Docket Optical System - Comments on the Draft AB 118 Investment Plan for Alternative and Renewable Fuel and Vehicle Technology Programs

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Docket # 08-ALT-1
AB 118 Investment Plan for the Alternative and Renewable Fuel and Vehicle Technology Program

Dear Commissioners,

These comments on the proposed AB 118 Investment Plan are made in conjunction with those of Dr. David Grantz of today's date. Dr. Grantz is the Director of the University of California Kearney Agricultural Center and an expert in sugar cane, as more fully set forth in his comment letter.

Dr. Grantz and I made complementary and related presentations at the San Pedro Regional Workshop as an example of a "shovel-ready" project with patent-pending technology that would be a public-UC academic-private project funded under AB 118. This is a project that can yield incomparable benefits in terms of GHG reduction, economic development, renewable electricity that will help fulfill CA's Renewable Portfolio Standard (RPS) and provide a transition to cellulosic ethanol and the hydrogen fuel cell, i.e., in the immediate to 2050 time frame.

As I stated in the Workshop, I want to thank Pete Ward and the rest of the AB 118 team for all of the evident hard work that they have put into developing this proposed Development Plan. I have participated in and followed the AB 118 process in the Energy Commission, and I make these commments with the background of having done so and having knowledge of the competing interests and concerns that have been an important part of the process.

My two principal comments are as follows:

1. All of the biofuels funds are currently in the Ultra Low Carbon Fuels Category to which a small amount of funding is allocated. However, ethanol made from sugar cane should be in the Super Ultra Low Carbon Fuels category if the percentages of funding remain the same in the final Plan. That is because sugar cane ethanol grown in one or more areas of California will produce GHG reductions of 95% or more.

In support of that statement, I am attaching 3 documents:

(a) A 2008 peer-reviewed paper written by Dr. Isaias Macedo et al which gives the current energy balance of sugar cane ethanol produced in Brazil (9.3) and projects the energy balance for such ethanol in 2020 when a number of desirable changes have been made to the Brazilian business model (12.6:1). Our project will incorporate all of those changes and other changes that will lead to further GHG reduction and greater sustainability. Consequently, Dr. Macedo and we project conservatively, that our GHG reduction will be greater than 90%

(b) A PPT prepared by the International Energy Association from Geneva, Switzerland, that demonstrates that ethanol derived from sugar cane is the lowest carbon transportation fuel with the greatest GHG reduction characteristics, even in comparison with celllulosic ethanol, which we all know is not commercially viable yet. The predictions of when cellulosic ethanol will be commercially viable are 5 - 8 years, the same as they have been since the 1970's when research into cellulosic ethanol was commenced in earnest as a result of the Arab oil crisi. It is worth noting that this PPT was presented when Brazilian ethanol had an energy balance of 8.3:1, i.e., less GHG reduction that currently in Brazil and substantially less than we can do in California.

(c) An article from OPIS Ethanol re the 95% or more GHG reductions that can be achieved by sugar cane ethanol produced in CA from sugar cane grown in CA. Acccording to the article, a CA sugar cane ethanol development company commissioned a fuel pathway analysis of sugar cane ethanol produced in CA from CA-grown sugar cane. The analysis was done by Life Cycle Associates (LCA), a company hired by the Energy Commission in conjuction with the Air Resources Board's Low Carbon Fuel Standard (LCFS) implementation to do all of the CA fuel pathways. As reported in OPIS Ethanol Alerts, the same service used by the Energy Commission, the GHG reductions of sugar cane ethanol produced in CA are over 95% compared with gasoline.

2. Purpose grown energy crop developers need funds for the establishment of a commercial crop of the feedstock in question in CA and for development and permitting costs. We can not avail ourselves of the subsidies and tax credits that corn ethanol producers have because we can't get to the place where we have our plants operating until we get them developed and permitted. (The corn ethanol producers did not have to establish a commercial corn crop - it has existed for 200 years in the US - and the sugar cane ethanol producers in Brazil did not have do so either - sugar cane has been grown in Brazil for over 500 years.) The TIAX gap analysis is highly misleading relating to the subsidies and other incentives for biofuels made from California feedstocks. There is currently $0 available for the kind of projects that are unique to CA.

Sincerely,

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Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020

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ABSTRACT

This work presents the evaluation of energy balance and GHG emissions in the production and use of fuel ethanol from cane in Brazil for 2005/2006 (for a sample of mills processing up to 100 million tons of sugarcane per year), and for a conservative scenario proposed for 2020. Fossil energy ratio was 9.3 for 2005/2006 and may reach 11.6 in 2020 with technologies already commercial. For anhydrous ethanol production the total GHG emission was 436 kg CO_2 eq m^{-3} ethanol for 2005/2006, decreasing to 345 kg CO_2 eq m^{-3} in the 2020 scenario. Avoided emissions depend on the final use: for E100 use in Brazil they were (in 2005/2006) 2181 kg CO_2 eq m^{-3} ethanol, and for E25 they were 2323 kg CO_2 eq m^{-3} ethanol (anhydrous). Both values would increase about 26% for the conditions assumed for 2020 mostly due to the large increase in sales of electricity surpluses.

A sensitivity analysis has been performed (with 2005/2006 values) to investigate the impacts of the huge variation of some important parameters throughout Brazilian mills on the energy and emissions balance. The results have shown the high impact of cane productivity and ethanol yield variation on these balances (and the impacts of average cane transportation distances, level of soil cultivation, and some others) and of bagasse and electricity surpluses on GHG emissions avoidance.

1. Introduction

The transport sector is almost exclusively dependent on petroleum-based fuels and attention has been given to the potential use of biomass as the basis for production of an alternative (and renewable) motor vehicle fuel. The global warming issues have been increasingly a focus of attention and greater use of biofuels, which have been able to compete with (and displace) petroleum-based fuels in the transportation market, could help to comply with the Kyoto Protocol. However, the extent to which biofuels can displace fossil fuels depends on the way in which they can be produced. All processing technologies involve (directly and/or indirectly) the use of fossil fuels; the benefit of biofuels displacing their fossil fuel equivalents depend on the relative magnitude of fossil fuels input to fossil fuel savings resulting from the biofuel use [1].

Among the biofuels, ethanol is the one that is attracting most attention; it is already produced in large scale (Brazil and USA) and it can be easily blended with gasoline to operate

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in spark ignition (SI) engines. In Brazil, bioethanol is used as neat ethanol in 100% alcohol-fuelled passenger cars (hydrous ethanol) or is blended (anhydrous ethanol) with all the gasoline in proportions of usually about 24% to operate in gasoline engines; or it is still used (as hydrous ethanol) in any proportion in flexible-fuel vehicles (FFV).

Fuel ethanol utilization in Brazil reached 14.1 hm^3 in 2006 (production was 17.7 hm^3), close to 40% of the fuel for SI engines; it also generated 11.3 TWh electricity and mechanical power, which were mostly used internally by the cane processing industry. In addition, the use of bagasse as fuel was 20.2 Mt, equivalent to all fuel oil plus Natural Gas used in Brazil, again mostly for internal use in the sugar and ethanol industry [2].

The environmental advantages of sugarcane-based ethanol, regarding gasoline substitution and GHG emissions mitigation, have been known since the first comprehensive energy balance [3] and GHG emissions in the life cycle [4] were available. In 1998, Macedo [5] updated and revised these estimates using 1996 data. In 2003 (data from 2002), the information was again updated indicating a value of 8.3 for the ratio (renewable energy in ethanol) × (fossil fuel energy input)$^{-1}$ in the life cycle, and avoided emissions corresponding to 2.6 and 1.7 $t\,CO_2\,eq\,m^{-3}$ ethanol anhydrous and hydrous, respectively, for the Brazilian Center-South conditions [6].

