=j$, by definition).

In this manner, we have for each column vector j ,

$$\sum_{i=1}^{11} a_{i,j} - a_{j,j} = 0, \quad \text{for } j = 1, \dots, 11.$$

b. Net substitution vector of sugarcane

Defining the column vector $\mathbf{a} = a_{ix1}$, to $i = 1, \dots, 11$, as the elements of the first column of the matrix LUCabs and the horizontal vector $\mathbf{b} = b_{1xj}$, to $j = 1, \dots, 11$, as the elements of the first line of the matrix LUCabs. Thus, the column vector \mathbf{l} is defined, which represents the net increase of sugarcane over the other land uses where

$$\mathbf{l} = \begin{cases} \mathbf{a} - \mathbf{b}^t, & \text{if } \mathbf{a} > \mathbf{b} \\ 0, & \text{if } \mathbf{a} \leq \mathbf{b} \end{cases}$$

The above definition is the equivalent to:

$$\mathbf{l} = a_{t1} - a_{1,t}, \quad \text{where } t \in [1, 11].$$

c. Direct matrix substitution -relative values

From matrix LUCabs the direct substitution matrix in relative values LUCrel is defined with the same dimension. LUCrel has the same meaning as the LUCabs matrix, but with the values of each element of the column vector normalized (excluding the elements of the main diagonal), in the manner where

$$\sum_{i=1}^{11} b_{i,j} = 1.$$

Therefore, for each element $b_{i,j}$, $i \neq j$, the following operation was carried out:

$$b_{i,j} = \frac{a_{i,j}}{\sum_{i=1}^{11} a_{i,j}}, \quad \forall (j \neq 1 \vee i \neq j)$$

All elements of the main diagonal principal are equal to 1.

d. Direct matrix substitution, in relative values, without sugarcane

As in the matrix LUCrel, the squared matrix LUCSCrel of the order of 11 informs the direct substitution between land uses in relative values, but without considering the participation of sugarcane. This annuls all the elements of the first line and all the elements of the first column of the matrix LUCrel. The other $c_{i,j}$ elements of the LUCSCrel matrix are defined as

$$c_{i,j} = \frac{b_{i,j}}{\sum_{i=2}^{11} b_{i,j}}, \quad \forall (i \neq 1 \vee i \neq j)$$

e. Productivity gain vector

The horizontal vector \mathbf{y} with 11 elements represents the productivity gain of each land use between 2005 and 2008. This is indexed in the same order as all matrices, so the element $y_{1,3}$ indicates the productivity gain of corn between 2005 and 2008. The productivity gain will be used in the following stages in order to obtain the amount of each use area that should be reallocated. The calculation to be carried out estimates the area needed to maintain the same quantity produced in 2005, but with the productivity of 2008.

f. Indirect matrix substitution, in absolute values

The indirect matrix substitution ILUCabs represents the quantity of area for each use that is indirectly displaced by sugarcane, already discounting the productivity gain. For this, each $l_{i,1}$ element of vector \mathbf{l} , of net direct substitution is divided by the corresponding element $y_{i,1}$ of productivity gains \mathbf{y} , obtaining a vector \mathbf{r} of order 11. The \mathbf{r} vector represents how much the area of each use should be displaced over the remainder (not including itself and the sugarcane)¹¹ to replace what was lost to sugarcane, once discounted the productivity gain. Each element of the \mathbf{r} vector is construed in the manner where

$$r_{i,1} = y_{i,1} \times l_{i,1}, \quad \forall i \in [1,11].$$

Then, each vector column of the matrix LUCSCrel is multiplied by the element corresponding to the vector of column \mathbf{r} , obtaining elements $k_{i,j}$ of the matrix ILUCabs. Succinctly it can be defined:

$$k_{i,j} = c_{i,j} \times r_{i,1}, \quad \forall j \in [1,11].$$

¹¹ For the ILUC calculus, it is not necessary to consider the quantity of area that the other crops grew over the sugarcane once this value was already considered in the calculus of the \mathbf{l} vector.

As an example, the element $k_{2,11}$ represents the quantity of soybean deforestation which could theoretically be attributed to sugarcane expansion.

g. Consistency and need for relocation between regions

Due to the manner in which the ILUCabs matrix was built, it is possible that it is generating values of indirect substitution which do not respect LUCabs matrix limits.

Taking as an example the case in which $k_{3,2} > a_{3,2}$, we will have that the indirect effect of sugarcane over corn, via soybean (cane substitutes soybean, which in turn substitutes corn) would be greater than all the substitution of corn by soybean (element $a_{3,2}$ of the LUCabs matrix). This could be considered an inconsistency, as sugarcane has only partial responsibility for the substitution of corn by soybeans. The occurrence of this type of event is possible in situations where the use which is substituted by sugarcane has its area reduced in that region. The ILUC concept indicates that production not replaced in one determined region will be replaced in another.

To control such an effect, it was decided to calculate: (1) the amount of production of each crop which should be reallocated to other regions and; (2) check that such a reallocation would need expansion in terms of area or if the productivity gain of another region would solely be enough to absorb the reallocated production.

The calculation of the production which should be reallocated among regions was carried out in the following manner: it has been verified that all cases in which the area where the estimated ILUC is greater than the LUC in absolute values and the difference added created a stock of area of each crop in each region. In each region z , for each crop j the following procedure is carried out:

$$\text{Area}_j^z = \sum_{i=1}^{11} k_{i,j} - a_{i,j}, \forall k_{i,j} > a_{i,j}.$$

The excess area of each crop j - multiplied by the respective productivity - is equal to the production of each of the six BLUM regions which should be reallocated, Q_j . The total quantity to be reallocated in Brazil $Q_{j,Brazil}$ is equal to the sum of the production Q_j of each one of the six BLUM regions.

$$Q_{j,Brazil} = \sum_{z=1}^6 Q_{j,z}, \text{ where}$$

z represents each one of the BLUM regions.

