SUSTAINABILITY OF THE PRODUCTION OF ETHANOL FROM SUGARCANE: THE BRAZILIAN EXPERIENCE

By

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Abstract

THE INCREASE in production of liquid biofuels from different feedstocks is causing concern for potential importers and users, as an alternative to reduce greenhouse gas (GHG) emissions. The sustainability of the whole production chain of each biofuel is under review. Some countries, especially in the European Union (EU), are jumping ahead in the process of preparing certification procedures to assure the sustainability of the different alternatives under consideration; this is the beginning of the process to show that all biofuels are not equal. Ethanol from sugarcane has demonstrated, so far, superiority over other biofuels (ethanol from grains or sugar beet, and biodiesel from soybeans or rapeseed), but the demonstration process must be clear and based on measurable parameters. Surplus power generation is an important point to improve the energy and Green House Gas (GHG) balances, increasing the value of ethanol in the GHG abatement process when it displaces the use of gasoline as a transport fuel. Brazil as a major producer and exporter of ethanol from sugarcane is working hard to demonstrate the sustainability of its ethanol, using reliable information, well established procedures and participating in the worldwide effort to produce certification standards. Net energy ratios above eight and GHG abatement efficiency better than 80% for the Brazilian production and use chain have been demonstrated. This paper presents a comprehensive assessment of this Brazilian work toward the demonstration of sugarcane ethanol sustainability, offering some insights and lessons for other countries starting in this process.

Introduction

The fast increase in the production of liquid biofuels from different feedstocks is becoming a cause of concern to the major users, especially with respect to the most important expected benefits, such as Greenhouse Gas (GHG) emission reduction in transport, and the sustainability of the whole production chain of each biofuel alternative.

As a consequence, several countries in the European Union and the USA are starting to develop certification procedures to make sure that the biofuel options under consideration are sustainable and really contribute significantly to the reduction of GHG emissions in the transport sector. This represents a considerable effort in preparing paperwork to demonstrate the carbon footprint and the other important characteristics of the specific biofuel with respect to its sustainability and contribution to global warming mitigation.

Figure 1 shows the growth of biofuels production from 2000 to 2005 (IEA, 2007), and it is a clear indication that choices have to be made at this stage to avoid embarking in a biofuel alternative without future–it is the realisation that biofuels are not equal; not only the biofuel itself, but also the feedstock used in its production. The main driving forces behind the production and use of biofuels are:

- Energy security: the volatility of oil prices since 2002 and the political instability in some major oil producing countries are threats for the economies of countries that depend on oil imports.
- GHG emission reduction: the transport sector is responsible for 14% of the global GHG emissions and, therefore, the substitution of renewable fuels for fossil fuels has an enormous potential for mitigation.
- Rural jobs: the potential of biofuels production to increase the demand for agricultural products has attracted the interest of many countries, especially developing ones, to use this option to strengthen their rural economies and to create jobs in agriculture.

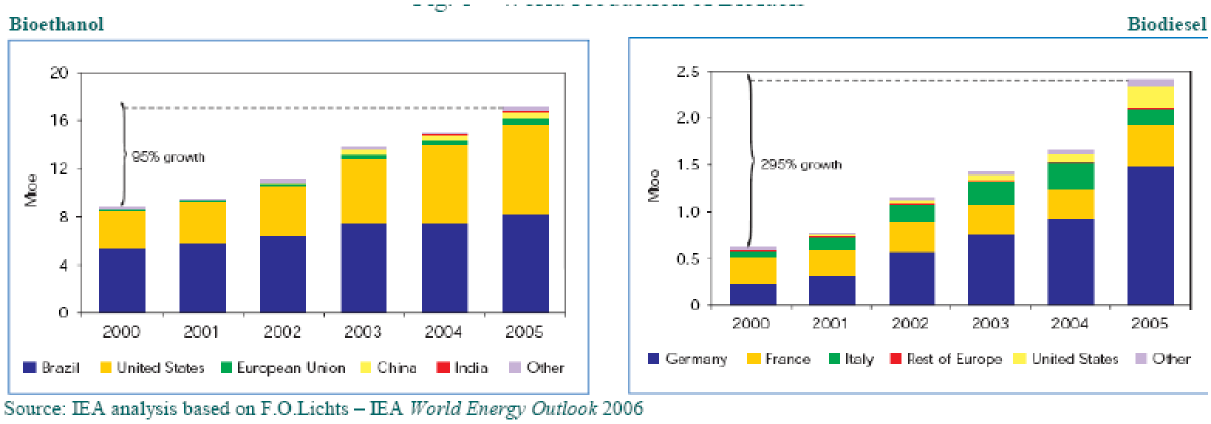

Fig. 1—World biofuels production, 2000–2005 (IEA, 2007).

