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E2025 - BRAZIL'S ASPIRATIONS FOR A MASSIVE WORLDWIDE SUBSTITUTION OF GASOLINE BY 2025[1]

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ABSTRACT: In 2004, the Center for Strategic Studies and Management (CGEE), a Brasilia based think tank was commissioned by the Brazilian government to project and evaluate the possibilities of a massive expansion of sugarcane cultivation in order to substitute up to 10% of worldwide gasoline consumption with ethanol by 2025. This study and later updates were to develop mechanisms that should induce and guide the expansion in a sustainable manner. Our paper presents and analyzes the projections assumed in this "government-initiated" scenario. The historical development of sugar and ethanol production and the productivity increases are examined in order to better understand Brazilian projections and aspirations within that most dynamic agricultural subsector. With the envisaged expansion of sugarcane, questions arise concerning land zoning, technological developments, GHG mitigation and trade potentials as well as market demands for sugar, ethanol and their byproducts.

KEYWORDS: Sugarcane, Biofuel, Brazil

1 INTRODUCTION AND CURRENT DISCUSSIONS

Within alternative energies, biofuels play a very distinct role, since they are prone to suggest both, a markedly *alternative* as well as a *lifestyle and business as usual* option for the future of public and private mobility. That is why high hopes - and high subsidies - are attached to ethanol and biodiesel, those first-generation biofuels already in use for some time. And a great deal of research and hopes are also invested into second and third generations of ways to make use of biomass for mobility purposes. Currently, ethanol derived from sugarcane, corn, wheat or sugar-beet is undoubtedly the most prevalent biofuel. In 2009, the leading producers were the USA, with a production volume of 34 billion liters made from corn and Brazil with 25 billion liters made from sugarcane [1].

Future demand for fuels is very likely to rise globally, due to economic and demographic growth. And in order to develop substitutes for fossil fuels, large-scale governmental programs are designed for strategic reasons, namely increasing independence from OPEC countries, for economic reasons, because oil, natural gas and coal are expected to become more and more expensive, and last but not least for environmental reasons, in order to mitigate greenhouse gas (GHG) emissions. The latter is usually considered to be one of the crucial benefits of biofuel, even though the reduction potential differs largely between the various raw materials [2], [3], and [4]. However, regardless of short-term GHG and energy balances, the European Union postulated a 10% target for renewable energies in transport [5] by 2020, and the United States plans to increase its biofuels consumption from around 34 up to 136 billion liters by 2022 [1]. A minimum amount of GHG reduction that gradually increases over time is one of the central stipulations for the promotion of biofuels within those programs. Second thoughts have since arisen on both sides of the Atlantic because of the food vs. fuel debate and the expansion of the "frontier" into forests, wetlands and peasant and agro-forestry farming, but still it is to be expected that those and similar national goals and programs will create a huge global demand for further fossil fuel substitution through biofuels in the near future.

To this day, ethanol derived from sugarcane is the most promising, if not only biofuel on an industrial scale that will be able to comply with meaningful GHG requirements. Therefore, it is understandable that in Brazil, the sugar industry as well as the government are keen to play crucial parts in meet-

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ing those possible export demands. For 2025, the think-tank Centro de Gestão de Estudos Estratégicos (CGEE) has developed detailed scenarios aiming at substituting 10% of worldwide gasoline demand through ethanol made from Brazilian sugarcane. In the following, a closer look into those scenarios and a critical assessment of its assumptions will be based on historical developments as well as on similar outlooks and studies about the development of the Brazilian sugar and ethanol industry until 2025 and 2030.

2 HISTORICAL DEVELOPMENT OF THE ETHANOL SECTOR

This section describes the rise of the ethanol industry and depicts the developments that made Brazilian sugarcane one of the most successful agricultural products worldwide. The plant was brought to Brazil more than 400 years ago, and until today it is one of the most frequently cultivated primary products (only soybean and corn cover larger cultivation areas in Brazil). Industrialization and mechanization as well as modern breeding have helped to increase productivity and yields of sugarcane enormously, especially during the last 60 years. Until today, however, in Brazil a great deal of human labor is still used in cane-cutting, even though competition with mechanized harvesting is often only possible with an over-exploitation of workers. Further mechanization, stricter enforcement of labor laws, better education as well as migration to the towns and cities are likely to reduce the employment potential of the sugar complex substantially in the next few years.