On the other hand, the quantity of each crop to be reallocated ($Q_{j,Brazil}$) is compared with the quantity of the productivity gain. The hypothesis is that if the production to be reallocated is less than the quantity of the productivity gain, there would be no need for expansion in area, as all production would have been compensated by productivity gains. For each crop j in each region z , the production of the productivity gain $Q'_{j,z}$ can be represented by the equation:

$$Q'_{j,z} = A_{j,z} \times (Y_{j,z}), \text{ where}$$

$A_{j,z}$ indicates the area occupied by use j in the region in 2005 and $Y_{j,z}$ represents the productivity gain of use j in the region z between 2005 and 2008. Naturally there is $Q'_{j,Brazil}$ which is equal to the sum of each one of the regions

$$Q'_{j,Brazil} = \sum_{z=1}^6 Q'_{j,z}$$

For all crop areas j , it is seen that $Q'_{j,Brazil} > Q_{j,Brazil}$, thus there was no need to reallocate areas between regions, as the productivity gain has already overcome the fall in production caused by sugarcane.

3.3. Third stage: Methodology of calculation of GEE emissions associated with the expansion of ethanol in Brazil

After determining the direct and indirect areas displaced by sugarcane in each region, GHG emission factors were determined for the expansion of perennial crops, temporary crops, and pasture over native vegetation (Tables 5, 6 and 7). Therefore, of the area of native vegetation converted due to the advance of sugarcane – directly or indirectly – was multiplied by an emission factor associated with the soil use after the conversion. Emissions and removals coming from conversions between agricultural and cattle raising were also considered. Such emission factors represent the difference in carbon stocks – above and below ground – between the different land uses.

It is important to mention that the emission factors presented in the tables below are already defined for the six BLUM regions, which allows their direct use in the LUC emission calculations developed in this study.

Table 5: Emission factors associated with conversion of natural vegetation (t CO₂eq ha⁻¹ in 30 years).

Region	Previous land use		
	Perennial crops	Temporary crops	Pastures
South	235	407	239
Southeast	253	395	257
Center-West Cerrado	300	443	304
North Amazon	616	784	620
Northeast Coast	155	267	159
Northeast Cerrado	330	456	334

Source: HARRIS *et al.* (2009). Arranged by: ICONE.

Table 6: Emission factors associated with conversion of perennial crops (t CO₂eq ha⁻¹ in 30 years).

Region	Previous land use	
	Temporary crops	Pastures
South	150	4
Southeast	119	4
Center-West Cerrado	116	4
North Amazon	112	4
Northeast Coast	99	4
Northeast Cerrado	97	4

Source: HARRIS *et al.* (2009). Arranged by: ICONE.

Table 7: Emission factors associated with conversion of pastures, (t CO₂eq ha⁻¹ in 30 years).

Region	Previous land use	
	Temporary crops	Perennial crops
South	150	-4
Southeast	119	-4
Center-West Cerrado	116	-4
North Amazon	111	-4
Coastal Northeast	98	-4
Northeast Cerrado	96	-4

Source: HARRIS *et al.* (2009). Arranged by: ICONE.

To determine an ILUC factor for ethanol it is necessary to divide all the estimated emissions caused by such changes by the total additional production of ethanol. Therefore, the so-called marginal LUC+ ILUC factor, that is the quantity of GHG emitted by each additional unit of ethanol produced, is determined. The marginal LUC + ILUC factor can be calculated by unit of volume (liters) or by unit of energy (Mega joule – MJ), and here we have opted for the latter as it better represents the relation between emissions and associated energy content. It is worth pointing out that the marginal LUC + ILUC factor is different than the average LUC + ILUC factor, as the latter is obtained by dividing the total emissions of the period by all the biofuel production.

4. Results

4.1. Historical pattern of substitution between several agricultural uses in Brazil and the advance of these uses over native vegetation

The substitution coefficients are presented in two forms:

- (i) Absolute variation in hectares: expansion in area of a determined productive activity and its effects on the substitution of other activities and on native vegetation;
- (ii) Substitution coefficients calculated from the variation of a unit of area (1 hectare).

Here we present the substitution matrices between land use (crops, pastures and native vegetation) for the six Brazilian regions, in absolute values and in coefficients. As already mentioned, the data refers to the period from 2005 to 2008. Columns represent areas taken over, while rows show areas freed from other uses. The main diagonal reports the absolute growth values of each activity (which does not consider the microregions where there has been a reduction in the area of activity). In each column the values outside the main diagonal indicate the area which each one of the activities of the “row” ceded area to the activity of the “column”. In each column the sum of the elements outside the main diagonal is equal to the value of the main diagonal, thus ensuring that there is one hectare conceded for each hectare of expansion.

Region 1 – South

As can be observed in the substitution matrix below, there was a growth of 211 thousand ha of sugarcane, where the greatest part of this growth was due to soybean reduction (110 thousand). There was also substitution of pastures (40 thousand ha), cotton (22 thousand ha), and other annual crops (21 thousand ha). In the first line, the areas which sugarcane ceded to other crops can be observed: 4 thousand ha for corn, 10 thousand ha for pasture and so on.

The activity with the greatest expansion in the Southern region was pasture, with 569 thousand ha of growth in the period from 2005 to 2008. This growth occurred mainly in areas of soybean (246 thousand

ha), and corn (102 thousand ha) on a lesser scale. This can be explained by the fact that these crops have presented a drop in profitability and therefore, a reduction in the area cultivated during the period analyzed.