The rapid growth of the cane sector in Brazil (from 357 Mt cane in 2003 to 425 Mt cane in 2006, and expected 728 Mt cane in 2012) and some legal constraints and technology developments are changing important parameters in this evaluation. New varieties and productivity changes the legal restrictions to burning sugarcane and the increased harvesting mechanization influence energy and the GHG emissions in different ways. The mills started a strong action in selling surplus electric power and the use of portion of the cane trash for energy will be seen in the next years. In addition, the end use has changed, with the growing fleet of flexible-fuel vehicles (82% of the new cars).

This work presents the situation (energy balance and GHG avoided emissions) today, based on the 2005/2006 average conditions (2002 parameters [6] are also presented for comparison), with the best available and comprehensive data for the Brazilian Center-South Region. Some important parameters for this evaluation present a large range of variation from mill to mill, so a sensitive analysis was performed in order to cover the different possibilities of impacts on energy/emissions balance throughout Brazilian mills. It was also evaluated the situation for a 2020 scenario; this scenario is very conservative, considering only the commercially available technologies (today) and the trends clearly identifiable.

The basic biomass production and conversion data, as well as the most important coefficients used (energy conversion, efficiencies, energy to produce materials, energy for chemical inputs) are presented so that the results for GHG emissions can be compared to other biomass-based energy systems. The specific parameters for the Brazilian end uses of ethanol are used to estimate GHG emission mitigation.

2. Database

The great attention that has been given to ethanol in the last years as an important tool for greenhouse emissions mitigation is leading to some studies about energy balance and GHG emissions in the production and use of Brazilian ethanol. Most of the analyses, however, are based on information provided by only a few mills (sometimes only one) and they may be far from representative of the average national scenario. Unfortunately, a comprehensive countrywide database for the sugarcane sector has not yet been established; the use of a database covering part of the sector, but based on reliable and traceable information, has been preferred by the last comprehensive studies [5,6]. In those cases, the main references were Sugarcane Technology Centre, in that time, Copersucar Technology Centre (CTC) surveys about agricultural and industrial performance parameters of its associated units. Because of the quality of the information (traceable and well-established procedure for data collection and laboratorial analysis, over the last decade), CTC's database was used in this study with data of 2005/2006 and 2006/2007 seasons for agricultural and industrial parameters of 44 mills (~100 Mt cane year^{-1}). It is important to point out that most of these mills are placed in Center-South of Brazil, which is responsible for more than 90% of all ethanol currently produced in Brazil [2]. The evaluation for the agricultural parameters used the weighted average of the individual values for each mill with respect to its size (cane crushing rate). For the industrial parameters, the weighting factor was the cane processed exclusively for ethanol production.

One point deserves further comments. Diesel consumption is a key parameter in this analysis, and for its estimation we considered the methodology used by Macedo et al. [6]. In this procedure the total consumption is obtained through the equipments' specific fuel consumption and the level of their utilization in the different productive operations (see details in [6]). The data used in that analysis had been originally taken from Copersucar reports (Agricultural Monthly Performance Follow up Program and Agricultural Benchmark Program), which were revised for this present evaluation. Through this methodology, we found a total diesel consumption of 164 $L\,ha^{-1}$.

These calculations consider all the essential operations involved in the sugarcane production chain, but there is a portion of the total diesel consumption (other, diversified operations) that is not accounted for. The information of the sugar mills about this portion is incomplete and non-homogeneous; based on the information to CTC, for a sample of 40 mills, the total diesel consumption (agricultural processes) varied from 68 to 285 $L\,ha^{-1}$ in 2005/2006 season (without including the fuel for stillage and filtercake mud distribution). Those values also may not include third party tractors. On the other side, the total diesel consumption related in some other cases includes operations not related to the ethanol production (sugar transportation in the mill, operations with cattle raising and other cultures, new land development, operations with third party cane, etc.). This leads the huge variation of the values, and to the preference for the direct calculation methodology. In an (conservative)

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estimation of the total diesel consumption average, we took (arbitrarily) only the values higher than 160 L ha^{-1} and added to them 15 L ha^{-1} (for stillage and filtercake mud distribution operations [6]). The weighted average of these values was 230 L ha^{-1}, which has been adopted as the total diesel consumption of the average mill. Actually, when we consider all activities performed by the mill, we may find values higher than that (eventually 400 L ha^{-1}) [7]. A large share of this consumption, however, is related to certain services which were already accounted in other items of the analysis (maintenance, for example), or it is not even related to sugarcane production chain (e.g. soybean or peanut cultivation, land development for new areas).

The difference between these estimations (164 and 230 L ha^{-1}) is associated to other activities and small services that are performed during productive operations, but are not individually identified. This difference was allocated as "other agricultural activities". It is desirable that in the near future the complete, homogeneous information may be added to the database.

3. Ethanol fuel chain: expected evolution

3.1. *Sugarcane production (agriculture)*

The complete sugarcane crop cycle is variable, depending on local climate, varieties and cultural practices; in Brazil, usually it is a 6-year cycle, in which five cuts, four ratoon cultivation treatments and one field reforming are performed. Generally, the first harvest is made 12 or 18 months after planting. The following ratoon cane harvests are made once in a year, during 4 consecutive years, with gradual decrease in cane productivity. In the Center-South of Brazil the average productivity is about 78–80 t of cane per hectare (tc ha^{-1}), while in São Paulo State it ranges from 80 to 85 tc ha^{-1}, both considering a complete cycle with five cuts [2].

Since early 1980s the evolution trend in cane productivity has been continuous, from 70 tc ha^{-1} to more than 80 tc ha^{-1} in early 2000s [8]. This trend might be kept for the next years, and the same can be said about cane quality (sucrose content), for which is expected an increase of one basis point in the next 15 years [9].

The agricultural operations in cane cultivation are not expected to change much in the next years, except for the modifications due to increasing harvest mechanization. However we might see an increase of low tillage practices in the next years. The main alteration expected is the adoption of mechanical planting, in substitution of separated operations of furrowing and fertilizer application and seed distribution [9].

The most important changes may happen in cane harvesting, which will move from burned cane manual harvesting to mechanical harvesting of unburned cane. Essentially, this change is related to a schedule adjustment with Government (Federal and State levels) specifically for the gradual reduction of the cane trash pre-burning (see Fig. 1). Recently, UNICA signed a protocol of intentions in which its associates (individually and voluntarily) may accept to phase out trash

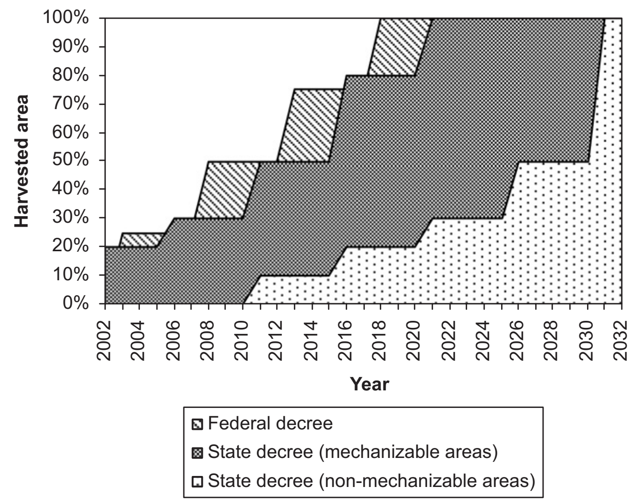

Fig. 1 – Phase out schedules for trash burning practices (based on [10]).

burning practice until 2014, in mechanizable areas, and 2017, in non-mechanizable areas.

As a consequence, great amounts of trash will be available, and its use as energy source is already becoming an attractive option for mills, although the route for trash recovery (harvest and transportation) is still not well established. For those cases in which the trash recovery is intended, the best alternative at the moment is the mechanical cane harvesting with partial cleaning [11], i.e. part of the trash would be transported to the mill with cane, and there it would be separated and used as fuel.

For the logistics the trend is the replacement of single load trucks by trucks with lower specific fuel consumption and higher load capacities (3 and 4 wagons). Nonetheless, the eventual implementation of government regulations restricting the load capacity for cane transportation in the next years could impose large barriers to such evolution [12].