For the countries interested in producing biofuels for export, there are some additional points that need to be evaluated: the potential of biofuel use and which countries are an important target; regulations and certification activities underway in these countries; scenarios for future use of biofuels.

Considering the case of ethanol, the present use of gasoline is an indication of the potential for use of this renewable fuel. Table 1 presents the main gasoline consumers in the world.

Table 1—Main gasoline consumers in the world

Country	Gasoline consumption (million m^3/year)	%
USA	517	42.6
EU-27	143	11.8
China	71	5.8
Japan	60	4.9
OECD	836	68.8
World	1215	100.0

Source: IEA (2009)

Table 1 shows that the main gasoline consumers are the developed countries, totaling close to 70% of the world consumption. Since nearly all of them are oil importers, they are potentially ethanol users. USA and EU, in particular, deserve closer attention for those who want to become ethanol exporters and their legislation and certification steps are important points to study. In reality, nowadays the major biofuels producers and users are USA and Brazil for ethanol and Germany for biodiesel.

Methodology

In this section, the main points are reviewed for selecting biofuel options and compared with the main characteristics of the Brazilian ethanol with respect to sustainability issues. Although the main focus of this work is on ethanol, in many instances biofuels will be treated in a similar way, because they all compete with ethanol in the liquid transport fuel market.

Certification initiatives

As explained above, the USA and EU countries are the ones with the highest potential for producing, using and importing biofuels, and for this reason will be the ones focused in this section.

USA

There are two major biofuel certification initiatives in the USA: the Energy Independency and Security Act of 2007 (EISA) and California Low Carbon Fuel Standard of 2009. EISA 2007 includes the Renewable Fuel Standard (RFS).

The RFS mandates the use of renewable transport fuels in an increasing proportion, reaching a total of 136 billion litres (36 billion US gallons) per year in 2022 and divides the biofuels in four different categories: renewable fuel, advanced biofuel, biomass-based diesel and cellulosic biofuel; the 136 billion litres are allocated to each category as 15, 4, 1 and 16 billion US gallons, respectively. The US Environmental Protection Agency can change these quantities in the future. The eligibility requirements for each category include the mandatory GHG reduction thresholds of 20%, 50%, 50% and 60% for renewable fuel, advanced biofuel, biomass-based diesel and cellulosic biofuel, respectively. First generation biofuels such as sugarcane ethanol can be in the advanced biofuel category if it satisfies the GHG reduction threshold. The California GHG target is 10% over the 1990 emissions level in the transport sector. In all cases, the GHG reduction is in comparison with gasoline.

EU

The Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources (Official Journal of the European Union, L140/16, 5.6.2009) establishes mandatory targets of 20% share of renewable energy sources in energy consumption and a minimum of 10% for biofuels in transport to be achievable for each Member State. Extensive procedures to calculate GHG reductions are described and the Sustainability Criteria for Biofuels and Bioliquids are indicated in Article 17 of the Directive. The threshold limits for GHG reductions are set at 35% for plants coming into production from 2010 and will be increased to 50% for plants starting up in 2017 and 60% in 2018 (the existing plants will have so satisfy the limit of 50% minimum reduction).

There are other important certification initiatives in progress such as the Renewable Transport Fuel Obligation (RTFO) in the UK and the Cramer Report in Holland (Cramer *et al*., 2007), Roundtable of Sustainable Biofuel (RSB) in Switzerland, and Global Bioenergy Partnership (GBEP) coordinated by the UK.

The Better Sugarcane Initiative (BSI) mission is to ensure that current and new sugarcane production is produced sustainably (www.bettersugarcane.org) and is preparing the BSI Standard that is presently going through a public consultation process. Of all initiatives on biofuels sustainability, the BSI is the most specialised in sugarcane and depends on Technical Working Groups with reputable members of the international sugarcane sector to assist in the development of its work.