Figure 6: South Region: land use substitution matrix (ha).

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	210,529	323	3,528	328	95	10	324	92	102	10,084	0
Soybeans	109,597	118,991	204,513	105	37,922	2,948	39,317	4,721	16,040	245,588	0
Corn	9,132	39,912	377,953	0	2,838	5,206	22,116	2,147	903	101,921	0
Cotton	22,431	894	7,509	533	471	153	4,408	261	618	14,446	0
Rice	2,490	3,128	11,376	9	62,464	480	9,576	2,131	1,704	40,576	0
Dry beans	2,950	6,163	11,994	21	489	25,093	19,814	2,078	860	25,628	0
Commercial forest	1,534	19,808	14,362	1	4,509	3,136	345,896	2,111	418	67,341	0
Perennial crops	1,869	1,232	3,696	68	706	154	4,654	37,181	892	11,836	0
Other temporary crops	20,831	2,308	19,540	0	4,426	508	21,898	1,909	30,362	33,197	0
Pastures	39,695	42,695	96,966	0	10,727	11,441	210,680	20,550	8,606	569,152	0
Deforestation	0	2,529	4,468	0	282	1,057	13,109	1,182	219	18,535	41,381

In the coefficient matrix below, one can see the displacement impact of the other crops due to an expansion of 1 hectare of a given crop. Therefore, for each hectare of expansion of sugarcane, the substitution of 0.52 ha of soybean, 0.04 ha of corn and 0.19 ha of pasture occurs.

Figure 7: South Region: Coefficient matrix.

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	1.00	0.00	0.01	0.62	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Soybeans	0.52	1.00	0.54	0.20	0.61	0.12	0.11	0.13	0.53	0.43	0.00
Corn	0.04	0.34	1.00	0.00	0.05	0.21	0.06	0.06	0.03	0.18	0.00
Cotton	0.11	0.01	0.02	1.00	0.01	0.01	0.01	0.01	0.02	0.03	0.00
Rice	0.01	0.03	0.03	0.02	1.00	0.02	0.03	0.06	0.06	0.07	0.00
Dry beans	0.01	0.05	0.03	0.04	0.01	1.00	0.06	0.06	0.03	0.05	0.00
Commercial forest	0.01	0.17	0.04	0.00	0.07	0.12	1.00	0.06	0.01	0.12	0.00
Perennial crops	0.01	0.01	0.01	0.13	0.01	0.01	0.01	1.00	0.03	0.02	0.00
Other temporary crops	0.10	0.02	0.05	0.00	0.07	0.02	0.06	0.05	1.00	0.06	0.00
Pastures	0.19	0.36	0.26	0.00	0.17	0.46	0.61	0.55	0.28	1.00	1.00
Deforestation	0.00	0.02	0.01	0.00	0.00	0.04	0.04	0.03	0.01	0.03	0.00

Region 2 – Southeast

The Southeast region is the one with the greatest expansion of sugarcane area, a little over 1.7 million ha. As can be seen in the substitution matrix below, this growth has mainly displaced pasture: 900 thousand ha. Sugarcane has also increased 370 thousand ha over soybean, 16 thousand over corn, and in a smaller proportion over other crops, apart from 5 thousand over natural vegetation.

Figure 8: Southeast Region: land use substitution matrix (ha).

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	1,736,552	0	597	0	245	8	2,007	199	185	32,205	0
Soybeans	371,119	37,754	42,022	9	19	2,137	38,708	7,161	16,253	63,860	0
Corn	115,590	751	132,536	24	117	1,834	33,201	18,001	7,483	51,755	0
Cotton	85,239	4,722	9,024	323	337	1,403	11,506	2,976	2,587	10,847	0
Rice	16,666	3,491	3,020	1	1,271	175	10,304	4,628	2,714	16,403	0
Dry beans	9,118	6	1,050	1	60	20,884	11,621	5,566	646	8,882	0
Commercial forest	76,348	1,791	4,635	287	10	2,426	866,293	5,346	2,333	517,210	0
Perennial crops	75,936	52	3,050	1	60	935	24,371	115,798	956	66,809	0
Other temporary crops	81,315	7,318	3,458	0	60	211	4,279	3,701	53,162	11,689	0
Pastures	900,131	2,825	61,056	0	249	10,671	697,684	62,063	16,154	897,594	0
Deforestation	5,091	16,798	4,624	0	114	1,082	32,611	6,157	3,850	117,933	188,260

In the coefficient matrix we can see in the first column the substitution of sugarcane over other land uses. For each 1 ha of sugarcane increase 0.52 ha of pasture are displaced and practically no native vegetation is displaced. Soybean advances 0.07 and 0.44 ha over pasture and native vegetation, respectively, for each hectare of expansion.

Figure 9: Southeast Region: Coefficient matrix.

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	1.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.04	0.00
Soybeans	0.21	1.00	0.32	0.03	0.02	0.10	0.04	0.06	0.31	0.07	0.00
Corn	0.07	0.02	1.00	0.07	0.09	0.09	0.04	0.16	0.14	0.06	0.00
Cotton	0.05	0.13	0.07	1.00	0.27	0.07	0.01	0.03	0.05	0.01	0.00
Rice	0.01	0.09	0.02	0.00	1.00	0.01	0.01	0.04	0.05	0.02	0.00
Dry beans	0.01	0.00	0.01	0.00	0.05	1.00	0.01	0.05	0.01	0.01	0.00
Commercial forest	0.04	0.05	0.03	0.89	0.01	0.12	1.00	0.05	0.04	0.58	0.00
Perennial crops	0.04	0.00	0.02	0.00	0.05	0.04	0.03	1.00	0.02	0.07	0.00
Other temporary crops	0.05	0.19	0.03	0.00	0.05	0.01	0.00	0.03	1.00	0.01	0.00
Pastures	0.52	0.07	0.46	0.00	0.20	0.51	0.81	0.54	0.30	1.00	1.00
Deforestation	0.00	0.44	0.03	0.00	0.09	0.05	0.04	0.05	0.07	0.13	0.00

Region 3 – Center-West Cerrado

In the Center-West region, pasture was the use representing the greatest area expansion, about 1.9 million ha, while the area of sugarcane grew 345 thousand ha. The area of sugarcane increased mainly over soybeans, rice and pasture.