The summary of the main agricultural parameters considered for energy and emission analyses for 2005/2006 and the projected values estimated for the 2020 scenario are presented in Tables 1 and 2 (2002 data is also presented for comparison). For 2020 scenario, many opinions from different specialists were considered in order to identify the most probable scenario [9,13]; we adopted a very conservative set of conditions, and it may be considered a "minimum" expected performance.

3.2. *Sugarcane processing (industry)*

Because of the great advantages of producing sugar and ethanol simultaneously, the most adopted mill configuration in Brazil is an ethanol distillery annexed to the sugar mill. In this study an autonomous distillery was considered, just to facilitate the evaluation of energy and materials flows concerned only to ethanol production, disconnected from sugar. This assumption does not compromise the quality of the analysis, since ethanol and sugar production involve processes clearly distinguished, with very well known system boundaries, specific equipment and energy use. The data

Table 1 – Basic data for sugarcane production, harvesting and transportation

Item	Units	2002[a]	2005/2006[b]	Scenario 2020[c]
Sucrose	% cane stalks	14.53	14.22	15.25[d]
Fiber	% cane stalks	13.46	12.73	13.73[e]
Trash (dry basis)[f]	% cane stalks	14	14	14
Cane productivity	$t\,cane\,ha^{-1}$	82.4	87.1	95.0
Seed efficiency	$(ha\,cane)\,(ha\,seed)^{-1}$	7.0	6.9	7.0
Fertilizer utilization				
P_2O_5				
Plant cane	$kg\,ha^{-1}$	120	125	134
Ratoon without stillage	$kg\,ha^{-1}$	25	25	34
K_2O				
Plant cane	$kg\,ha^{-1}$	120	117	138
Ratoon without stillage	$kg\,ha^{-1}$	120	114	138
Nitrogen				
Plant cane	$kg\,ha^{-1}$	30	48	48
Ratoon with stillage	$kg\,ha^{-1}$	90	75	55
Ratoon without stillage	$kg\,ha^{-1}$	80	88	120
Lime	$t\,ha^{-1}$	2.2	1.9	2.0
Herbicide[g]	$kg\,ha^{-1}$	2.2	2.2	2.2
Insecticide[g]	$kg\,ha^{-1}$	0.16	0.16	0.16
Filtercake application	$t\,(db)\,ha^{-1}$ (% area)[h]	5 (30%)	5 (30%)	5 (30%)
Stillage application	$m^3\,ha^{-1}$ (% area)[i]	150 (30%)	140 (77%)[j]	140 (90%)[j]
Mechanical harvesting	% area	35	50	100[k]
Unburned cane harvesting	% area	20	31	100[k]
Machinery utilization				
Tractors+harvesters	$kg\,ha^{-1}$	41.8	41.8	210
Implements	$kg\,ha^{-1}$	12.4	12.4	13
Trucks	$kg\,ha^{-1}$	82.4	82.4	100

[a] [6].
[b] [14].
[c] Author's projections.
[d] 2020: increasing 1 point (%) in 15 years (variety development and better allocation).
[e] Apparent fiber increasing with increase in green cane harvesting (trash).
[f] [11].
[g] Macedo, 2005.
[h] Reforming areas (1/6 of total area).
[i] Ratoon areas (4/6 of total area).
[j] Stillage is an ethanol production residue, but it is spread over both cane areas, for sugar and ethanol production, since they are not distinguished in cane field. However, to limit ethanol system boundaries, in this study it was considered that all stillage is destined exclusively to "ethanol cane area", but keeping the suitable level of application ($\sim 140\,m^3\,ha^{-1}$).
[k] Considering the legislation and phase out schedules for cane trash burning in São Paulo, 2006.

Table 2 – Parameters for diesel consumption estimation

Parameter	Units	2002[a]	2005/2006	Scenario 2020[b]
Agricultural operations				
Plant cane	$L\,ha^{-1}$	102.6	102.6	132.3
Ratoon	$L\,ha^{-1}$	9.1	9.1	9.1
Harvester	$L\,tc^{-1}$	0.898	1.050	0.986
Loader	$L\,tc^{-1}$	0.154	0.163	0.171
Tractor hauler/transloader	$L\,tc^{-1}$	0.257	0.376	0.395
Transportation distance	km	20	23	30
Trucks' energetic efficiency	$t\,km\,L^{-1}$	49.0	52.4	62.0
Other activities[c]	$L\,ha^{-1}$		67.0	85.0

[a] [6].
[b] Authors' projections.
[c] See details in text body (Section 2). For 2020 scenario, the projection was based on the increase of diesel consumption expected for basic productive activities.

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obtained for combined sugar and ethanol production considers the allocation issues for the industry (energy consumption, equipment, inputs) and agriculture (residue recycling), using also the long experience in Brazil with the autonomous distilleries in the 1970–1980 period. Most of the new projects involve only autonomous distilleries.

The production scheme is basically the same for an integrated mill: the process begins with cane cleaning and crushing, when the juice is separated from bagasse (which is sent to power island section). The treated and slightly concentrated juice follows to fermentation, producing the wine, which will result in hydrous ethanol after the distillation; the hydrous ethanol may be stored as final product or dehydrated to produce the anhydrous ethanol.

Process yield depends on cane quality (sucrose content) and the efficiency in sucrose utilization. At present the industrial efficiency (sugar recovery) is around 90% and it is difficult to expect a large evolution considering only today's commercial technologies. So, for 2020 the possibilities to enhancing ethanol yields are basically related to cane quality improvements.

The main (energetic) co-products of ethanol production are bagasse and electricity surpluses. Nowadays, the energy generation in mills is based on "pure" cogeneration steam cycle systems (at pressure of 2.2 MPa), which are capable to attend whole mill energy demand and still produce small amounts of bagasse (5–10% of biomass) and electricity surpluses (0–10 kWh tc^{-1}). However, new mill units are already equipped with high-pressure steam systems (e.g. 6.5 MPa—480 °C; some units with 9.0 MPa), besides the utilization of more efficient equipment and better process integration designs. The implementation and evolution in cane trash recovering will enable the production of greater amounts of electricity surplus, easily overcoming 100 kWh tc^{-1}.

The main residues are filtercake mud and stillage; they are very important for their use as fertilizers, reducing the need for agricultural inputs. For the coming years, since their production is determined by the amount of cane crushed and ethanol production, the only expected change is the increase of the total area in which they are used (optimizing the fertilizer savings, and using more energy).

The basic parameters considered for ethanol production phase are presented in Table 3. The projections for the 2020 scenario, again, were made based on specialists' opinions [9,13].

4. Methodology

4.1. *Energy input and GHG emissions*

In this analysis a "seed-to-factory gate" approach was adopted, which comprehends the sugarcane production and processing, coming to fuel ethanol at the mill gate. Three levels of energy flows were considered in the energy balance and GHG emissions evaluation:

Table 3 – Basic data: cane processing to ethanol

Item	Units	2002[a]	2005/2006[b]	Scenario 2020[c]
Electricity use in processes	kWh tc^{-1}	12.9	14.0	30
Mechanical drivers	kWh tc^{-1}	14.7	16.0	0
Surplus electricity	kWh tc^{-1}	0	9.2[d]	135[e]
Trash recovery	% total	0	0	40
Surplus bagasse	% total	8	9.6	0[f]
Ethanol yield	L tc^{-1}	86	86.3	92.3[g]
Equipments[h]				
Boilers	t	310	2400	2400
Crushers and driving devices	t	312	1300	1300
Conveyors	t	225	450	450
Distillery	t	476	3000	3000
Tanks	t		1540	1540
~~Edifications~~				
Industrial buildings	m^2	5000	12,000	12,000
Offices	m^2	300	800	800
Labs, repair shops	m^2	1500	3800	3800
Yards	m^2	4000	10,000	10,000

[a] [6].
[b] [9].
[c] Authors' projections.
[d] Based on Cogen's estimations [15]. But only about 10% of the mills operate with higher pressure boilers, and the remaining 90% still use 2.1 MPa/300 °C, with very low surplus energy.
[e] All mills operating at 6.5 MPa/480 °C, CEST (condensing extraction steam turbine) systems; process steam consumption ~340 (kg steam)(t cane)$^{-1}$, and using recovered trash (40%).
[f] All biomass (bagasse and 40% trash) is used for power generation.
[g] Only the increase in sucrose % cane was considered.
[h] 2002 data were based on a 120,000 L day^{-1} distillery size; for 2005/2006 and 2020 scenario we considered an 860,000 L day^{-1} unit.