2.1 First Oil Crises and the PROALCOOL Program

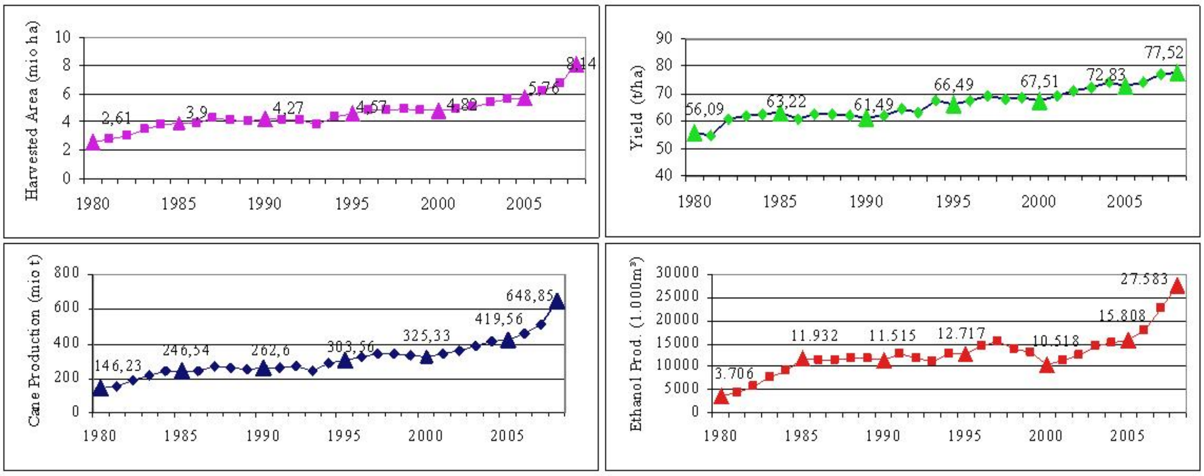
During the first oil crisis in 1973 that marked the end of cheap energy, Brazil was still heavily dependent on imports of fossil fuels which became manifested in the costs of oil imports that absorbed around half of all exports receipts. The oil price hike strained the Brazilian economy considerably, and it coincided with a sharp slump in international sugar prices so that substituting fossil fuel with ethanol made from sugarcane became the logical consequence [6].

The Brazilian government launched the National Alcohol Program (PROÁLCOOL) in 1975. In the beginning, sugarcane ethanol was used for low blending with gasoline (up to 10% ethanol) which was a fitting measure to quickly increase the demand for ethanol while basically no technological adaptations were needed [7]. In 1979, another coincidence spurred ethanol: The second oil crisis occurred around the time when the technical institute of the Brazilian air force developed an engine that could run on 100% hydrous (wet) ethanol, whereupon the international car companies with facilities in Brazil agreed to introduce that technology; the government guaranteed to look after supply, to boost demand with lower taxes on ethanol-fueled cars, and added other incentives. Although skeptical at first, by 1984 the consumers followed suit so that more then 90% of all new cars sold in Brazil were ethanol fueled [8]. The PROALCOOL program can be seen as a unique example for different stakeholders (government, automobile industry, sugar cane producers, research institutes, and PETROBRAS, the state-owned oil company) cooperating and adapting to exogenous occurrences by creating and supporting their own national market [9].

By the mid-1980s, the Brazilian economy had serious problems and the sugar complex in particular. Low world market prices for oil increased the costs of PROALCOOL, and the European Community dumped so much beet sugar on the world market that Brazil was no longer able to cover costs for that commodity. Other countries such as Cuba went out of the sugar business altogether. As the numbers in Figure 1 show, cane and ethanol production stagnated, but were kept alive by government intervention. After the promulgation of the new Constitution in 1988, all permanent subsidies were to be phased out leading to the official termination of the PROALCOOL program [10]. However, the ongoing blending of E10 – E20 saved the ethanol market from a complete collapse and the sugar complex from bankruptcy. Meanwhile deregulation and shrinking demand in the 90’s led to efficiency gains, market concentration and reduced production costs especially in the state of São Paulo [11].

2.2 The FFV Technology and rising demand for ethanol

In the early 2000s, oil prices began to rise again putting ethanol back in place. The development of so-called Flexible-Fuel Vehicles (FFV) in Brazil was another decisive factor of reawakening the interest in ethanol as an alternative to fossil gasoline, since that technology made it possible to run the engine on any blending of gasoline and ethanol. Apart from the regulation that mandated a blending of up to 25% ethanol with gasoline, the FFV's quickly dominated the domestic car market and by 2006 almost 75% of all new cars manufactured in Brazil were Flexible-Fuel Vehicles [12].



Source: AgriEnergy Statistical Yearbook 2009. MAPA Agroenergia.

Figure 1 Development Ethanol and Cane Production; Yields and Harvested Areas 1985 – 2008 [13].

Given competitive markets and new technologies, combined with a growing awareness and readiness to pay for substituting fossil fuels, with the record oil price in summer 2008 of over 140 US$ per barrel, more and more nations implemented incentive and regulatory systems and programs for bioethanol and biodiesel while at the same time, the very environmental-friendly character of those fuels became controversial. Figure 1 clearly depicts the strong impact of PROALCOOL. Distinct yield and production increases as well as expanding cultivation areas and a steady growth of ethanol production can be seen until 1985. Afterwards, the sector grew only slowly between 1990 and 2000, and between 1995 and 2000 a clear downturn can even be observed in ethanol production. Within the last decade and especially since 2005, the demand for sugarcane products rose again by more than 50% and ethanol production almost tripled between 2000 and 2008.