Figure 10: Center-West Cerrado Region: land use substitution matrix (ha).

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	344,825	3	261	271	0	0	77	340	389	9,350	0
Soybeans	214,366	65,289	162,111	26,146	0	7,663	42,490	2,700	75,522	934,823	0
Corn	8,291	45	284,921	157	0	10	1,771	286	1,212	8,101	0
Cotton	21,652	1,651	21,388	51,802	11	764	2,331	483	7,089	73,885	0
Rice	32,361	42,712	31,224	24,542	235	1,212	8,149	5,538	36,771	159,151	0
Dry beans	422	23	216	18	0	12,181	183	13	284	806	0
Commercial forest	17,558	548	1,282	27	0	96	100,292	79	2,306	49,483	0
Perennial crops	428	10	279	126	16	27	213	13,460	453	2,563	0
Other temporary crops	21,582	0	6,026	151	0	243	527	375	160,991	40,781	0
Pastures	25,962	1,746	40,278	299	0	1,280	7,104	300	14,485	1,946,946	0
Deforestation	2,203	18,551	21,855	67	208	886	37,446	3,345	22,479	668,002	775,044

In the coefficient matrix, we can see in the first column the substitution of sugarcane over other land uses. For each 1 ha of of sugarcane increase, 0.62 ha of soybean and only 0.01 ha of native vegetation are displaced. Soybean expands 0.28 ha over native vegetation for each hectare of its expansion. Since substantial sugarcane growth is expected in this region, the observed dynamic here is very important to project the impact on future land use change.

Figure 11: Center-West Cerrado Region: Coefficient matrix.

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	1.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Soybeans	0.62	1.00	0.57	0.50	0.00	0.63	0.42	0.20	0.47	0.48	0.00
Corn	0.02	0.00	1.00	0.00	0.00	0.00	0.02	0.02	0.01	0.00	0.00
Cotton	0.06	0.03	0.08	1.00	0.05	0.06	0.02	0.04	0.04	0.04	0.00
Rice	0.09	0.65	0.11	0.47	1.00	0.10	0.08	0.41	0.23	0.08	0.00
Dry beans	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Commercial forest	0.05	0.01	0.00	0.00	0.00	0.01	1.00	0.01	0.01	0.03	0.00
Perennial crops	0.00	0.00	0.00	0.00	0.07	0.00	0.00	1.00	0.00	0.00	0.00
Other temporary crops	0.06	0.00	0.02	0.00	0.00	0.02	0.01	0.03	1.00	0.02	0.00
Pastures	0.08	0.03	0.14	0.01	0.00	0.11	0.07	0.02	0.09	1.00	1.00
Deforestation	0.01	0.28	0.08	0.00	0.88	0.07	0.37	0.25	0.14	0.34	0.00

Region 4- Northern Amazon

In the North Amazon Region pasture has expanded greatly, about 4.5 million ha, while the area of sugarcane grew only 21 thousand ha. This small increase of sugarcane occurred mostly over rice, soybeans and corn, in this order.

Figure 12: North Amazon Region: land use substitution matrix (ha).

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	21,255	3	11	9	0	1	0	1,125	140	5,229	0
Soybeans	8,108	139,205	5,617	6,067	187	466	0	3,262	25,291	121,256	0
Corn	3,047	262	66,632	337	1,219	469	811	10,201	8,938	82,875	0
Cotton	10	63	3	33,992	0	0	0	12	5	2,016	0
Rice	9,294	96,718	37,953	27,444	1,638	1,857	6,896	26,158	37,264	319,346	0
Dry beans	4	234	88	26	0	4,402	0	28	32	1,933	0
Commercial forest	173	1,479	2,165	8	0	0	34,941	79	1	523	0
Perennial crops	85	58	706	0	0	746	0	59,241	2,277	24,930	0
Other temporary crops	536	828	3,323	102	6	0	0	4,498	84,244	35,671	0
Pastures	0	0	12	0	13	0	0	743	2,117	4,467,933	0
Deforestation	0	39,560	16,755	0	213	862	27,233	13,134	8,177	3,874,152	3,980,087

It can be seen that pasture has a large impact on deforestation. For each hectare of advance over pasture, 0.87 ha occurs over areas previously occupied by native vegetation.

Figure 13: North Amazon Region: Coefficient matrix.

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Soybeans	0.38	1.00	0.08	0.18	0.11	0.11	0.00	0.06	0.30	0.03	0.00
Corn	0.14	0.00	1.00	0.01	0.74	0.11	0.02	0.17	0.11	0.02	0.00
Cotton	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rice	0.44	0.69	0.57	0.81	1.00	0.42	0.20	0.44	0.44	0.07	0.00
Dry beans	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Commercial forest	0.01	0.01	0.03	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Perennial crops	0.00	0.00	0.01	0.00	0.00	0.17	0.00	1.00	0.03	0.01	0.00
Other temporary crops	0.03	0.01	0.05	0.00	0.00	0.00	0.00	0.08	1.00	0.01	0.00
Pastures	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.03	1.00	1.00
Deforestation	0.00	0.28	0.25	0.00	0.13	0.20	0.78	0.22	0.10	0.87	0.00

Region 5 – Northeast Coast

In the Northeast Coast region the sugarcane area grew 147 thousand ha, mainly over pasture (130 thousand ha). Other crops whose area expanded in the period were corn (283 thousand ha) and drybeans (136 thousand ha). However, this region is not very dynamic especially due to the edaphoclimatic conditions not very favorable to agriculture.

