cgee

CNPEM

CTBE

Sustainability of sugarcane bioenergy

Updated edition

Centro de Gestão e Estudos Estratégicos
Ciência, Tecnologia e Inovação

Sustainability of sugarcane bioenergy

Updated edition

cgee

Brasília – DF – Brazil
2012

ISBN 978-85-60755-47-9

Organização Social supervisionada pelo Ministério da Ciência, Tecnologia e Inovação (MCTI)

President
Mariano Francisco Laplane

Executive Director
Marcio de Miranda Santos

Directors
Antonio Carlos Filgueira Galvão
Fernando Cosme Rizzo Assunção
Gerson Gomes

Edition / *Tatiana de Carvalho Pires*
Graphic designer / *Eduardo Oliveira*
Front cover / *Diogo Moraes*

Cataloging in publication

C389s
Sustainability of sugarcane bioenergy - Updated edition. – Brasília, DF : Center for Strategic Studies and Management (CGEE), 2012.

360 p: il. ; 24 cm.
ISBN 978-85-60755-47-9

Sugarcane - Brasil. 2. Bioenergy - Brasil. I. CGEE. II. Title.

CDU 620.925:664.111 (81)

Center for Strategic Studies and Management (CGEE)
SCN Qd 2, Bl. A, Ed. Corporate Financial Center, Room 1102
70712-900, Brasília, DF
Telephone: +55 61 3424-9666
www.cgee.org.br

This publication is part of the activities developed under the Management Contract CGEE/MCT/2009 – 15º Adictive Term/Action: “Subsídios Técnicos para a Agenda Brasileira de Etanol” – Subaction: “Sustentabilidade – Etanol – Fase II.

Printed in 2012.

Sustainability of sugarcane bioenergy

Updated edition

Supervision

Marcio de Miranda Santos (Executive Director - CGEE)
Antonio Carlos Filgueira Galvão (Director – CGEE)
Marco Aurelio Pinheiro Lima (Director – CTBE, 2008-2012)
Carlos Eduardo Vaz Rossell (Director – CTBE)

Editors

Marcelo Khaled Poppe (CGEE)
Luis Augusto Barbosa Cortez (Nipe/Feagri/Unicamp)

Authors

André Aranha Corrêa do Lago (MRE)
André Nassar (Icone)
André Tosi Furtado (Nipe/IG/Unicamp)
Andres da Silva (Eacea)
Arnaldo Walter (CTBE - Nipe/FEM/Unicamp)
Camila Ortolan F. de Oliveira (CTBE)
Gilberto de M. Jannuzzi (Nipe/FEM/Unicamp)
Heitor Cantarella (Apta/IAC)
Henrique C. Junqueira Franco (CTBE)
Isaias C. Macedo (Nipe/Unicamp)
Joaquim Eugênio A. Seabra (CTBE - Nipe/FEM/Unicamp)
Juan Castañeda-Ayarza (FEM/Unicamp)
Klever João Mosqueira-Salazar (Unicamp)
Laura Antoniazzi (Icone)
Leila Harfuch (Icone)
Luciane C. Bachion (Icone)
Luis Augusto B. Cortez (Nipe/Feagri/Unicamp)
Luis Franco de Campos Pinto (Unisoma)
Luiz Augusto Horta Nogueira (Unifei)
Manoel Regis Lima Verde Leal (CTBE)
Marcelo Moreira (Icone)
Marcelo Pereira da Cunha (CTBE)
Mauro F. Chávez-Rodriguez (Unicamp)
Miguel Taube-Netto (Unisoma)
Oscar Braunbeck (CTBE)
Paulo Sérgio Graziano Magalhães (CTBE - Nipel/Feagri/Unicamp)
Raffaella Rossetto (Apta/IAC)
Rodolfo D. M. Gomes (IEI)
Silvia Azucena Nebra (Nipe/Unicamp)
Simone Pereira Souza (CTBE - FEM/Unicamp)
Terezinha de Fátima Cardoso (CTBE)

CGEE Technical Team

Marcelo Khaled Poppe (Coordinator)
Antonio Geraldo de Paula Oliveira
Mayra Juruá Gomes de Oliveira
Olivia Felicio Pereira

Table of contents

PART IV
Indicators and certification issues

PART V
Life cycle analysis, energy and greenhouse gases balance

PART VI
Post-scriptum

Presentation

This book deals with the sustainability characteristics of sugarcane bioenergy in Brazil. Due to the strong relation of sugarcane agroindustry to the Country's economic, social and environment sustainable development (around 18% of total primary energy supply), it was organized having in mind the United Nations Conference on Sustainable Development (UNCSD), Rio+20. Most of the chapters present some of the results of studies carried out in partnership between the Center for Strategic Studies and Management (CGEE)[1] and the Brazilian Bioethanol Science and Technology National Laboratory (CTBE)[2]. These studies followed CGEE and the Interdisciplinary Energy Planning Nucleus of the University of Campinas (Nipe/Unicamp)[3] initiatives that gave origin to CTBE. The updated edition includes the chapter "3A" on Fertilizer concerns.