During the observed period, dramatic changes took place also in the international sugar markets. The Brazilians were the main protagonists who pressured so hard against the sugar export dumping of the EU at the World Trade Organization that beet sugar lost much of its internal support, and the price on the world market increased from around 6-8 US$ cents per pound around 1990 to 20-24 cts/lb in 2010/11. At that price range of sugar, the price of oil has to be markedly over 100 US$ per barrel in order to make a comparable profit. With production costs estimated at equivalently around 7 - 10 cts/lb for sugar and 50 - 65 US$/b for oil in the major areas of sugarcane production, both products promise very comfortable rents, and the bidding-up of land prices and growing interest of international investors are a logical consequence. However, when it comes to decide over a firm's offer to supply ethanol or sugar, it is the opportunity cost which counts so that the value of the lost opportunity to sell sugar determines the costs of ethanol, and vice versa. It already happened recently that Brazil had to import ethanol, because the *usineiros* (sugar facility owners) preferred to make sugar and sell it on the world market. In general, calories in the form of human food, and mostly also of animal fodder, are likely to be treated as more "noble", i.e. higher-valued than fuel. That is why ethanol from molasses (sugar juice) is not necessarily a viable option for massive future expansion on the global fuel markets.

2.3 Latest Developments

In comparison to the 1970s and 80s, when ethanol production was boosted and supported by PROALCOOL, today's sugarcane complex is far more profitable. World market prices for oil and sugar, but also for other agricultural goods are at a long time high, and international demand for commodities and alternative energy carriers is continuously increasing. Even the tariffs of 14 US$ cents in the US and 19 Eurocents per liter on ethanol at the European Union's borders are being questioned and might be removed, once the Doha Round negotiations at WTO should come to a positive end.

In the whole world, research and development as well as scientific and technological progress are leading to new applications creating new markets and new demands for all kinds of biomass. Latest developments are to be seen not only within the field of energy production but also within the whole range of material utilizations in biorefineries. Various biotechnology laboratories and companies are currently examining new applications for sugarcane. For example, research and development is being done on genetically modified yeasts that will convert sugar into diesel fuel and also provide other alternatives to petroleum based chemicals. The produced diesel would not only have higher energy content than ethanol but it would also enjoy a huge internal market since fossil diesel consumption in Brazil is more than double that of gasoline [14]. More research has been done in other areas such as electricity generation (including e-mobility) and – above all - enzymatic hydrolysis of bagasse and the whole sugarcane plant, mostly termed “second-generation” biofuel [15]. Those examples can only give a glimpse of the volumes and demands the sugarcane complex might be facing in the future.

Finally, sugarcane is becoming again a magic plant in that it is the world’s champion in the absorption of carbon dioxide and other GHGs per hectare and year. Of course, that status only applies as long as it is not counterbalanced with the negative effects of deforesting and wetland drainage. However, once those environmental services are monetized and internationally traded, an important additional benefit or “output” is added to sugar, ethanol and bagasse biomass, making the advance of cane plantations an even more probable – promising as well as menacing - development in Brazil. Along that path or better: highway, severe problems are likely to be encountered, such as the expansion of monoculture, rivalries of land and water usage, deforestation and degradation of soils as well as loss of biodiversity [16],[17], [18], all of which are also of global interest.

3 PRESENTATION OF THE CGEE STUDIES

In 2005, the Center for Strategic Management and Studies (CGEE) published a study about the Brazilian biofuel sector and its perspectives. The focal point was the importance of the ethanol production chain for the Brazilian economy and its perspectives on the global fuel market [19]. CGEE is a “think tank” related to the Brazilian Federal Ministry for Science and Technology, which finances and executes different kinds of projects and studies that are considered “strategic” for the country. Thus, in 2007 CGEE conducted a further study which aimed to prepare the country for a massive expansion of ethanol production in order to satisfy both domestic and foreign demands in a sustainable way. It postulates an efficient and sustainable utilization of the country’s resources in order to substitute up to 10% of worldwide gasoline consumption through Brazilian sugarcane ethanol by 2025 [20].

It is perhaps worth mentioning that between 2003 and 2005, the current Brazilian President Dilma Rousseff was the Federal Minister of Mining and Energy, and, after that, between 2005 and 2010, chief of staff of the Presidency under President Lula. Therefore, it is likely that most of these studies were conducted with the knowledge of Dilma Rousseff herself or at least of some persons belonging also to the present Government, which might indicate continuing support for the project ideas.

3.1 Approach of the CGEE studies

The studies take data from the National Energy Information Center (NEIC) of the United States for the future demand for gasoline. The NEIC projects a worldwide gasoline consumption of 1.7 trillion liters annually by 2025, which would represent an increase of 48% in comparison to 2005. Considering the difference in calorific content between gasoline and ethanol (anhydrous ethanol has about 75% of the calorific content of gasoline) and also the motor efficiency, the study calculates that it would be necessary to produce 205 billion liters ethanol in order to substitute 10% of the worldwide gasoline consumption by 2025, which would be equivalent to 170 billion liters of gasoline. Based on the productivity levels of 2005, it would be necessary to cultivate around 35 million hectares of sugarcane in order to produce such a quantity of ethanol [19]. The agrarian productivity that corresponds to the amount of sugarcane per hectare was defined at 70 t/ha whereas the industrial productivity, i.e. ethanol per processed ton of sugarcane, was calculated with 85 l/t. Thus, the overall productivity can be specified with 5.950 or roughly 6.000 liters of ethanol per harvested hectare of sugarcane.