Figure 14: Northeast Coast Region: land use substitution matrix (ha).

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	146,740	0	1,603	1	204	753	1	813	1,008	32,018	0
Soybeans	46	302	16	0	0	0	0	0	88	0	0
Corn	2,545	0	282,653	3	57	1,396	0	1,267	5,740	9,986	0
Cotton	1,614	23	13,663	723	277	3,303	742	2,751	6,224	8,328	0
Rice	287	0	5,144	102	8,534	2,467	0	2,083	739	778	0
Dry beans	53	0	386	4	32	136,903	0	571	613	4,568	0
Commercial forest	0	0	0	0	0	0	9,393	0	0	0	0
Perennial crops	5,233	0	5,460	16	20	1,642	419	54,559	3,242	7,666	0
Other temporary crops	3,820	0	10,770	110	87	8,144	1,169	2,989	108,327	5,132	0
Pastures	133,142	279	245,611	486	7,858	119,198	7,063	44,084	90,672	68,476	0
Deforestation	0	0	0	0	0	0	0	0	0	0	0

The sugarcane substitution coefficient over pasture in the Coastal Northeast is 0.91, quite a high value. As no deforestation was observed in this region, the pasture accounts for all the difference in growth or retraction of the agricultural crop areas.

Figure 15: Northeast Coast Region: Coefficient matrix.

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	1.00	0.00	0.01	0.00	0.02	0.01	0.00	0.01	0.01	0.47	0.00
Soybeans	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn	0.02	0.00	1.00	0.00	0.01	0.01	0.00	0.02	0.05	0.15	0.00
Cotton	0.01	0.08	0.05	1.00	0.03	0.02	0.08	0.05	0.06	0.12	0.00
Rice	0.00	0.00	0.02	0.14	1.00	0.02	0.00	0.04	0.01	0.01	0.00
Dry beans	0.00	0.00	0.00	0.01	0.00	1.00	0.00	0.01	0.01	0.07	0.00
Commercial forest	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Perennial crops	0.04	0.00	0.02	0.02	0.00	0.01	0.04	1.00	0.03	0.11	0.00
Other temporary crops	0.03	0.00	0.04	0.15	0.01	0.06	0.12	0.05	1.00	0.07	0.00
Pastures	0.91	0.92	0.87	0.67	0.92	0.87	0.75	0.81	0.84	1.00	1.00
Deforestation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Region 6- Northeast Cerrado

The area of sugarcane grew 43 thousand ha, mainly over pasture and rice. The greatest area expansion in the region was caused by pasture which increased 920 thousand ha.

Figure 16: Northeast Cerrado Region: land use substitution matrix (ha).

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	42,843	27	227	2	8	118	1	1,037	1,244	412	0
Soybeans	1,501	151,919	2,892	2,002	73	381	17	671	2,167	28,525	0
Corn	3,334	744	119,150	1,225	9	1,744	729	7,614	6,813	51,422	0
Cotton	1,395	200	3,504	108,866	8	3,201	0	8,296	5,664	24,472	0
Rice	10,531	31,666	13,162	14,213	14,309	8,830	2,082	6,233	13,725	72,976	0
Dry beans	2,888	709	11,919	37	55	57,989	236	14,278	2,376	103,622	0
Commercial forest	1,896	0	0	0	0	0	89,482	2	0	2	0
Perennial crops	314	56	374	32	0	329	3	220,101	569	1,477	0
Other temporary crops	2,109	1,714	10,319	202	9	2,760	0	19,653	116,305	77,068	0
Pastures	16,438	23,920	23,429	273	5,736	13,795	86,354	158,838	63,668	919,502	0
Deforestation	2,437	92,883	53,325	90,881	8,410	26,830	61	3,479	20,078	559,528	857,911

In this region the expansion coefficients, i.e. the crop substitution coefficients over native vegetation are relatively high. This fact is a characteristic of agricultural frontier regions.

Figure 17: Northeast Cerrado Region: Coefficient matrix.

	Sugarcane	Soybean	Corn	Cotton	Rice	Dry beans	Comm. Forest	Perennial	Other temp.	Pastures	Defor.
Sugarcane	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Soybeans	0.04	1.00	0.02	0.02	0.01	0.01	0.00	0.00	0.02	0.03	0.00
Corn	0.08	0.00	1.00	0.01	0.00	0.03	0.01	0.03	0.06	0.06	0.00
Cotton	0.03	0.00	0.03	1.00	0.00	0.06	0.00	0.04	0.05	0.03	0.00
Rice	0.25	0.21	0.11	0.13	1.00	0.15	0.02	0.03	0.12	0.08	0.00
Dry beans	0.07	0.00	0.10	0.00	0.00	1.00	0.00	0.06	0.02	0.11	0.00
Commercial forest	0.04	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Perennial crops	0.01	0.00	0.00	0.00	0.00	0.01	0.00	1.00	0.00	0.00	0.00
Other temporary crops	0.05	0.01	0.09	0.00	0.00	0.05	0.00	0.09	1.00	0.08	0.00
Pastures	0.38	0.16	0.20	0.00	0.40	0.24	0.97	0.72	0.55	1.00	1.00
Deforestation	0.06	0.61	0.45	0.83	0.59	0.46	0.00	0.02	0.17	0.61	0.00

Comparing the different regions, pasture ceded more areas to sugarcane, in relative terms, in the Coastal Northeast region (0.91), Southeast (0.52) and Northeast Cerrado (0.38). This significantly high coefficient indicates the importance of the intensification of cattle raising as an instrument annulling the indirect effect of sugarcane over natural vegetation. In the Center-West Cerrado, South and North Amazon regions this coefficient was low or null and therefore the crops conceded more area than in the other regions.