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1. The direct consumption of external fuels and electricity (direct energy inputs).
2. The additional energy required for the production of chemicals and materials used in the agricultural and industrial processes (fertilizers, lime, seeds, herbicides, sulfuric acid, lubricants, etc.).
3. The additional energy necessary for the manufacture, construction and maintenance of equipment and buildings.

The energy flows were calculated in terms of Gross Energy Requirement (GER), i.e. the energy inputs required during the extraction, transportation and production of fuels (or electricity) were measured, as primary energy [1]. The possible evolution of energy and emission factors along the time was not considered in this analysis, so the same values were adopted for both studied cases: 2005/2006 and 2020 projected conditions. The coefficients used to determinate the energy consumptions and GHG emissions are discussed below.

4.1.1. *Fuels*

Since local reliable data were not available, we used international consolidated data about energy consumption and GHG emissions in the production of oil-derived fuels [16,17]. Brazilian particularities regarding oil extraction technology (most of the oil comes from deep water) and oil type (mostly heavy oil) may result in higher energy consumption for extraction and refining, but eventual variations in comparison with international values would not be so that may compromise this analysis. Table 4 shows the values considered.

4.1.2. *Electricity*

Despite the recent investments in the construction of NG thermoelectric plants, the power generation in Brazil is still based on hydroelectric stations (>85%). Actually, power generation from fossil fuels accounts for less than 10% of all electricity produced in Brazil [18]. Evidently this low fossil fuel consumption is reflected in GHG emissions. According to the evaluations presented by MME for the determination of baselines (CDM projects), in 2006 the emissions related to power generation in Southeast-Midwest Region were between 78 and 180 kg CO_2 MWh^{-1}. Bearing these values in mind and the low utilization level of external, acquired electricity in cane ethanol life cycle (it's related only to embodied energy in machinery, equipments and chemicals), this share of energy consumption was not considered for global energy and GHG emissions accounting.

4.1.3. *Embodied energy in agricultural machinery and industrial equipments*

Usually, embodied energy uses in equipments manufacturing (agricultural and industrial) and buildings are low in comparison to energy flows associated to energy production. In the case of cane ethanol, however, this share is not so small, once there is no demand for fossil fuels in the ethanol production step (differently from other biofuels). Actually, in the last evaluation [6] this share was equivalent to 30% of the total energy requirement.

In this evaluation, we kept the same characterization for equipment types division made by Macedo et al. [6], but the data about embodied energy in materials and their respective GHG emissions was updated. Only one additional simplification was made: all materials were considered generally as metallurgical products.

According to the Brazilian Energy Balance [18], the specific energy consumption in metallurgical industry was 27.2 MJ t^{-1} (in 2005), of which around 65% were provided by fossil energy sources. In terms of emission, Kim and Worrell [19] estimated a Brazilian emission factor of 1.25 t CO_2 t^{-1} of iron-steel, considering a specific energy requirement near to the 2005 data. So, here we considered a fossil energy requirement of 17.7 MJ t^{-1} and an emission factor of 1.25 t CO_2 t^{-1}. For the machinery and equipments manufacturing step, since electricity is the main energy source, here this share of energy was not considered.

4.1.4. *Embodied energy in mill's constructions*

The energy consumption for buildings construction varies from 3.0 to 5.0 GJ m^{-2}, according to their type. For a Brazilian standard residential construction, it is estimated an energy requirement of 3.5 GJ m^{-2}, in which the energy associated to

Table 4 – Energy demand and GHG emissions in fossil fuels production

Fuel	Energy demand[a] (MJ MJ_f^{-1})[b]	Direct emission[c] (gC MJ_f^{-1})	Emissions in production[d] (gC MJ_f^{-1})	Total emissions (gC MJ_f^{-1})
Gasoline	1.14	18.9	3.41	22.3
Diesel	1.16	20.2	3.87	24.1
Fuel oil	1.24	21.1	4.95	26.1
Natural gas	1.12	15.3	9.53	24.8
Petroleum coke[e]	1.00	27.5	–	27.5

[a] [16].
[b] MJ_f = Mega Joule of fuel.
[c] [17].
[d] [16]; considering extraction, transportation and processing.
[e] Considered as residue; emissions related to its production were not considered.

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cement production is the main part [20]. In the national cement industry [18], about 60% of energy requirement is provided by fossil fuels (petroleum coke mainly) and, for simplification, here we extended this ratio to all edifications. With these considerations, and for the different types of mill's constructions, we proposed the values presented in Table 5 as defaults for calculations. The emission factor was equivalent to the petroleum coke emission factor, i.e., 100.8 kg CO_2 GJ^{-1}.

4.1.5. *Energy requirement for fertilizers production*

Fertilizers have received a special attention in life cycle analyses especially because mineral nitrogen, which, besides its N_2O emission, also demands large amounts of energy for production. When local data about energy consumption for fertilizers (and defensives) production were not available, we used international data (EBAMM and GREET models' values). The correspondent emission factors were also based on the values presented by EBAMM and GREET models [21,22], which represent the US default values (see Table 6).

4.1.6. *Energy requirement for chemicals production*

The estimation of energy requirements and associated emissions in chemicals production were based on general information of Brazilian chemical industry. In 2005, the specific energy consumption in chemical industry in Brazil was 8.1 MJ t^{-1} of shipment, with 73% been provided by fossil sources (essentially NG and petroleum coke) [18]. For simplification, this coefficient was attributed to all chemicals and with an emission factor of 95 kg CO_2 GJ^{-1} (derived from NG and petroleum coke use). Table 7 shows the energy consumption per liter of ethanol associated to each product.

The evaluation of the GHG emissions included the emissions due to fossil fuel utilization (all three levels) and those not related to fossil fuels. The most important emissions that are not derived from use of fossil fuels are:

- methane and N_2O emissions from the burning of sugarcane trash before harvesting;
- N_2O and CO_2 emissions from soil by fertilizers and lime application and crop residues returned to soil.

The process conditions allowed for stillage recycling adopted today (stillage cannot stay in ponds; application volume is site dependent) do not promote anaerobic digestion. The same is true for bagasse storage (usually less than 5%; short off season periods); so methane emissions are not included in the analysis.

Emissions from sugarcane trash burning in the field and soil emissions were evaluated according IPCC (2006) recommendations [17], with the corrected values for the GWP-100 [24]. Since urea is the main N-fertilizer used [25], besides N_2O emissions, the emissions of CO_2 must also be accounted for [17]. Nitrous oxide emissions regarding unburned trash that is not taken to the mill, added to stillage and filtercake mud emissions (industrial residues that carry part of cane nitrogen), were determined with IPCC values indicated for "residues returned to soil" category [17], although they do not necessarily represent the reality verified for sugarcane biomass. The summary of emission factors used for emissions not derived from the use of fossil fuels considered in this analysis is presented in Table 8.

4.2. *Energy output and GHG avoided emissions*

The total renewable energy produced in ethanol life cycle was considered as the sum of the thermal energy contribution of ethanol and co-products (bagasse and electricity surpluses). For ethanol and bagasse, the energy content were the low heating values (LHV), while for electricity, we considered the

Table 5 – Estimated embodied energy for mill's edifications[a]

Edification	Embodied energy[b] ($GJ\,m^{-2}$)
Industrial buildings	1.8
Offices	2.4
Labs, restore shops	2.4
Yards	1.2

[a] Based on [20].
[b] Fossil energy.