The methodology used is based on the fact that Brazil has a total area of about 852 million hectares, of which about 400 million ha correspond to the size of the Amazon forest, 14 million ha to the Pantanal region and 3.5 million ha to the Atlantic Forest. Besides that, 75 million ha present an unsuitable declivity for mechanization, which is an important figure, since mechanized harvesting is already applied in the majority of current sugarcane expansion areas and will certainly increase in the future [21]. After all, there are approx. 360 million ha theoretically available for sugarcane cultivation. The studies point out that Brazil could designate more than 80 million ha of available area for sugarcane production, which would result in a production of over 5 billion tons of sugarcane [20]. This calculation leaves room for a certain amount of crop rotation and also for a total of 8.5 million hectares or more for sugar.

The new areas would require viable characteristics of soil and climate but should not be allowed to encroach on preservation areas, nor should they endanger food production, although it is obvious that such an expansion would lead to significant displacement effects. However, CGEE stresses that the investment in large-scale agriculture might have beneficial job creation effects in the respective areas and would lead to a decentralization of sugarcane cultivation. Thus it identifies 17 areas in Brazil which would encompass around 42.2 million hectares and would be sufficient to develop the project and to arrive at the envisaged 205 billion liters per year.

It is interesting to note that most of the expansion should take place in the Center West as well as in the Northeast regions. The Center West is the region in which most of the recent increase has taken place and where large areas are technically apt, whereas the choice for the Northeast represents primarily a social aspect of the project, given that this is the poorest region of the country. One important criterion used was the selection of sample areas mainly in states where there is still little or no sugarcane production. Regions in the Amazon forest and the wetlands of the Pantanal are to be strictly off-limits [19]. This mapping suggests a rather smooth and sustainable expansion of sugarcane cultivation.

Responding to national and international concerns about the expansion of the sugarcane frontier, the Brazilian government introduced sugarcane zoning (Zoneamento Agroecológico da Cana-de-açúcar - ZAE) in 2008 [22]. The objectives were to provide a technical instrument identifying the aptness and location of appropriate areas and to rebuke criticism from abroad. The document shows 65 million ha of land categorized as areas with high, medium and low suitability for sugarcane. However, it has to be understood that the ZAE zoning is an indicative, not a binding land use planning instrument.

3.2 Technology Scenarios

The CGEE studies develop four different scenarios. "*No technology adoption*" represents the continuity of 2005's productivity level until 2025 (no hydrolysis implementation). The second scenario, "*Cautious technology adoption*", indicates a slow introduction of optimization processes in the distilleries and the introduction of hydrolysis only in 2015. The third scenario, "*Progressive technology adoption*", assumes a faster implementation of optimization technologies, the adoption of hydrolysis stage I in 2010 and the adoption of hydrolysis II in 2020. Finally, the fourth scenario, "*100% technology adoption*", hypothesizes that already in 2015 all distilleries constructed from that year on will be equipped with the most efficient technologies (including hydrolysis). The clue of that technology is the conversion of the total plant or its residual bagasse into fuel. The studies indicate that the most probable scenario would be the "*Progressive technology adoption*" [20] which would result in yields of 124.3 liters of ethanol per ton of sugarcane by 2025 (92.5 liters from the plant and 31.8 liters through hydrolysis). A great volume of biomass is left for the generation of electricity. With the overall production of 205 billion liters in 2025, the studies project a surplus of 106 TWh, i.e. equivalent to 28.3% of Brazil's total electricity consumption in 2005 [20].

3.3 Market Developments

The studies analyze the scenarios about production and consumption of both sugar and ethanol. Estimates show that Brazil will have up to 50 million automobiles by 2025, of which more than 46 million will be cars and light trucks. The participation of flex-fuels cars in total car sales is expected to level at 85% by 2025. Thus the total domestic demand for ethanol is assumed to be 41 billion liters, which would equal an area of 8.5 million ha of sugarcane (at 2005's productivity level). Likewise, the export projections for 2025 would be 164 billion liters which would require 26.5 million ha of sugarcane cultivation.

Regarding the sugar market, an expansion of the sugar production in accordance with the future development of both domestic and international markets is calculated. The *per capita* sugar consumption in Brazil is considered to be dependent only on the population growth, i.e. around 1%. The export of sugar is expected to rise by 2% p.a. These two factors together should result in an increase of 235% of Brazilian sugar production by 2025 in comparison to 2005, expecting a total demand of 61.5 million tons of sugar by 2025/2026. Productivity increases are assumed up to 111.7 t/ha sugarcane until

2025, and the overall sugar yield is to amount up to 138.6 kg per ton of sugarcane. Around 4.5 million ha of new land will be needed in order to satisfy the estimated future demand for sugar summing up to a total of 8.5 million ha [20].

3.4 Impacts of the Expansion - Sustainability

Sustainability is discussed in order to evaluate the environmental, economic and social impacts of the massive expansion of the Brazilian sugarcane and ethanol production. The idea is to set the basis for a future certification process, which would be required by the main importing markets as is already happening. Due to the lack of an international certification system for biofuels in 2005, the relevant study used the methodology developed by the Dutch Parliament for imported and domestically produced biofuels [20]. Sixteen criteria were listed and aggregated in six main topics: GHG emission; competition between food, energy and other utilizations, biodiversity, wealth, human welfare and environment [20]. Just to exemplify, in the point about GHG, the study calculates the energy balance of ethanol, indicates an input-output relation of 8.3 in 2004 and projects an increase to 11.5 by 2020 [20]. None of the criteria listed above are considered problematic by the study. Only some precautionary suggestions are made, indicating that more investments should be made in education, security and against corruption.