The production of bioethanol from sugarcane in Brazil, associated with the production of bioelectricity, sugar and biomaterials, presents attractive returns and constitutes the best alternative to use labor, land, water and sunlight in the production of biofuels. Nowadays, sugarcane bioethanol is already economically competitive; it does not adversely affect food production, has a great productivity of biomass (over one hundred tones per hectare), presents an excellent ratio between the renewable energy produced and the fossil energy consumed in the production (up to ten times), considerably mitigates climate change (more than 80% GHG emission reduction), and causes minimal environmental impact by fully utilizing the raw material. This energy source still offers a substantial potential for improvement, optimizing the agroindustrial processes and developing its high-valued byproducts trough biorefinery approach, green chemistry etc. In the forthcoming years, production could exceed ten thousand liters of bioethanol and fourteen thousand kilowatt-hours of bioelectricity per hectare, with low exogenous energy requirements and emissions of greenhouse gases one-tenth of the amount generated using oil products with the same energy output. Next generation biochemical (cellulosic hydrolysis) or thermochemical (gasification and gas-to-liquid, pyrolysis) technologies for liquid biofuels production are certainly worth developing, but they are in no way indispensable to promote the increasing use of sugarcane bioethanol as from now.

---

[1] http://www.cgee.org.br.

[2] http://www.bioethanol.org.br.