Key issues

From the analysis of the main biofuels certification initiatives, the key issues for sustainability can be selected for a more detailed assessment:

- Energy balance: it is normally represented by the Net Energy Ratio–NER (renewable energy output of biofuel and co-products divided by the fossil energy input in the whole production chain). The NER gives a good indication of the capacity of the biofuel to reduce the dependency on fossil energy and can be extended to indicate the oil use in the process.

- Greenhouse Gas mitigation potential: this is presently the main characteristic of the biofuel to contribute to the global warming mitigation; it is an indication on how efficient and competitive it is in this process, for the abatement cost can be easily calculated. The procedures and standards to perform the so called GHG lifecycle analysis (LCA) are yet to be universally defined and accepted; a search in the technical literature shows a wide variation for different biofuels and even for the same biofuel and feedstock (Larson, 2006), mainly due to system boundaries definition, co-products credits calculation, soil emissions and land use change emissions.
- Demand for natural resources: it has to do, mainly, with the land and water demand, and is the key point in the, more emotional than technical, discussions about the impacts of biofuels on the food and feed availability and prices. Therefore, the productivity of the feedstock/biofuel pair in terms of litres/ha, or better GJ/ha, is very important as well as the ability to use rain-fed crops. A careful Agro-ecological Zoning of the main feedstocks is an important tool to demonstrate the ability to produce the biofuels without jeopardising the food and feed production.
- Production cost: there is no doubt that the economic leg of the Sustainability triad is the strongest one and, for this reason, the production cost of the biofuel, preferably measured in terms of US$/litre of gasoline or diesel equivalent, is the best indication if it will be able to compete with fossil fuels and other renewable energy alternatives to reduce GHG emissions, without subsidies in the long term; the parameter here will be US$/tonne CO_2 equivalent.
- Impacts on biodiversity: a good Agro-ecological Zoning for the feedstocks will solve most of the problems and doubts. Just by avoiding planting in sensitive areas can be an important step to satisfy the requirements in this area.
- Social impacts: this issue is difficult to quantify. Procedures need to be developed to assess the impacts of the biofuel production on jobs, wealth of the local communities, labour issues, land ownership and others.
- Local environmental impacts: this is easier to monitor and quantify than the social impacts, but nevertheless it brings some challenging issues such as water contamination, soil quality and loss, waste management and air emissions.

There are other topics normally included in the certification procedures being proposed, but the above are the ones normally present in all initiatives.

The Brazilian experience

Having a long tradition in and being the second largest producer and user of ethanol in the world has brought to Brazil some valuable experiences that can be used by other countries to avoid repeating some of our mistakes and to indicate the shortest route to success. Of course this does imply that the Brazilian model can be used as is by any country. Each country has its own culture, experiences, laws and regulations and talents that need to be taken into account.

In sequence, the several indexes and conditions in the Brazilian ethanol production chain will be described and, where possible, quantified.

Energy balance

The energy balance in the ethanol production in Brazil has been analysed since the 1980s bringing some insights to the evolution and critical points for improvements (Macedo and Nogueira, 1985; Macedo, 1992). The methodology was consolidated by Macedo *et al.* (2004) and updated by

Macedo *et al*. (2008) with projections for 2020. In all these references, three levels of energy were considered: (a) Level 1: energy consumed directly in the feedstock production and processing such as fuels and electricity; (b) Level 2: energy required for the production of chemicals and materials (fertilisers, herbicides, seeds, chemicals, lubricants, etc.); (c) Level 3: energy embodied in the equipment and buildings and consumed in their maintenance.

A summary of the results is presented in Table 2.

Table 2—Energy consumption in ethanol production (MJ/t cane).