Current Demand – Sugarcane Area		
2010	4.0 million ha	Ethanol Production
2010	4.0 million ha	Sugar Production
Additional demand – CGEEE scenario (Productivity Levels of 2005)		
2025	31.0 million ha	Ethanol Production
2025	4.5 million ha	Sugar Production
TOTAL in 2025	43.5 million ha	Sugarcane Area

Table 1 Expansion of Sugarcane Cultivation Areas

3.5 Summary of the CGEE Studies

Today, Brazil cultivates around 8 million ha with sugarcane, from which about 50% is converted into ethanol and 50% into sugar. In order to reach the 10% substitution scenario, the area has to quintuple from today’s levels until 2025. The CGEE denominates 17 areas mostly in the Northeast and Center regions of 42.2 million ha that are presumed to be suitable due to “high” and “good” productivity levels in terms of soil and climate. However, later indicative zoning by the government did not comply with these suggestions but indicated wider areas which would be apt for sugarcane totaling 65 million ha. Here, the most suitable expansion areas were identified close to the traditional sugar areas in the Center and South states. According to the CGEE studies, sustainability does not pose major problems. However, propositions regarding better public policies in some areas are made with a special emphasis on technological developments and access to export markets.

4 FURTHER STUDIES AND THE RELEVANCY OF GHG REDUCTIONS

In order to analyze whether the assumptions of the CGEE scenarios are realistic and what they imply, this section takes a closer look into the projections of a study conducted by the Ministry of Mines and Energy (MME) as well as the development of GHG reduction-induced demand in order to identify further drivers and barriers for ethanol and sugar production. In 2009, the MME estimated that around R$ 50 billion (€ 22 billion - June 2011) will be invested in the biofuel sector between 2008 and 2017; R$ 40 billion into the ethanol production and R$ 9 billion into infrastructure [11]. Evidently, an expansion strategy of a size up to 35 million ha of newly cultivated sugarcane areas requires an enormous amount of capital and prudent risk management and planning.

4.1 The “National Energy Plan 2030” projections

Already in 2007, the MME formulated the “National Energy Plan 2030” projecting the development for all relevant energy carriers as well as the possible composition of the Brazilian energy matrix until 2030 [23]. The years of reference are 2005 and 2030. Its projections foresee a steady growth rate between 6 and 9% until 2020. Within the last decade, the growth rate will slow considerably so that the overall projection for 2030 amounts to 62 billion liters with a total cultivation area of sugarcane of 14 million ha. The expansion will take place modestly in the Northeastern states from 1.0 to 2.4 million ha, compared to the Center and South states where the cultivation areas will increase from 4.6 to 11.6 million ha. Yet, productivity will increase significantly in the former and only modestly in the latter. They also project a sharp increase in the overall ethanol yield in liters per ton of sugarcane. Yet, the largest advancement is expected to be ethanol by hydrolysis conversion. Those projections start only in 2010 with 130 million liters of ethanol and spurt up to 7.1 billion liters in 2030. Only due to that increase, Brazil can produce the 62 billion liters of ethanol in 2030 (of which 11% are hydrolysis ethanol).

Ethanol exports are expected to peak in 2020 with 18.6 billion liters and are then to decline significantly to 9.6 billion liters in 2030, whereas the domestic consumption will rise continuously from 13.5 in 2005 up to 52.5 billion liters in 2030. The Plan explains the decrease of ethanol exports by the small growth rates of ethanol production between 2020 and 2030, and the ever increasing domestic demand that would have to be satisfied first. Compared to the scenarios in the CGEE studies, the overall ethanol production is significantly smaller which might be explained by less ambitious goals and a smaller expansion area (205 billion liters versus 62 billion liters and 42.2 versus 14 million ha total sugarcane area). Another reason might be that the MME projections mirror the complete energy matrix until 2030 including other renewable energies like biodiesel as well as fossil energies such as natural gas and particularly domestic oil, which has recently raised very high expectations.

4.2 GHG Emissions and external demand effects of Certification

When it comes to the question of future external demand for sugarcane ethanol, one of the most crucial and most debated issues is its GHG and CO_2 reduction potential. As mentioned above, the two largest gasoline consuming markets in the world, namely the US and the EU, have very ambitious programs to reduce oil consumption and dependency, and to implement GHG mitigation measures. Biofuels are considered to be suitable substitutes, - but only if a meaningful reduction of CO_2 emissions can reliably be guaranteed. The amount of CO_2 absorbed and emitted along the life cycle is therefore an integral product feature of sugarcane ethanol and other biofuels. In order to guarantee a substantial reduction of GHG emissions, certification systems have already been implemented in the EU for biofuels, and future mandates in other countries are also depending on the overall GHG balance of biofuels when they are to substitute gasoline or diesel.