Table 6 – Energy demand and GHG emissions in fertilizers/defensives production[a]

Fertilizer	Energy demand ($MJ\,kg^{-1}$)	Emission factor (kg CO_2 eq (kg^{-1})
Nitrogen (N)	56.3[b]	3.97
Phosphorus (P_2O_5)	7.5[b]	1.30[c]
Potash (K_2O)	7.0	0.71
Lime	0.1	0.01[d]
Herbicide	355.6	25.00
Insecticide	358.0	29.00

[a] [21,22].
[b] [23].
[c] Adapted from [21].
[d] Author's estimation.

Table 7 – Energy associated to chemicals and lubricants (ethanol production step)

Chemical	Fossil energy (kJ (L ethanol)$^{-1}$)
NaOH	98.6
Lime	64.9
Sulfuric acid	48.0
Cyclohexane	5.2
Antifoam	2.6
Lubricants	1.6
Others	2.0
Total	222.9

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Table 8 – Emission factors in processes not related to fossil fuels use

Source	Emission factor ($kg\,CO_2\,eq$ (kg-source)$^{-1}$)
Trash burning	
N_2O[a]	0.021
Methane[b]	0.062
Nitrogen application[c]	
N_2O[d]	6.163
CO_2[e]	1.594
Lime[f]	
CO_2	0.477
Returned residues[g]	
N_2O (stillage)[h]	0.002
N_2O (filtercake mud)[i]	0.071
N_2O (unburned trash)[j]	0.028

[a] Based on IPCC emission factor: 0.07 (kg N_2O) (t dry matter burnt)$^{-1}$ [17].
[b] Based on IPCC emission factor: 2.7 (kg CH_4) (t dry matter burnt)$^{-1}$ [17].
[c] Urea is the main N-fertilizer used [25].
[d] 1.325% of N in N-fertilizer is converted to N in N_2O [17].
[e] For urea, the emission factor indicated by IPCC is 0.2 kg C (kg urea)$^{-1}$ [17].
[f] Based on IPCC default emission factor for dolomite (0.13 kg C kg^{-1}) [17].
[g] For residues, it was considered that 1.225% of N in residue is converted to N in N_2O [17].
[h] Stillage nitrogen content: 0.36 kg m^{-3} [26]. During distillation, about 11 L of stillage are produced for each liter of ethanol.
[i] Filtercake nitrogen content: 12.5 kg t^{-1} [26]. After juice treatment, 6–8 kg (dry basis) of filtercake mud per ton of cane are produced.
[j] Trash nitrogen content: 0.5% [11].

thermal equivalences for power plants with 40%$_{LHV}$ (for 2005) and 50%$_{LHV}$ (for 2020) efficiencies. This is quite arbitrary, but the data present allows the use of other hypotheses, if needed for comparisons. The energy ratio of the system was calculated as

$$\text{Energy ratio} = \frac{\sum \text{Renewable energy output}}{\sum \text{Fossil fuel energy input}}. \quad (1)$$

The evaluation of avoided emissions depends on the equivalences between the renewable fuel (ethanol, bagasse and electricity) and the fossil fuels replaced (therefore, on the processes used and energy contents); and, of course, on their respective life cycle emissions.

For ethanol there are a number of possibilities. The experience in Brazil and in some other countries shows that today's technologies lead to averages as listed below [27] (however, there are large differences):

- Anhydrous ethanol in blends up to 10% (volume) with gasoline: 1 L ethanol = 1 L gasoline.
- Hydrous ethanol, dedicated ethanol engines (Brazil): 1 L ethanol = 0.75 L gasoline.
- FFV engines in Brazil, 2005: variable, with average: 1 L ethanol = 0.72 L E25 (25% anhydrous ethanol, 75% gasoline).

It must be emphasized that for each application the specific equivalences (gasoline:ethanol) related to the technology employed must be considered. In general, most applications in the world (in the near future) will be using gasoline–ethanol blends, lower than 10% ethanol so that an equivalence of ~1:1 is acceptable. In Brazil, ethanol is mainly used as E25 blends, for which we adopted an equivalence of 1 L ethanol (anhydrous) = 0.8 L gasoline. However, here again the data presented allows for the use of other hypotheses for comparison.

For bagasse, we considered the substitution of bagasse fired boilers (79% efficiency, LHV) for oil fired boilers (92% efficiency, LHV), which is the most significant application in Brazil. For electricity, the analysis was based on the world average emission factors for power generation considering both scenarios (2005 and 2020). According to IEA evaluations [28], the world emission factor for power generation in 2002 was ~579 t CO_2 eq GWh^{-1}; for 2030, IEA estimates total emissions of ~16.9 G t CO_2 eq for a total generation of 31,657 TWh, which would lead to an emission factor of ~535 t CO_2 eq GWh^{-1}. Taking 2002 and 2030 values as reference, it was adopted, arbitrarily, an emission factor of 560 t CO_2eq GWh^{-1} for the 2020 scenario. These are not standard baselines used for computing carbon credits (within the CDM); actually there has been much controversy about the baselines in Brazil. They are used here because they indicate clearly the mitigation obtained with the ethanol production and use, as related to the global emissions. Comparisons with other standards can be made from the data presented.

5. Results

5.1. *Energy balance*

Table 9 shows the fossil energy consumption regarding production, harvesting and transportation of sugarcane. Taking 2005/2006 values, the fossil energy required to produce 1 t of cane is 210 MJ, while, for 2002 evaluation, this value was estimated in almost 202 MJ. This difference is small, but important differences can be seen in energy use distribution; the main reasons are the updating of embodied energy coefficients and diesel consumption for cane production. For the 2020 scenario, a considerable increase is expected (to 238 MJ), mainly due to diesel consumption associated to the growth of mechanical harvesting and trash recovering. Furthermore, higher levels of agricultural machinery utilization will lead to higher values of embodied energy. Higher utilization of residues in ferti-irrigation, however, will lead to significant reductions of mineral fertilizers demand.

In ethanol processing evaluation (see Table 10), the differences in value from 2002 analysis correspond mainly to the updating of embodied energy coefficients, chemicals use and mill scale. But for 2020 scenario few changes are expected, related only to the improvement of ethanol yield.

The total energy produced in industrial phase (result of the sum of ethanol and the surpluses of bagasse and electricity energy flows) is presented in Table 11, with a comparison with

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Table 9 – Fossil energy consumption (MJ tc^{-1}) in sugar-cane production, harvesting and transportation

Item	2002[a]	2005/2006	Scenario 2020
Agricultural operations	16.4	13.3	14.8
Harvesting	21.7	33.3	46.9
Cane transportation	39.0	36.8	44.8
Inputs transportation	4.0	10.9	13.5
Other activities		38.5	44.8
Sub total	81.0	132.8	164.8
Fertilizers	66.5	52.7	40.0
Lime, herb., insect.	19.2	12.1	11.1
Seeds[b]	5.9	5.9	6.6
Sub total	91.6	70.7	57.7
Machinery	29.2	6.8	15.5
Subtotal	29.2	6.8	15.5
Total	201.8	210.2	238.0

[a] [6].
[b] Energy for seeds corresponds to 2.9% of total for cane.

Table 10 – Fossil energy consumption (MJ tc^{-1}) in the production of ethanol

Item	2002[a]	2005/2006	Scenario 2020
Chemicals and lubricants	6.4	19.2	19.7
Edifications	12.0	0.5	0.5
Equipments	31.1	3.9	3.9
Total	49.5	23.6	24.0

[a] [6].