As was seen in the matrices above, sugarcane had little influence on deforestation in all regions – after all, by the basic assumption of the methodology and based on existing evidence that sugarcane does not directly convert natural vegetation, the crop areas were allocated first over soil use which diminished, and only when there were no more conceded areas, was cane allocated over areas of native vegetation.

4.2. Indirect effect of land use change caused by expansion of sugarcane for ethanol

According to the methodology described for the second stage, the land use change due to the sugarcane expansion in Brazil was estimated for each region (the contribution of ethanol and sugar in the advance of sugarcane are later separated). The land use changes caused by all the activities directly displaced by sugarcane were evaluated. It was noted that the conversion of native vegetation caused indirectly by sugarcane is much greater – about 20 times – than the conversion caused directly (Table 8).

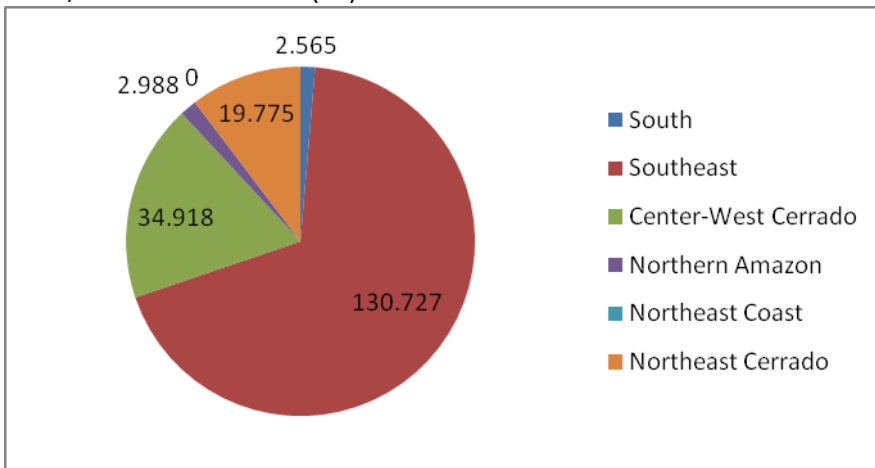
It is important to note that the direct conversion estimated of native vegetation is minimal (9,7 thousand ha) and nearly all of this conversion in Brazil occurred indirectly (181 thousand ha). The greatest areas of conversion of native vegetation occurred in those regions where sugarcane growth was more evident, in the Southeast and slightly less so in the Midwest Cerrado (Graph 5). As discussed in topic “g” of sub-chapter 3.2, for the analyzed period, there was no need to relocate the excess crop area between regions substituted by sugarcane, as the productivity gain was sufficient to replace the drop in production caused by the expansion of sugarcane. This means that in the period analyzed and specifically for the ILUC of sugarcane, there was no indirect effect between regions.

Table 8: Sugarcane area net expansion and associated conversion of natural vegetation according to BLUM regions, from 2005 to 2008 (ha).

Region	Sugarcane area net growth	Natural Vegetation Conversion Associated with Sugarcane		Conversion of natural vegetation with respect to sugarcane expansion		
		Directly	Indirectly	Direct	Indirect	Total
				conversion	conversion	conversion
South	195,644	0	2,565	0%	1.31%	1.31%
Southeast	1,701,105	5,091	125,637	0.30%	7.39%	7.68%
Center-West Cerrado	334,134	2,203	32,715	0.66%	9.79%	10.45%
Northern Amazon	14,737	0	2,988	0.00%	20.28%	20.28%
Northeast Coast	110,339	0	0	0.00%	0.00%	0.00%
Northeast Cerrado	39,768	2,437	17,338	6.13%	43.60%	49.72%
Brazil	2,395,726	9,731	181,243	0.41%	7.57%	7.97%

In relative terms, however, it can be seen that in the Northeast Cerrado region the area of converted native vegetation was nearly half the area of expansion of sugarcane, while in the Southeast it was less than 8% (Table 8). This difference in relative terms between Brazilian regions can be explained by the greater or lesser competition with other crops. Therefore, in those regions where other crops and pasture decreased, the expansion of sugarcane had less impact on the conversion of native vegetation. This difference is also due to the deforestation accumulated in the region, and as according to the methodology proposed here the total deforestation is distributed among the different land uses proportionally to their growth.