The CO_2 and GHG emission savings from different biofuels have been topics of fierce debates. In the early 2000’s, biofuels were claimed to be basically zero-CO_2 emission fuels, since they emit only as much CO_2 as they store during the growth periods of the plant. More diligent and sophisticated analyses of energy and emission life cycles followed, taking into account the whole production chain of fuels derived from biomass as well as the inputs and energies needed for those processes. Land Use Change (LUC) became a large issue calculating the conversion related emission when turning pasture or forests into crop land for biofuel purposes. Further indirect Land Use Change (iLUC) effects turned out to be even more difficult to identify and calculate [18]. However, in Brazil iLUC might present a crucial factor, whenever the expansion of the agricultural “frontier” into forest areas would lead to high GHG emissions from deforestation.

Since the beginning of 2011, Germany and Austria have already implemented certification systems that require specific product features as well as production and cultivation compliances according to the renewable energy directive (RED) established by the EU in 2008. This Directive stipulates that the sustainability baseline shall at least be 35% GHG emission savings when compared to fossil fuels until 2017, rising up to 60% by 2018. Within a short period of time, all 27 EU countries will need to comply with this regulation [5]. In the US, a current mandate pushed by the Energy Independence and Security Act (EISA) calls for an increase of the use of biofuels up to 136 billion liters by 2022 (which represents up to 30% of today’s gasoline consumption). A portion of at least 14% of this figure has to come from so-called “advanced biofuel”, with a minimum GHG emission saving of 50% compared to gasoline, - and Brazilian sugarcane ethanol already qualifies for this category [1].

Sugarcane is not only the champion of all biofuel energy balances with its already-mentioned 9.3 input-output ratio, but also ranges first in the overall GHG emission reductions of all major biofuels [24], [25], [2]. However, the above-mentioned LUC and iLUC effects are normally left out in those calculations, and the byproducts of the production process are often not taken into consideration. That is why a huge demand can be expected by countries that mandated biofuel blending and consumption, once tariffs and other trade barriers would be removed. However, protests, boycott claims and reverse regulations can also be expected when the iLUC effects on forests and other vulnerable areas as well as the rise of food prices are rightly or wrongly attributed to biofuels.

4.3 Cogeneration and Carbon Trade

Sugar and fuel are not the only products of the sugarcane plant. The byproduct bagasse (fibrous waste after the sugarcane is crushed – around 30% of the total sugarcane) has manifold applications. Being burnt for generating steam and electricity ("cogeneration") is currently a largely favored option in Brazil, also by the electricity companies, since the main period of electricity production from bagasse is after the harvest during the Brazilian summer, which complements well with the hydro power season when the water levels are usually low. According to a 2007 report from CONAB (National Agricultural Supply Company), already 48 ethanol and sugar production facilities were connected to the national electricity grid feeding in excess energy from the cogeneration process [26]. The Brazilian Sugarcane Association UNICA estimates a potential of surplus in electricity production in 2020 which would contribute up to 15% of total electricity production in Brazil [27]. The MME Energy Plan projects that the consumption of sugarcane bagasse might increase around 300% between 2005 and 2030, if the bagasse would be used almost exclusively for energy purposes [28].

But as already mentioned, a much more promising utilization is the additional ethanol production from bagasse through hydrolysis and its use in biorefineries. Those are still rather medium-term technologies, but in any case, the GHG emission reduction potential of sugarcane offers significant additional benefits beyond sugar and fuel. Through the still incipient global carbon trade mechanisms, further monetization of these benefits is to be expected, such as eligibility for CDM (Clean Development Mechanisms) projects so that sugarcane would become even more profitable [25].

Concerning the ethanol production there are at present no CDMs or carbon credits, but the Brazilian Sugarcane Association is advocating the introduction of a domestic cap and trade system in Brazil [29], and several CDM cogeneration projects already exist. According to the latest compilation of the Federal Ministry of Science and Technology (MCT), there are 262 projects approved by the Brazilian Designated National Authority. Those projects have an installed capacity of 4032 MW of which more than 30% is cogeneration from bagasse [30]. So far, CDMs and carbon credits play only a marginal role for the sugarcane industry, but if more cogeneration projects will be approved and CDM initiatives are further promoted, the ability of sugarcane to absorb so much CO_2 and other GHGs might become an additional important driver for investments [31].

5 CONCLUSIONS AND FINAL ASSESSMENT

Looking at the situation of the Brazilian sugar and ethanol sector today and at the projections of future developments, four key factors can be identified as crucial for the crop and its products. First, the volume and location of the envisaged sugarcane expansion; second the technological advancements on all the stages of the production chains; third, the role and effects of the GHG mitigation potential of ethanol; and forth, the intertwining of the world markets for sugar, ethanol, oil and "carbon".