Table 11 – Energy balance, external flows (MJ tc^{-1})

	2002[a]	2005/2006	Scenario 2020
Cane production/transportation	201.8	210.2	238.0
Processing to ethanol	49.5	23.6	24.0
Fossil input (total)	251.3	233.8	262.0
Ethanol	1921.3	1926.4	2060.3
Bagasse surplus	168.7	176.0	0.0
Electricity surplus[b]	0.0	82.8	972.0
Renewable output (total)	2090.0	2185.2	3032.3
Renewable output/fossil input			
Ethanol+bagasse	8.3	9.0	7.9
Ethanol+bagasse+electricity	8.3	9.3	11.6

[a] [6].
[b] The values for electricity surplus are 9.2 and 135 kWh tc^{-1} for 2005/2006 and 2020, respectively. Considered thermal-electricity equivalences were 9 MJ kWh^{-1} (2005) and 7.2 MJ kWh^{-1} (2020).

Table 12 – Emissions not derived from fossil fuels use (kg CO_2 eq tc^{-1})

	2002[a]	2005/2006	Scenario 2020
Methane (trash burning)	6.6	5.4	0.0
N_2O (trash burning)	2.4	1.8	0.0
N_2O (N fertilizers, residues)	6.3	8.9	8.6
CO_2 (urea, lime)		3.4	3.0

[a] [6].

fossil energy demands. In order to facilitate comparisons with other biofuels these flow values are presented separately. The fossil energy demand decrease and the increasing of electricity surplus lead to significant alterations of energy ratios between 2002 and 2005/2006, leaving from 8.3 to 9.3. For 2020, a more significant increase is expected (to 11.6), when electricity surplus will reach 135 kWh tc^{-1}, consuming all bagasse and still a portion (40%) of the trash. Eventually, higher levels of trash could be used for power generation, which would enable even higher enhancements in energy ratio.

5.2. *GHG emissions balance*

In cane production significant alterations in the emissions pattern are expected in the coming years, essentially by reductions in trash burning (see Table 12). From 2002 to 2005/2006, however, the large difference is associated to the incorporation of N_2O emissions from agriculture/industrial residues that are returned to soil and CO_2 emissions from lime and urea application (in the occasion of 2002 analysis the main N-fertilizer was of NH_4 type). For the 2020 scenario, the banishment of trash burning and the reduction of mineral fertilizers application will lead to drastic emissions reduction, although there might be a small increase of emissions associated to the residues that are returned to soil (once again it must be stressed that such values were obtained from "default" emission factors suggested by IPCC). In short, the emission not derived from fossil fuels use would be reduced from 19.5 kg CO_2 tc^{-1} (in 2005/2006) to 11.6 kg CO_2 tc^{-1}, in the 2020 scenario.

In the ethanol production phase (industrial process), many changes were verified in comparison to the 2002 data (because of the differences in energy use), but small changes are foreseen for the 2020 scenario—from 2.15 kg CO_2 tc^{-1}, in 2005/2006, to 2.19 kg CO_2 tc^{-1}. Considering both agricultural and industrial phases, the total emissions of hydrous and anhydrous ethanol production for 2005/2006 were evaluated as 417 and 436 kg CO_2 eq m^{-3}, respectively. For the 2020 scenario the estimates are 330 kg CO_2 eq m^{-3} hydrous and 345 kg CO_2 eq m^{-3} anhydrous; the contribution of each source is presented in Table 13.

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Table 13 – Total life cycle GHG emissions (kg CO_2 eq m^{-3}-ethanol hydrous or anhydrous)

Year	2002[a]		2005/2006		Scenario 2020	
Ethanol	Hydrous	Anhydrous	Hydrous	Anhydrous	Hydrous	Anhydrous
Total emissions	390	401	417	436	330	345
Fossil fuels	217	223	201	210	210	219
Trash burning	102	105	80	84	0	0
Soil emissions	71	73	136	143	120	126

[a] [6].

Table 14 – Avoided emissions (kg CO_2 eq m^{-3}-ethanol hydrous or anhydrous)

Year	2002[a]		2005/2006[b]		Scenario 2020		
Ethanol[c]	HDE	E25	HDE	E25	HDE	FFV	E25
Avoided emissions	2190	2401	2181	2323	2763	2589	2930
Use of biomass surplus[d]	141	145	143	150	0	0	0
Electricity surplus[e]	0.00	0.00	59	62	784	784	819
Use of ethanol[f]	2049	2256	1979	2111	1979	1805	2111

[a] Based on [6]. The equivalence for HDE was considered here as 1 L ethanol = 0.75 L gasoline, and not 0.7. For E25, it was considered an equivalence of 1 L anhydrous ethanol = 0.8 L gasoline, instead of 1 (L et.) (L gas.)$^{-1}$.

[b] Gasoline heating values for 2005 (Brazil) are from the official Brazilian Energy Balance [16].

[c] HDE: hydrous-dedicated engines; E25: ethanol–gasoline blend with 25% anhydrous ethanol; FFV: flexible fuel vehicles (ethanol–gasoline), in Brazil.

[d] Considering the substitution of biomass-fuelled boilers (efficiency = 79%; LHV) for oil-fuelled boilers (efficiency = 92%; LHV).

[e] Considering emission factors of 579 and 560 t CO_2 eq GWh_e^{-1} for 2005 and 2020, respectively. See details in text (Section 4).

[f] Using the equivalencies listed in Section 4; note that in each case the ethanol–gasoline technical equivalence for the specific utilization must be considered.

Analyzing the avoided emissions for 2005/2006, ethanol and co-products use in substitution of fossil resources represent savings of 2181 kg CO_2 eq m^{-3} hydrous and 2.323 kg CO_2 eq m^{-3} anhydrous (see Table 14). In the 2020 scenario the possibility of hydrous ethanol use in FFV lead to emission avoidances of 2589 kg CO_2 eq m^{-3} hydrous, while for ethanol-dedicated engines this value would be 2763 kg CO_2 eq m^{-3} hydrous. For anhydrous ethanol, used in blends with gasoline (E25), the total avoided emission would be 2930 kg CO_2 eq m^{-3} anhydrous. Here we must remember the large contribution of surplus electricity to the total avoided emissions.

The net avoided emissions associated to ethanol utilization in Brazil may be then evaluated. For sugarcane ethanol we have verified values of 1764 kg CO_2 m^{-3} hydrous and 1886 kg CO_2 m^{-3} anhydrous, but with much more potential for the 2020 scenario, reaching 2433 kg CO_2 m^{-3} hydrous (2259 kg CO_2 m^{-3} considering FFV) and 2585 kg CO_2 m^{-3} anhydrous through the better use of sugarcane's energy (higher levels of electricity surplus) coupled with the banishment of trash burning practices.

The energy flows and GHG emissions are presented in Fig. 2 for 2005/2006 and Fig. 3 for the 2020 scenario.

5.3. *Sensitivity analysis*

As showed in Fig. 4, trash burning and N-fertilizers ~~used to~~ play an important role in GHG emissions, while diesel consumption in agriculture is a decisive parameter for energy balance and with a considerable contribution for emissions also. On the end use, besides the large emissions avoidance allowed by the use of ethanol substitution for gasoline, there is a considerable additional contribution with the use of bagasse in biomass fuelled boilers (replacing oil-fuelled boilers) and/or producing electricity surpluses. All these aspects have a considerable range of variation among the more than 400 Brazilian mills, leading to large differences in energy and emissions balances. For this reason, a sensitivity analysis was performed considering the ranges verified for the sample of mills used in this work. Table 15 shows the parameters used in the analysis and their ranges of variation.