Item/Reference year	2002	2005	2020
Agricultural operations	16.4	13.3	14.8
Harvesting	21.6	33.3	46.9
Cane transportation	39.0	36.7	44.8
Inputs (chemicals, etc.) transp.	4.0	10.9	13.5
Other field activities	–	38.5	44.8
Sub total	81.0	132.7	164.8
Fertilisers	66.5	52.7	40.0
Lime, herbicides, insecticides.	19.2	12.1	11.1
Seeds	5.9	5.9	6.6
Sub total	91.6	70.7	57.7
Machinery	29.2	6.8	15.5
Sub total	29.2	6.8	15.5
Total for cane production	201.8	210.2	238.0
Cane processing chemicals	6.4	19.2	19.7
Buildings	12.0	0.5	0.5
Equipment	31.1	3.9	3.9
Total for cane processing	49.5	23.6	24.0
Total for the production chain	251.3	233.8	262.0

Source: Macedo et al. (2008)

The differences between 2002 and 2005 are mainly due to an update of the facilities configuration, diesel consumption and embodied energy coefficients. Between 2005 and 2020, the projected differences are due to sugarcane burning phase out, gains in sugarcane yield and sugar content, and technological improvements.

The input/output energy balance is shown in Table 3, based on the average conditions in the Center-South region (90% of sugarcane production in Brazil)

Table 3—Energy balance for the ethanol production chain–renewable energy out/fossil energy in (MJ/t cane).

Item/Reference year	2002	2005	2020
Fossil energy in	251.3	233.8	262.0
Renewable energy out	2090.0	2185.2	3032.3
Ethanol	1921.3	1926.4	2060.3
Surplus bagasse	168.7	176.0	0.0
Surplus electricity	0.0	82.8	972.0
Renewable output/fossil input	8.3	9.3	11.6

Source: Macedo et al. (2008)

The details of this energy balance can be found in the reference (Macedo *et al*., 2008). The data presented in Table 3 show an excellent energy balance, and the methodology presented in the references can be used by any country to do its own energy balance and compare with the Brazilian one in detail.

GHG lifecycle analysis (LCA)

The GHG lifecycle analysis (LCA) derives mainly from the energy balance but there are non-energy related emissions that must be taken into account such as CO_2, methane and NO_2 emissions from cane burning, fertiliser, lime and residue decomposition, and soil carbon stock modification due to land use change. Table 4 presents a GHG LCA for the Brazilian conditions with projection for 2020 for anhydrous ethanol; the emissions due to direct and indirect land use change (LUC and ILUC) are not included due to the dependence on the local conditions (soil, climate, previous use of the land, specific agricultural practices, etc.) and the cause/effect relationship in the case of indirect land use change emissions.

Table 4—Lifecycle GHG for anhydrous ethanol production and use (kg CO2-equivalent/ m3 ethanol).

Item/Reference year	2002	2005	2020
Total emissions	401	436	345
Fossil fuels	223	210	219
Trash burning	105	84	0
Soil emissions	73	143	126
Avoided emissions1	2401	2323	2930
Use of ethanol	2256	2111	2111
Use of surplus biomass	145	150	0
Surplus electricity	0.0	62	819

Source: Macedo *et al.* (2008)
Note: 1 Displacing gasoline by the use of E25

It is interesting to look into the details of the analysis summarised in Table 4 in Macedo *et al*. (2008). It can be seen that, like in the energy balance, the agricultural area is the major source of GHG emissions and sugarcane yield plays a major role in the balance.

Demand for natural resources

In Brazil, sugarcane cultivation is mainly rain fed, although there is a trend to increase the use of irrigation in some dry areas such as the Northeast states and some areas in the new sugarcane frontier in the Center states savannah. The Agro-ecological Zoning of sugarcane will inhibit the expansion in these areas and the development and use of drought-tolerant varieties will help those already installed in these regions.

In most cases, only the salvation irrigation is used (less than 200 mm/year, and is intended only to keep the sugarcane from dying during an unusually dry spell), but full irrigation alternatives are being evaluated in a few cases.

The water intake for use in the mill is being continuously reduced in Brazil, especially in São Paulo, where the value of 1 m^3/t of cane was set as a limit for new mills being installed in the state; the average value for the Center/South region has been reduced from 5 m^3/tc to 1.8 m^3/tc in the past few years, motivated by the legislation that will introduce payments for water consumption and effluent discharge.

The water use main regulatory item is the Federal Law 9433 of 1997 that establishes the National Resource Policy and the National Water Resources Management System. This Federal law is complemented by several state level laws and regulations that create additional requirements and constraints.