(1) The expansion of the sugarcane "frontier" has been a controversial issue for decades, if not centuries in Brazil. Incursions into forests, wetlands and agricultural areas by purchases, land-grabbing and planning have kindled a heated national and even global debate so that the Brazilian Ministry of Agriculture (MAPA) felt obliged to introduce "Agroecological Zoning for Sugarcane" (ZAE). The Amazon rain forest and the Pantanal wetlands were declared off-limits, and the most likely expansion areas were identified close to the already existing und traditional cultivation areas in the Center and South states. The "National Energy Plan" of the MME in 2007 made similar assumptions regarding the expansion within its scenario, whereas the scenarios of 2005/07 presented by the CGEE, explicitly denominated areas where no or little sugarcane had been cultivated before in order to "promote decentralization" of the sugar and ethanol industry; following the implicit assumption that Brazil still has vast tracts of underutilized fallow land that just needs to be cultivated. However, these plans and reports over-

look a vital factor, namely the right of every landowner to plant whatever he or she wants to grow. Of course, there are legal restrictions such as the forest and water protection laws, but *Zoning* is only indicative and not compulsory. With indirect incentives such as loan conditions for agricultural credit, a certain effect can, of course, be achieved, but zoning maps and off-limits declarations can not been taken as definite decisions. Thus it seems likely that the expansion into new cultivation areas will take place first in regions with an existing infrastructure and significantly higher productivity. If demands and other market incentives develop further, expansion into the projected "new" areas is likely to occur, but even restricted areas might be affected even if only by iLUC effects.

(2) The agrarian yields and the industrial productivity of the conversion processes will be defining the future potential and cost effectiveness of sugarcane ethanol. One of the most crucial developments seems to be hydrolysis applications in order to convert bagasse and other cane residues into additional fuel and thereby improving total yields and the overall energy and GHG emission balance. However, applying hydrolysis technology would significantly reduce the volume of bagasse as an input for cogeneration processes. Regarding the technological potential, it can be argued that the advancements will lead to a situation where tough competition for different sugarcane applications is ever more likely - resulting in additional pressure on land expansion.

(3) The GHG emission mitigation potential of sugarcane ethanol can be considered as a major driver for continuous promotion and a rising market demand. Within the coming decades, exports to the US and EU markets will be depending more and more on the percentage of GHG emission reduction sugarcane ethanol will be able to reach, since this is regarded as one of the key issues of certification schemes that will be applied on a larger scale. The debates on how to calculate the iLUC effects induced by displacement are still ongoing, and until today it is unclear how to integrate that parameter into the overall GHG balance of biofuels.

(4) Within the last few decades, not only the world market prices for oil, gasoline and ethanol oscillated widely but also the prices for sugar and other agricultural commodities were subject to dramatic changes and all-time highs. Since Brazil is by far the largest exporter of sugar worldwide, the price sensitivity of the ethanol and sugar industry is respectively high. Furthermore, Brazil is the only exporter that has a so called "switch capacity" (around 10%) which enables the industry to shift between sugar and ethanol production within a year responding to profitability changes between the two products [32]. Therefore, periodically Brazil has had shortages of ethanol, exporting more sugar when prices favored the latter. In general, the end of EU sugar dumping has meant that there is a certain bias to be expected in favor of sugar, as long as ethanol is made of sugar molasses, since calories in the form of food tend to be higher priced than fuel. However, with hydrolysis using the residues from sugar production for "second-generation" ethanol, the rivalry between sugar and ethanol might be resolved into a complementary production chain. On the other hand, if the high GHG absorption potential of sugarcane would be turned into monetary benefits only for fuel, and not for sugar, the opportunity cost calculation might turn into the other direction making also "first-generation" ethanol an economically viable commodity rivaling or even surpassing sugar on the world market.

Recent Brazilian studies on the expansion of ethanol production based on sugarcane show an enormous increase of cultivation areas within the coming two decades. The main drivers are rising prices for energy and food, technological advancements as well as expectations about growing global carbon trade, based on the outstanding potential of sugarcane to absorb CO_2 and other greenhouse gases. In Brazil, this is likely to lead to further land conflicts and pressure on vulnerable biome. Strict domestic regulation and international certification are to mitigate the negative impacts and to utilize sugarcane as a fruitful source of food, fuel and GHG mitigation effects. When it comes to envision future global use and demand for biofuels, additional national strategic objectives, such as energy security and the protection of domestic agriculture cannot be ignored when trying to complete the picture.