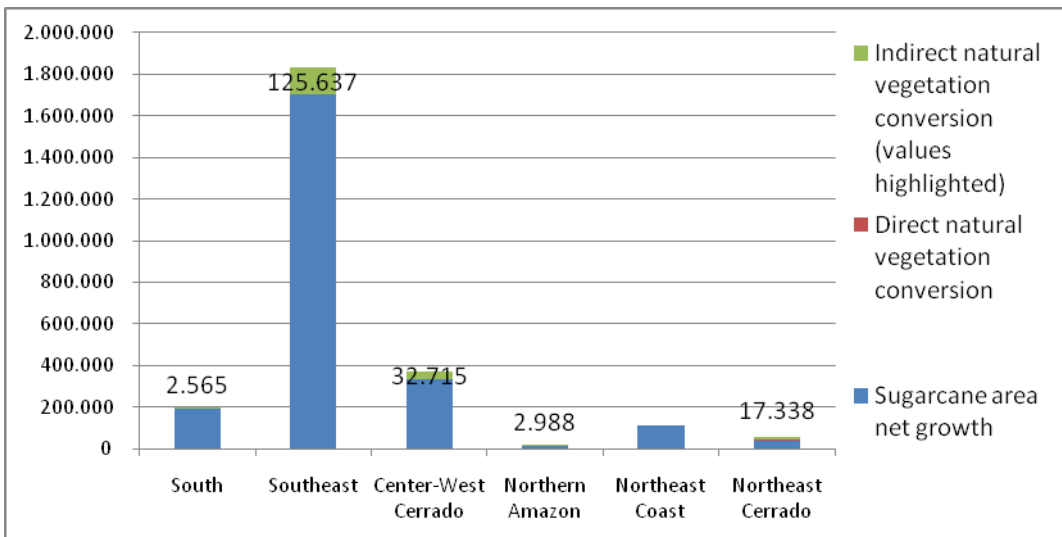
Graph 2: Conversion of natural vegetation caused directly and indirectly by the expansion of sugarcane, Brazil, from 2005 to 2008 (ha).



Source: ICONE

Thus, it can be seen that the indirect land use change is much less than proportional; for each hectare of crop or pasture displaced by sugarcane, less than 0.08 ha are then deforested in Brazil (Table 8 and Graph 6). Graph 6 presents the estimates for natural vegetation conversion caused by sugarcane expansion. The indirect conversion of native vegetation refers to deforestation caused directly by other activities that surrendered area to sugarcane. The direct conversion of native vegetation refers to the LUC caused directly by sugarcane (both presented in Table 6).

Graph 3: Sugarcane area net expansion and associated direct and indirect conversion of natural vegetation according to BLUM regions, 2005 to 2008 (ha).



Source: ICONE

4.3. GHG emissions associated with the expansion of ethanol in Brazil – factor of ILUC

Finally, the areas of converted native vegetation were transformed into GHG emissions according to emission factors described in Table 5. The LUC emissions from substitution between crops and pastures were also considered. In this case, the emissions were more than compensated by the carbon uptake coming from the substitution of pastures by sugarcane. Therefore, the direct land use changes caused by the expansion of sugarcane between 2005 and 2008 removed about 47 thousand tons of carbon (Table 9).

Table 9: Land use change GHG emissions and ILUC factor associated with sugarcane expansion, from 2005 to 2008.

Emissions associated with LUC (Ton CO ₂ eq)	-46,884
Emissions associated with ILUC (Ton CO ₂ eq)	2,462,069
Total emissions (LUC + ILUC) (Ton CO ₂ eq)	2,415,186
Additional ethanol production (Ton of total recoverable sugar)	19,672,059
Energy content of additional ethanol production (Gigajoule)	248,330,532
LUC + ILUC factor (g CO ₂ eq / MJ)	7.63

Considering the total emissions of land use changes (direct and indirect – LUC and ILUC) in the period, 2.4 million tons of carbon was emitted. As this emission refers to all sugarcane expansion, a discount factor of 0.79 was applied only to consider the emissions associated with the additional production of sugarcane for ethanol. This coefficient was estimated from statistics supplied by UNICA about the sugar content for ethanol (hydrous and unhydrous) and sugar, measured by their TRS (total recoverable sugar).

Thus, a LUC + ILUC factor was obtained for sugarcane ethanol of 7,63 g CO₂eq/MJ. This factor represents that for each additional megajoule of ethanol produced, 7,63 g CO₂eq was emitted due to land use changes. This factor was obtained accounting for all direct and indirect emissions and absorptions coming from the conversion of native vegetation and the substitution between different land use classes (temporary crops, permanent crops and pastures). Considering only the emissions from the conversion of native vegetation, a LUC + ILUC factor of 6,48 g CO₂ eq/MJ was obtained. This exercise was carried out due to the uncertainties about the emissions associated with the change in agricultural and cattle raising uses, which are very dependent on the management practices adopted.

The LUC + ILUC factor estimated here should not, therefore, be confused with the average ILUC, which considers all the production of ethanol and not just the additional production. The average ILUC factor from the database and the methodology presented here would be considerably lower than 7,63 g CO₂ eq/MJ.

5. Applications and Final Considerations

This study estimated a LUC + ILUC factor of 7,63 g CO₂eq. for each MJ of ethanol produced, for an ethanol production expansion of 248 million Gigajoules. This expansion generated, together with the additional sugar demand for the same period, an increase of 2,4 million ha of sugarcane and an estimated total LUC+ILUC of 191 thousand ha.

Apart from the final concrete results, this study generated important contributions from a methodological point of view. The organization of the database and its descriptive analysis presented in chapter 2 provide important elements for the ILUC debate on biofuels in Brazil and in the world. The study shows the importance of a continuous effort to publish up to date analysis of agricultural expansion dynamics in Brazil and the role of sugarcane in this scenario.

Regarding the development of the allocation methodology to evaluate land use change, we believe this approach has a lot of potential and opens up several possibilities. Within the context of the adopted method, it was found that the less expansion in sugarcane relative to the other crops and consequently to deforestation, the greater the impact of expansion relative to a hectare of sugarcane. In the same way, the less the crops expand given a certain amount deforestation, the more pasture expands, and as a consequence direct deforestation increases are attributed to crops. Therefore, it can be seen that the methodology hereby developed is very sensitive to deforestation, especially as we have adopted pasture as a residual. The same method applied for the period from 2002 to 2008, which presented much greater accumulated deforestation, would result in a much greater ILUC factor, despite the expansion of sugarcane

being very small between 2002 and 2005. If data were available concerning the annual evolution of pasture area, whether by gathering secondary data by sampling or by remote sensing, the result could change considerably. This is an improvement which could be carried out in the future when the series becomes available.