Sugarcane is one of the most productive crops for biofuel production; under the present Brazilian average conditions, some 150 GJ/ha/y of renewable fuel (6500 litres of ethanol/ha/y). This figure can be significantly improved by the increase in sugarcane yields, better agricultural practices (such as precision agriculture, no tillage, maximum use of residues in the fields), optimum use of the sugarcane biomass (power generation and/or advanced technologies for biomass to liquids, BTL, for additional biofuel production).

In Brazil, the expansion of sugarcane cultivation is taking place mostly in pasture lands. There is a growing interest in developing and using technologies to intensify the cattle husbandry activities in terms of reducing land demand through increasing the number of cows per hectare. The integration of cattle and sugar/ethanol mills is also being investigated, with respect to the possibility of the mills to produce cattle feed from bagasse (hydrolysed), molasses and dried yeast.

This intensification process is proceeding in some areas, like the state of São Paulo, and creating a tremendous potential for new areas for sugarcane, without impacts on food/feed production or deforestation, since presently the pasture area is around 200 million hectares; just 10% of that would be sufficient for the sugarcane expansion foreseen for a few decades.

Even bearing in mind that water is an important and critical resource, the use of irrigation should not be ruled out to reduce the land demand and the fossil fuel consumption in the ethanol production chain. It is expected that the Agroecological Zoning, that has been recently approved, will regulate and orient the sugarcane expansion and decrease the impacts on and pressures for land demand.

Today, sugarcane occupies 8 Mha and, bearing in mind that only 55% of that is for ethanol production, the 4.4 Mha devoted to bioethanol represents only 0.5% of the total country area or 7% of the total cultivated land.

Production cost

The economics of biofuels is certainly the most important item in the long-term sustainability of each alternative without subsidies. It is important also to point out that subsidies tend to distort the market balance between production for food/feed and fuel of the agricultural feedstock.

In the case of Brazilian ethanol, a parity price to make it unimportant to produce either sugar or ethanol was a key point at the beginning of the National Ethanol Program back in 1975. The ethanol subsidies were highly reduced in the mid 1980s, and were totally phased out at the end of the 1990s.

The sugar/ethanol parity price was terminated in 1995. In this way, there has never been a sugar shortage, neither for the internal market nor for export, since sugar has always been a better market product than ethanol. Ethanol had its learning curve effect that resulted in a significant production cost reduction (van den Wall Bake, 2006) as shown in Figure 2.

It is expected that further cost reductions are still achievable in this learning curve, due mainly to gains in scale, improved management, precision agriculture, no or minimum tillage, commercial use of transgenic sugarcane and the efficient use of the biomass residues to generate surplus power and/or for second generation biofuels production.

Impacts on biodiversity

Since it is difficult to precisely define and quantify the impacts on biodiversity, the reference on this matter found in the initiatives to produce certification procedures remain vague, stating generally that some attention should be paid to this item.

The most frequent mention is that biofuel feedstocks shall not be grown on areas of high biodiversity value and protected areas. Agro-ecological Zoning could take care of the biodiversity preservation issue by ruling out the use of high biodiversity and sensitive areas. Just by avoiding deforestation, a lot of the ground is covered toward this goal.