REFERENCES

[1] Crago, C.L.; Khanna, M.; Barton, J.; Guiliani, E.; Amaral, W.: Competitiveness of Brazilian sugarcane ethanol compared to US corn ethanol. Energy Policy 38, 2010.
[2] Cherubini, F. et al.: Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. Resources, Conservation and Recycling. Vol. 53, Issue 8, June 2009.
[3] Fritsche, U.; Wiegmann, K.: Treibhausgasbilanzen und kumulierter Primärenergieverbrauch von Bioenergie-Konversionspfaden unter Berücksichtigung möglicher Landnutzungsänderungen. Expertise im Auftrag des WBGU. Revidierte Endfassung. Berlin 2008.
[4] Searchinger, T. et al.: Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land Use Change. Published on *Science* Express, 7 February 2008.
[5] EC Directive 2008/0016 (COD) of the European Parliament and of the Council: Proposal for Directive on the promotion of the use of energy from renewable sources, 2008.
[6] Nitsch, M.; Hurtienne, T.; Freitag, H.; Borges, U.: PROALCOOL. Analyse und Evaluierung des brasilianischen Biotreibstoffprogramms. Saarbrücken: Breitenbach, 1984; updated Portuguese translation: PROÁLOOL. Economia política e avaliação sócio-econômica do programa brasileiro de biocombustíveis, Aracaju: UFS, 1988.
[7] Nitsch, M.; Giersdorf, J.: Biotreibstoffe in Brasilien. Diskussionsbeiträge des Fachbereichs Wirtschaftswissenschaft der Freien Universität Berlin. VOLKSWIRTSCHAFTLICHE REIHE. Nr. 12, 2005.
[8] Andrietta, M.G.S. et al.: Brazil, 30 years of PROALCOOL. International Sugar Journal, Vol. 109, 2007.
[9] Hall, J. et al.: Brazilian biofuels and social exclusion: established and concentrated ethanol versus emerging and dispersed biodiesel. Journal of Cleaner Production, 2009.
[10] Nass, L.L.; Arraes Pereira, P. A.; Ellis, D.: Biofuels in Brazil. An Overview; CropScience, Vol. 47, 2007.
[11] IPEA. Instituto de Pesquisa Econômica Aplicada – ipea 2010. Infraestrutura Econômica no Brasil: diagnósticos e perspectivas para 2025. Livro 6 – Vol. 1. Brasilia 2010.
[12] Moreira, J.R.: Brazil's experience with bioenergy. In: Hazell, P. and Pachauri, R.K. (eds.) Bioenergy and Agriculture: Promises and challenges. Focus 14. Int. Food Policy Research Institute. Washington D.C. 2006.
[13] MAPA, Ministry of Agriculture, Livestock and Food Supply. Secretariat of Production and Agrienergy: AgriEnergy. Statistical Yearbook 2009. Brasilia 2009.
[14] EPE, Empresa de Pesquisa Energética; MME, Ministério de Minas e Energia: Brazilian Energy Balance 2010. Base year 2009. Brasilia 2009.
[15] Rabelo, S.C., et al.: Ethanol production from enzymatic hydrolysis of sugarcane bagasse pretreated with lime and alkaline hydrogen peroxide. Biomass and Bioenergy 35, 2011.
[16] Martinelli, L. A., et al.: Sugar and ethanol production as a rural development strategy in Brazil: Evidence from the state of São Paulo. Agricultural Systems 104 (419–428), 2011.
[17] Goldemberg, J., et al.: The sustainability of ethanol production from sugarcane. Energy Policy 36 (2086– 2097), 2008.
[18] Lapola, D.M., et al.: Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Proceedings of the Nacional Academy of Sciences of the United States of America (PNAS). Vol. 107, No. 8. (3388–3393), 2010.
[19] CGEE, Centro de Gestão de Estudos Estratégicos: Estudo sobre as possibilidades e impactos da produção de grandes quantidades de etanol visando à substituição parcial de gasolina no mundo - Fase 1. Relatório final. Brasilia 2005.
[20] CGEE, Centro de Gestão de Estudos Estratégicos: Estudo sobre as possibilidades e impactos da produção de grandes quantidades de etanol visando à substituição parcial de gasolina no mundo - Fase 2. Relatório final. Brasilia 2007.
[21] Estado de São Paulo. LEI ESTADUAL Nº 11.241, de 19 de Setembro de 2002. Dispõe sobre a eliminação gradativa da queima da palha da cana-de-açúcar e dá providências correlatas, 2002.
[22] MAPA, Ministério da Agricultura, Pecuária e Abastecimento: Zoneamento Agroecológico da Cana-de Açúcar. Expandir a produção, preservar a vida, garantir o futuro. Rio de Janeiro 2009.

[23] MME, Ministério de Minas e Energia. Secretaria de Planejamento e Desenvolvimento Energético. Plano Nacional de Energia 2030 - Combustíveis Líquidos. Empresa de Pesquisa Energética. Brasília 2007.
[24] BNDES and CGEE: Sugarcane-based bioethanol. Energy for sustainable development. Rio de Janeiro 2008, p. 96.
[25] La Rovere, E. et al.: Biofuels and Sustainable Energy Development in Brazil. World Development Vol. 39, No. 6. (1026-1036), 2011.
[26] CONAB, Companhia Nacional de Abastecimento: Perfil do Setor do Açúcar e do Álcool no Brasil, Situação Observada em Novembro de 2007, abril/2008. Brasília 2008.
[27] Walter, A. et al. 2008: A Sustainability Analysis of the Brazilian Bio-ethanol. UNICAMP, Campinas 2008, p 27.
[28] MME, Ministério de Minas e Energia. Secretaria de Planejamento e Desenvolvimento Energético. Plano Nacional de Energia 2030 - Projeções. Empresa de Pesquisa Energética. Brasília 2007.
[29] Nelson, A.J.: Woodrow Wilson International Center for Scholars. Brazil Institute 2009. Special Report. Climate Change and Biofuels. Washington 2009.
[30] MCT, Ministério da Ciência, Tecnologia e Inovação 2011. http://www.mct.gov.br/index.php/content/view/30325.html#ancora. Current status of the project activities under the Clean Development Mechanism (CDM) in Brazil and the world. Last compilation from the UNFCCC webpage: May 24, 2011.
[31] Goes, T. et al: Sugarcane in Brazil. Current technological stage and perspectives. Revista de Política Agrícola. Ano XX – No. 1 – Jan./Fev./Mar, 2011.
[32] OECD-FAO: Agricultural Outlook 2011 – 2020. Chapter 6 – Sugar, 2011.