The individual impacts of each of the main parameters variation were evaluated separately, although of course there are interactions between many (for instance, the percentage of unburned cane and the level of mechanical harvesting). The individual results, therefore, are not to be added up. As can be seen in Figs. 5 and 6, ethanol yields and cane productivity are the most impacting parameters for both energy and emissions balance. Ethanol yield has larger specific impact on the balances, but since the range of

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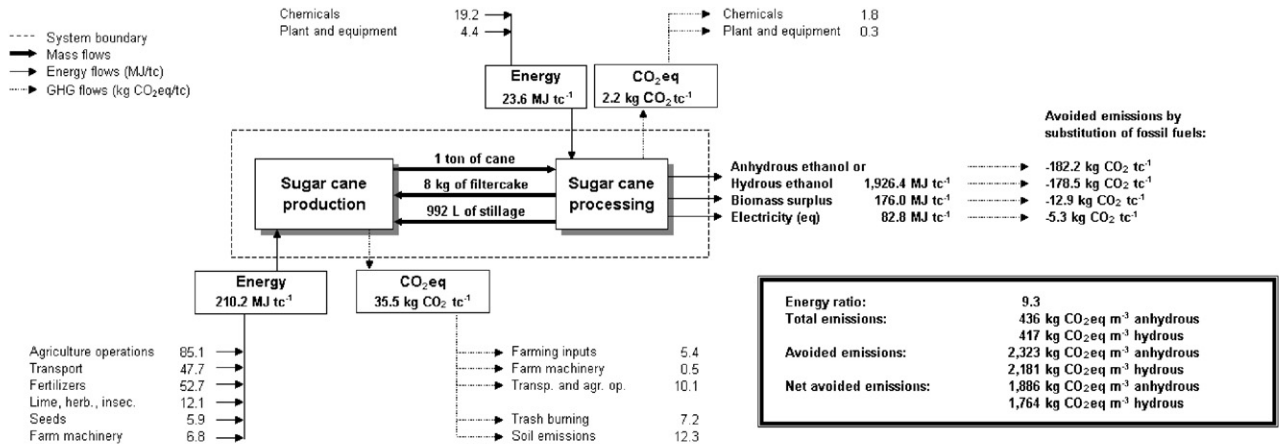

Fig. 2 – Energy flows and GHG emissions in ethanol production and use for 2005/2006 (tc = ton of cane).

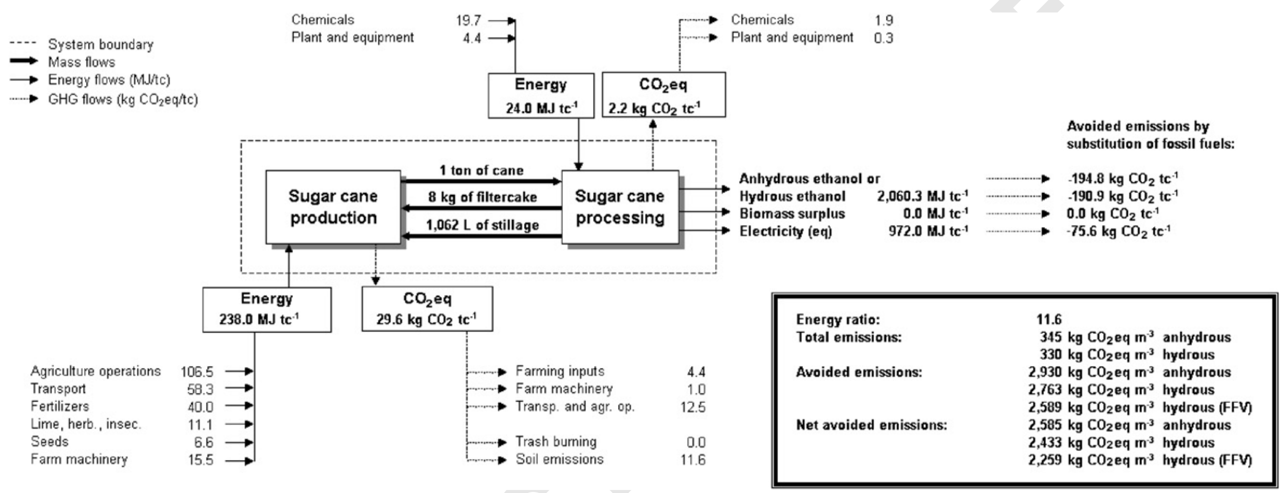

Fig. 3 – Energy flows and GHG emissions in ethanol production and use for 2020 scenario (tc = ton of cane).

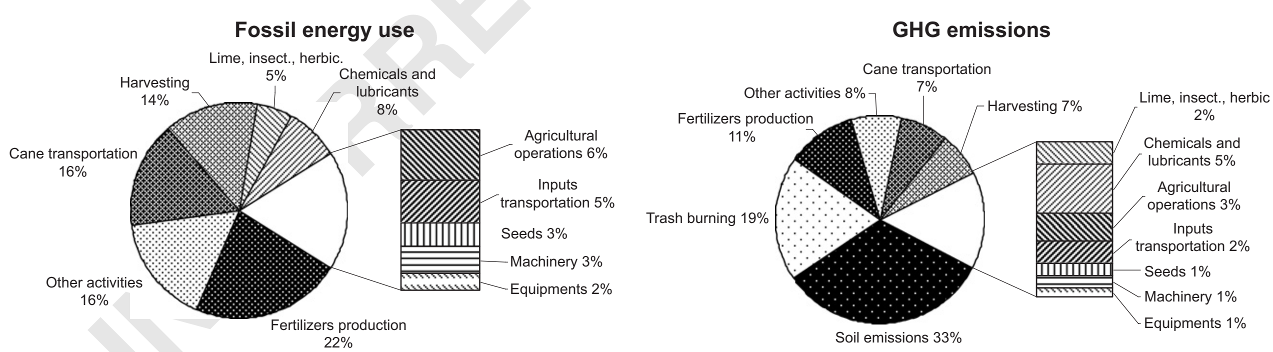

Fig. 4 – Fossil energy use and GHG emissions breakdown (2005/2006 values).

variation of cane productivity is far higher, it leads to higher final impacts (GHG emissions vary from 377 to 586 kg CO_2 (m^3 ethanol)$^{-1}$). The high range of variation for electricity surplus, however, presents a relatively low impact on energy ratio and avoided emissions.

For the parameters considered, individually, the maximum variation of energy ratio has been from 6.7 to 11.0, following the variation of cane productivity. Such range seems to be high, but, in fact, it represents just a small variation of fossil energy savings—from 85% to 91% (actually, above an ER of 6.0, even high variations would result in small alterations of fossil energy savings—see Fig. 7). This small variation in fossil energy savings is reflected on net avoided emissions, which, for such range, varies from 1736 to 1945 kg CO_2 m^{-3} of anhydrous ethanol. Higher variation of net avoided emissions

Table 15 – Parameters considered for sensitivity analysis (2005/2006 values)

Parameter	Units	Average	SD[a]	Min.	Max.	No. of mills	Cane[b]
N-fertilizer use	kg N (ha ano)$^{-1}$	60	16	35	97	31	72.52
Trucks' energy efficiency	t km L^{-1}	52.4	9.7	38.9	74.3	36	80.83
Transportation distance[c]	km	23.1	6.1	9.3	39.0	39	84.50
Mechanical harvesting	%	49.5	27.1	0	87.7	44	98.59
Other agr. activities	L ha^{-1}	67	38	2.7	136	27	67.23
Unburned cane	%	30.8	21.7	0	87.7	44	98.59
Cane productivity	tc ha^{-1}	87.1	13.7	51.3	119.8	44	98.59
Ethanol yield	L tc^{-1}	86.3	3.5	78.9	94.5	41	43.71[d]
Bagasse surplus	%	9.6	6.4	0	30.0	30	29.48[d]
Electricity surplus[e]	kWh tc^{-1}	9.2		0	50.0	22	28.61[d]

[a] Standard deviation.
[b] Mt year^{-1}.
[c] For cane transportation; this parameter is reflected on inputs transportation either.
[d] In the case of industrial parameters, for weighted averages calculation we have considered only the amount of cane used exclusively for ethanol production.
[e] Since the average value was obtained elsewhere (Cogen's estimation [15]), it was not possible to evaluate the standard deviation.