The sensitivity of the ILUC factor to deforested area is not a surprise. The logic of the allocation methodology assumes that the total deforested area needs to be allocated between productive uses and, given that some productive uses present a net reduction in total area, but an increase in area in some regions, greater deforestation will always result in a greater effect on land use caused by any expansion in agricultural activity. Therefore, several periods will necessarily result in several ILUC factors. Thus, once this study shows that the methodology hereby proposed is consistent and has practical applications for measuring LUC and ILUC, it can be replicated for several periods with the objective of evaluating the sensitivity of the ILUC factor to deforested area. However, it is important to mention that the methodology carries a basic assumption that each agricultural activity necessarily contributes, indirectly, to the advance of the frontier. Therefore, the choice of periods with very high deforestation will, without doubt, lead to an overestimation of this indirect contribution. The methodological option for this study was to choose the period of greatest expansion of sugarcane which, coincidentally, was also the period of least deforestation (if data from 2002 and onwards was used). We have not carried out quantitative analyses to evaluate the cause and effect relationship between sugarcane and natural vegetation conversion. Yet it is evident that there are other productive activities which contribute, directly and indirectly, in a more intense manner to the expansion of total agricultural area. This fact is also an important conclusion of this study, as it reinforces the idea that, although we have only calculated LUC and ILUC for sugarcane, the same could be done for all the other agricultural activities.

Since the proposed methodology is a very precise one considering the deterministic approach options, it could be used for other regions and conditions. Furthermore, the developed methodology may and should be used to analyze future scenarios. The tendency observed starting in 2005 is that the rates of deforestation are falling. If this trend of falling deforestation rates is maintained, future ILUC factors will be less than the value found in this study for the period from 2005 to 2008. Apart from this, considering that the period from 2005 to 2008 was marked by large expansion in the area of sugarcane, a trend not observed in 2009 and 2010, the future ILUC factors will also tend to be less than those calculated for this period. This will occur because the future area expansion of sugarcane, relative to 2008, will be proportionally less than the expansion of 2008 relative to 2005. Moreover, the larger the sugarcane base area, the higher production increase coming from yield improvement in already occupied sugarcane area. This means that a proportionally smaller area will be necessary to meet an equivalent increase in the demand for ethanol in the future, compared to the growth observed from 2005 to 2008, which in turn will result in a smaller ILUC factor.

Another conclusion associated with the above mentioned reasoning refers to the role of pastures in the LUC + ILUC of the other productive activities. As observed in the results, the pasture raising is still the productive activity which directly converts native vegetation the most. A smaller spatial expansion of pastures leads to less deforestation and, consequently, to a lower ILUC factor. This study concludes, as do several other analysis, that it is necessary to produce more beef per hectare, breaking the cattle raising current expansion process associated with greater herds and expansion in frontier areas. Although this study has not estimated the capacity of expanding beef production with a decrease in pasture area, nor exploited the synergy between sugarcane production and feedlot cattle, it indicates that beef production needs to improve yields, from the point of view of ILUC emissions,.

Other information coming from satellite images regarding conversion of native vegetation and substitution between crops could also greatly improve the processing and, therefore, the confidence in the results of the developed method. In the same way the information regarding areas displaced by sugarcane obtained

by CANASAT was used in the criterion of substitution between crops, similar studies for other crops could also contribute to the improvement of the criterion in this study.

The estimate of the ILUC factor hereby presented is an important indicator of the magnitude of the effects caused by land use change from sugarcane ethanol. The value of 7,63 g CO₂eq/MJ is considerably lower than the ones presented in other studies and therefore indicates that the ILUC effects may be overestimated. There are several practical applications for the results obtained here. The ILUC factor can be taken into account in life cycle analyses which do not incorporate the land use changes. Apart from this, the ILUC factor may be very useful for the debates aiming to develop certification criteria for biofuels. When such criteria include the adoption of measures to avoid ILUC, the ILUC factor can be added to those producers who have not adopted such measures.

Evidently, from the point of view of the formulation of a certification criteria, the incorporation of an ILUC factor only makes sense if applied, with homogenous methodology, to all the feedstocks used for biofuels. At this point there is another improvement which needs to be developed in the methodology presented here. Due to the high degree of detail, the methodology of this study cannot be easily replicated for calculations of an ILUC factor which takes into account the global changes in land use. However, Brazil is one of the few countries where the agricultural frontier is still expanding and it is in Brazil that a large part of the ILUC caused by biofuels of other countries should occur. This means it is possible to apply this methodology to evaluate the ILUC effects of biofuels produced in third countries that may occur in Brazil.

Although it is not the objective of this project, the coefficients will be used by ICONE to recalculate the parameters (elasticity) which define the competition (substitution) and scale (advance on the frontier) effects within the Brazilian Land Use Model (BLUM). For this calculation the coefficients will be associated with price variations. Finally, the result can be used to simulate the emissions which would be generated (and also those avoided) in a prospective analysis, starting from scenarios of future ethanol demand. This last option however, tends to be more coherently analyzed using more complex economic and geographic models.

Thus, both the development of the allocation methodology to evaluate land use changes, as well as the results obtained contribute to the current debate of biofuel sustainability. The methodology makes an effort to explicitly present the hypotheses, difficulties and limitations in land use change analysis. The current study is the first and only experience of deterministic methodology (or of allocation) which is specific for the Brazilian reality, apart from being the only proposal with conceptual rigor within this approach. Doing so, Brazil has been consolidated not only as an exponent of biofuel production and export, but also of the environmental assessment associated to this production.

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