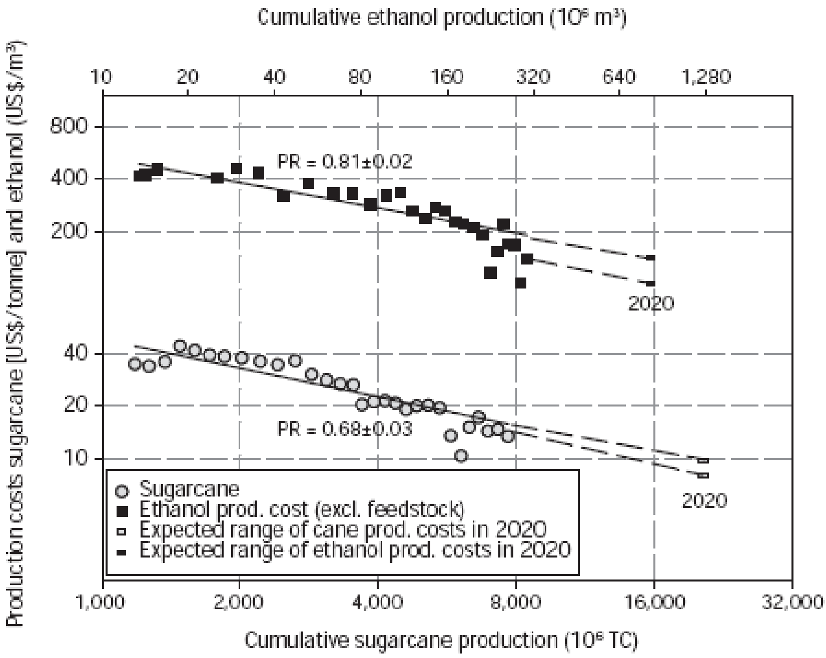

Fig. 2—Sugarcane and ethanol learning curves–the Brazilian case
Source: van de Wall Bake (2006) in Zuurbier and van de Vooren (2008)

In Brazil, there are laws protecting the biodiversity rich areas but the enforcement of these laws is still very loose. Since most of the expansion of sugarcane plantations is taking place on pasture and soy beans areas, the negative impacts on biodiversity are being minimised.

Social impacts

The observation of the human rights issues, commitment with the International Labor Organisation (ILO) and local workers organisation agreements are the key topics in the social impacts. Other important items are wages, working conditions, child and slave labour, land rights and competition with food production and jobs (in quantity and quality).

The Brazilian workers of the sugarcane sector are reasonably protected by the existing laws and regulations and, although the enforcement of the legislation is not adequate in some regions, we can say that there are no major problems in the sector compared with other sectors of agriculture (Macedo, 2005).

Government authorities, NGO’s members and even the Catholic Church look after the social issues in the country. If all existing laws were enforced, there would be no problem in this area in Brazil. Just to exemplify one aspect, the mean income of the sugarcane sector is compared with other representative sectors of the country’s economy and the numbers are shown in Table 5 (Macedo, 2005).

Table 5: Mean income in all jobs for people occupied or engaged in sugarcane sector and other industries in Brazil (2003).

Items	Sugarcane	Sugar	Ethanol	Food and beverage	Fuels	Chemicals
People x1000	789.4	126.0	67.0	1507.0	104.7	641.2
Mean age (years)	35.1	36.6	35.6	34.4	37.1	33.4
Education (years)	2.9	6.5	7.3	7.1	8.9	9.6
Mean income (R$/month)	446.6	821.3	849.9	575.0	1281.1	1074.6

Source: Macedo (2005)

These data show that the agriculture part of the production chain presents an unfavourable condition when compared with its factory part and other industrial sectors. With the increase of mechanisation in the agricultural operations (harvesting and planting), the situation tends to improve with the change of many low pay/hard work jobs by a smaller quantity of better paid and more stable jobs.

Local environmental impacts

Cane burning phase out in the states of São Paulo and Minas Gerais (approximately 2/3 of the total Brazilian cane) will be nearly accomplished by 2014 and totally finished by 2017, according to the Environmental Protocols signed by representative of the state government, cane growers, mill owners and workers representatives. Other important items such as improved working conditions, workers' qualification (cane cutters are being trained to perform more qualified functions in the mechanisation system), environmental conditions improvement, etc. Other states will probably follow suit and make similar agreements, resulting in a considerable reduction of negative environmental impacts, especially those derived from cane burning. Green cane harvesting will also decrease soil erosion, agrochemicals carryover to surface water and leaching to ground water and will create the adequate conditions to develop no tillage systems that will reduce even further the negative impacts on soil, air and water.

Final comments

The brief description of the differences in biofuels with respect to long-term sustainability issues and a quick look at the Brazilian experiences will hopefully help the potential biofuels producers to make a more technical decision about the best option for the local conditions.

The first points to be analysed have to do with the level of contribution to the GHG emission reductions (in terms of % of the equivalent fossil fuel emissions), the production costs (an indicator of the economic viability, or US$/t CO_2 eq. and US$/litre of gasoline/diesel equivalent) and the natural resources demands for the full dimension of the specific biofuel program. If the biofuel passes this first battery of tests, it can then go to the next steps of evaluation that are: social issues, impacts on biodiversity and environment. A clear view of the necessary public policies and the investments required to bring the program to a self-sustained level is a must to have a stable biofuel program on line.