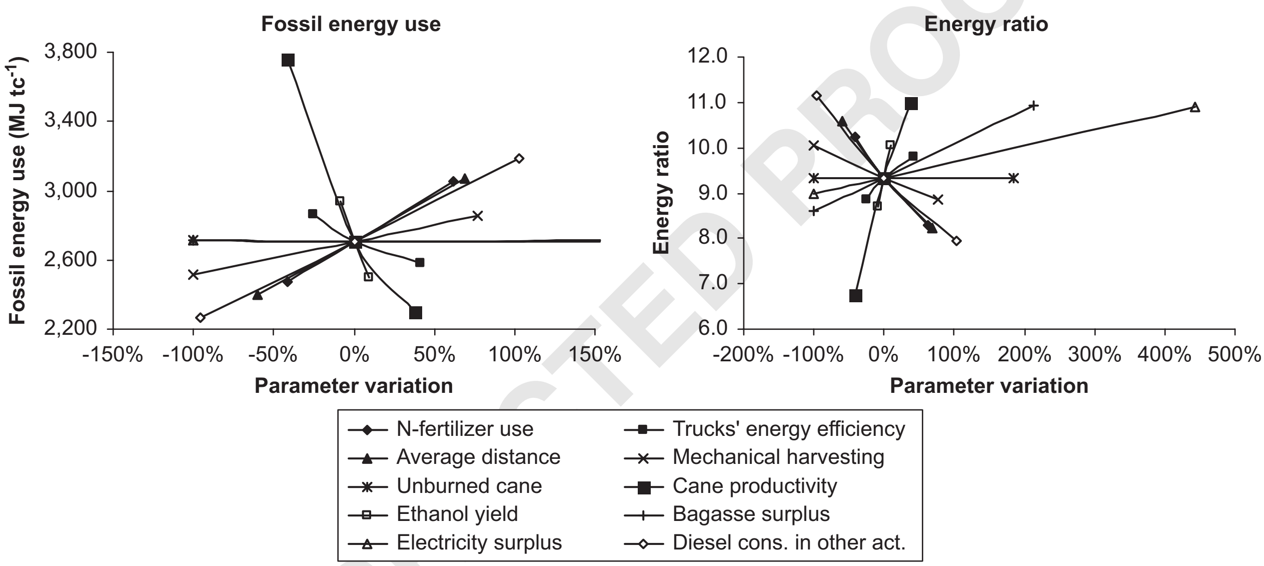

Fig. 5 – Sensitivity analysis for energy balance (2005/2006 values).

is from 1736 to 2205 kg CO_2 m^{-3} for anhydrous ethanol, verified for the different levels of bagasse surplus.

Considering the assumptions made here, the adoption of modern technologies for power generation (high-pressure CEST systems—condensing extraction steam turbines) associated to smaller process energy demands (lower steam consumption) would be much more effective to increase net avoided emissions than the reduction of diesel use in agriculture, or even some trash burning reduction, for instance. Even though the values presented are associated to local assumptions, there is no doubt about the importance of the better use of sugarcane's energy for further improvements of the already huge potential of ethanol as a good alternative for GHG emissions mitigation.

6. Conclusions

- A time series of studies on ethanol from cane have consolidated the data and refined the methodology, since 1992. The methodology used here includes a more detailed computation of fossil fuel use in agriculture; the N_2O emissions from soil with residue recycling (stillage, filter cake, sugarcane trash); and the emissions from agricultural and industrial input materials and processes have been updated.
- The methodology uses the stand-alone ethanol mill as a model. Data obtained for combined sugar and ethanol production considers the allocation issues for the industry (energy consumption, equipment, inputs) and agriculture (residue recycling).
- Significant process changes, including the phasing out of cane burning (in course) and the increase in surplus

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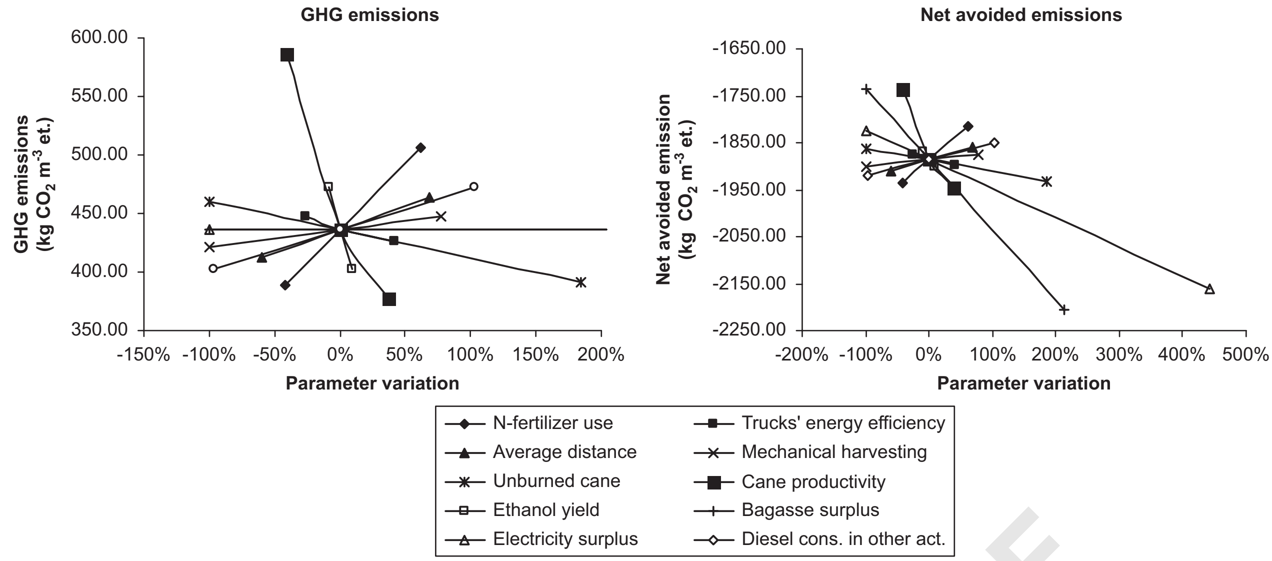

Fig. 6 – ~~Sensitive~~ analysis for GHG emissions balance (2005/2006 values).

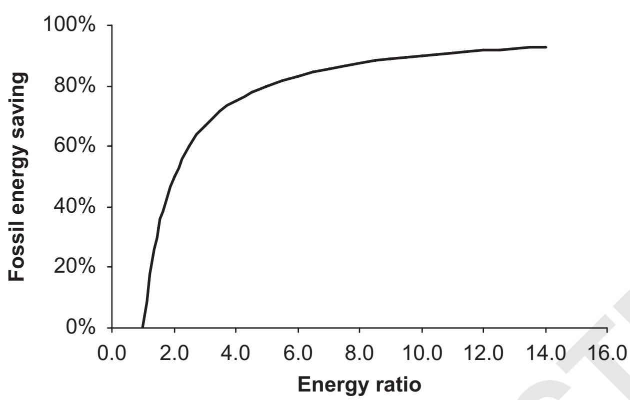

Fig. 7 – Relation between energy ratio and fossil energy savings.

electricity are already shown in the results for 2005.

- The extension of improvements in cane growing and harvesting, as well as the more efficient use of cane biomass for electricity, will not only increase ethanol yield significantly over the next 14 years, but will also improve the net energy balance and reduce the GHG emission. One moderate scenario for 2020 (only commercial technologies, all surplus biomass used for electricity generation) presents average GHG emission of 345 kg CO_2 eq m^{-3} ethanol, compared to 436 in 2006; and energy ratio reaching 11.6 (9.3 in 2006).
- A sensitivity analysis based on actual data (2006) for 35 mills shows that both the energy ratio and the GHG total emissions in ethanol production (calculated for each parameter variation, independently) may vary significantly among the mills. The average energy ratio was 9.3 but it could vary from 6.7 to 11.0 (cane productivity, electricity and bagasse surpluses, diesel utilization were the most important factors). Average GHG emission was 436 kg CO_2 eq m^{-3} ethanol; values from 377 to 586 were found (cane productivity, N-fertilizer use and ethanol yield were the main factors). This is important as some mills are starting to consider ways for improving their energy ratio and reduce emissions.

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