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LA DURABILITÉ DE LA PRODUCTION D'ÉTHANOL À PARTIR DE SUGARCANE: L'EXPÉRIENCE BRÉSILIENNE

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MOTS-CLÉS: Biocarburants, Durabilité,
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Résumé

L'AUGMENTATION de production de biocarburants liquides à partir de différents substrats est une source de préoccupation pour les importateurs éventuels et les utilisateurs dans le cadre des solutions alternatives pour la reduction des émissions de gaz à effet de serre (GES). La durabilité de l'ensemble de la chaîne de production de chaque biocarburant est sous étude. Certains pays, en particulier ceux de Union Européenne (UE), vont de l'avant dans la préparation des procédures de certification afin d'assurer la durabilité des différentes alternatives proposées; c'est le début du processus pour démontrer que tous les biocarburants ne sont pas égaux. L'éthanol produit à partir de la canne à sucre a démontré à ce jour sa supériorité sur les autres biocarburants (éthanol de betterave à sucre ou de céréales) et le biodiesel de soja ou de colza, mais la démonstration du procédé doit être évidente et basée sur des paramètres quantifiables. La production d'énergie excédentaire est un point important pour améliorer l'équilibre entre la production d'énergie de celle de GES, de ce fait augmentant la valeur de l'éthanol dans le processus de réduction des GES lorsqu'il déplace l'utilisation de l'essence comme un combustible de transport. Le Brésil comme un producteur et exportateur majeur d'éthanol à partir de la canne à sucre s'efforce à démontrer la durabilité de l'éthanol, à l'aide d'une information fiable, des procédures bien établis et à travers la participation à l'effort à travers le monde entier pour produire des normes de certification. Des rapports d'énergie superieurs à huit et des reductions GES supérieures à 80% ont été démontrés à travers la chaîne de production au Brésil. Cette communication présente une évaluation complète des travaux éxecutés au Brésil pour démonstrer la durabilité de la production d'éthanol à partir de la canne à sucre, propose certaines idées et des enseignements utiles pour les autres pays qui s'apprettent à se lancer dans ce processus.

SOSTENIBILIDAD DE LA PRODUCCIÓN DE ETANOL DE LA CAÑA DE AZÚCAR: LA EXPERIENCIA BRASILEÑA.

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PALABRAS CLAVE: Biocombustibles, Sostenibilidad, Certificación, Caña de Azúcar, Gases de Efedcto Invernadero.

Resumen

EL AUMENTO de la producción de biocombustibles líquidos a partir de diferentes fuentes está generando preocupación en potenciales importadores y usuarios, como una alternativa para reducir la emisión de gases de efecto invernadero (GHG). La sostenibilidad de la cadena total de producción de cada biocombustible está bajo escrutinio. Algunos países, especialmente en la Unión Europea, están saltando adelante en el proceso de preparación de procedimientos de certificación para asegurar la sostenibilidad de las diferentes alternativas bajo consideración, este es el inicio del proceso para demostrar que no todos los biocombustibles son iguales. El etanol de la caña de azúcar ha demostrado, hasta ahora, superioridad sobre otros biocombustibles (etanol de granos, de azúcar de remolacha y bio diesel de soya ó colza), pero el proceso de demostración debe ser claro y basado en parámetros medibles. La generación de energía sobrante es un punto importante para mejorar el balance de energía y de gases de efecto invernadero (GHG), aumentando el valor del etanol en el proceso de abatir los GHG cuando desplaza el uso de la gasolina como combustible automotor. Brasil, como mayor productor y exportador de eatanol a partir de la caña de azúcar, está trabajando fuerte para demostrara la sostenibilidad de su etanol, empleando información confiable, procedimientos bien establecidos y participando en el esfuerzo mundial para elaborar estándares certificables. Se han demostrado relaciones de energía neta por encima de ocho y eficiencias de abatimiento de los GHG mejores del 80% para la producción y la cadena de usos brasileña. El artículo presenta una explicación compresible de este trabajo brasileño dirigido a la demostración de la sostenibilidad del etanol de la caña de azúcar, ofreciendo apreciaciones y lecciones para otros países que inician este proceso.