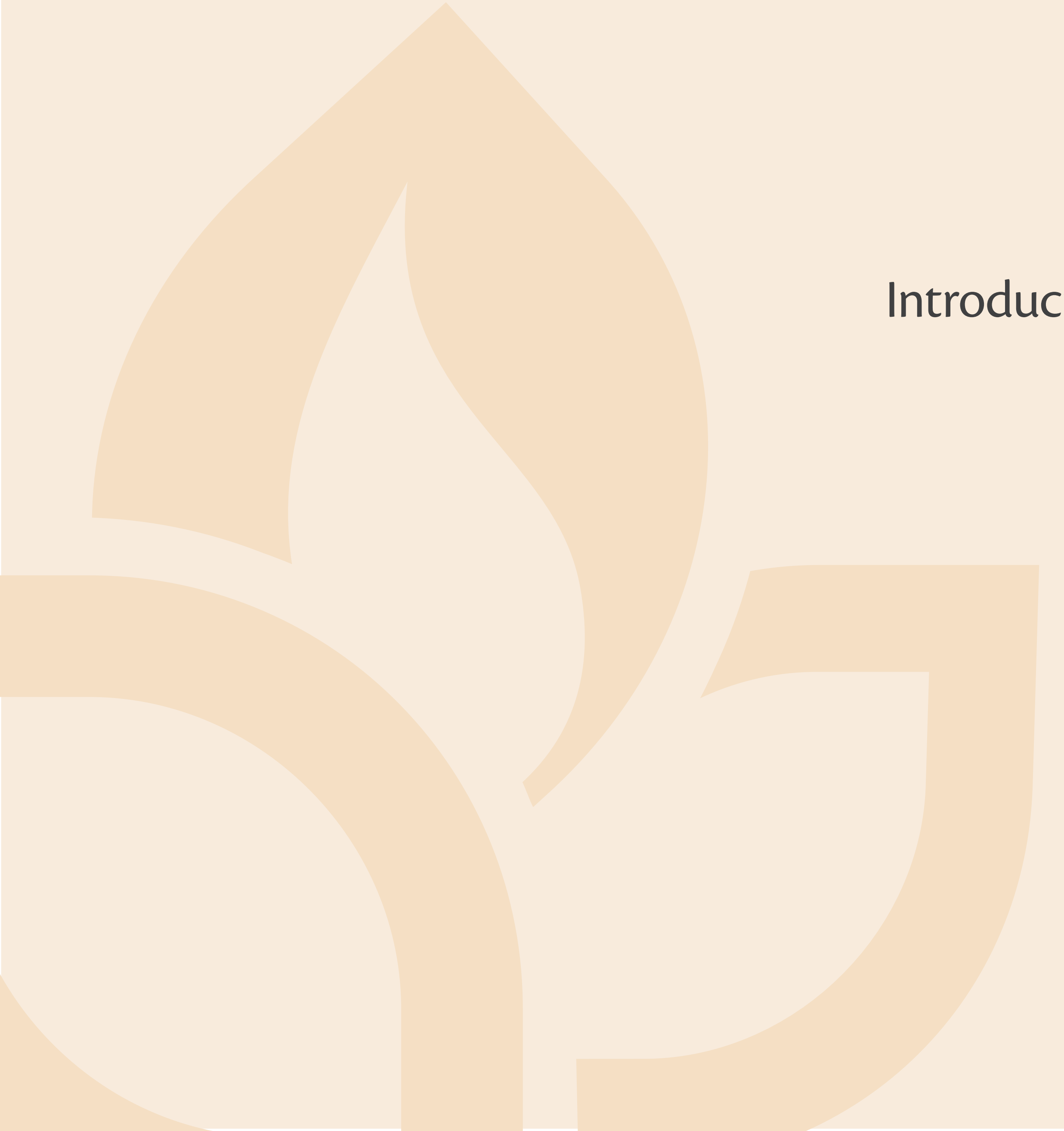
[3] http://www.nipeunicamp.br

Rural development issues, particularly regarding developing countries, are the key factor usually pointed out to give reason for the promotion of bioenergy, frequently linked to the rural poverty reduction agenda. The agricultural objectives foresee new opportunities, not only for modern commercial energy crop production, but also for small-scale production of more accessible goods. Increased biofuels use is a real opportunity to enlarge access to modern energy, including rural electrification and cooking fuel for advanced cooking stoves (to replace traditional use of firewood and charcoal). Considering the availability of unused lands or lands used for low-productivity cattle-raising activities, the production of bioenergy and other byproducts from sugarcane is highly likely to increase, not only in Brazil, but also in other tropical-humid countries, benefiting from the progress achieved by the Brazilian innovative path.

Mariano Francisco Laplane
President of CGEE

Part I

Introduction



Chapter 1

International negotiations on bioenergy sustainability

André Aranha Corrêa do Lago[1]

Energy is one of the economy's largest and most relevant sectors today for contemporary international relations. As an indispensible source for development, the continued access to energy is crucial to all countries and is often the cause of international disputes. Furthermore, energy is closely related to other themes of primary importance on the international agenda, such as global warming and, increasingly, access to modern forms of energy for billions of people.

In spite of its undeniable importance in so many areas – or, perhaps, as a consequence of this – the energy sector is perhaps the subject of greatest global relevance that does not have a specific forum where it can be internationally discussed. There is not, for example, an institution like the World Trade Organization, which regulates the sector's international relations. The existing arrangements, such as the International Energy Agency (IEA) and the Organization of the Petroleum Exporting Countries (OPEC), do not have universal participation and generally represent the interests of specific groups of countries.

The renewable energy sector, whose rapid growth over the last few years places it among one of the most promising areas of the global economy, is not an exception to the rule. Its only specific multilateral institution, the International Renewable Energy Agency (Irena), has not yet been capable of offering a balanced forum for discussions on different alternatives for renewable energy. As it is headed mainly by European developed countries, Irena tends to only associate the theme with environmental and economic questions. In this context, it promotes the expansion of the generation

---

[1] It would not be fair, on my part, if I did not mention the help I received from two of my assistants in preparing this chapter. I would like to take this opportunity to thank Vicente de Azevedo Araújo Filho for his invaluable contribution toward the drafting of this text. He has been my loyal collaborator since I was head of the Energy Department at the Ministry of Foreign Affairs and there could no better person to help me with his experience and knowledge on this subject. Filipe Sobreira Lopes, for his part, assisted me in translating my sometimes not so clear ideas into English that could be comprehended by the readers of this book. For that, I thank both very much.

of wind and solar energy and tends to direct its attention away from bioenergy and hydroelectricity, which is the reason why Brazil has not yet joined the organization.

Brazil internationally defends that modern bioenergy can be a superior renewable energy alternative, especially for developing countries, as it generates notable benefits in the three pillars of sustainable development, as set in stone at the Rio-92 Summit – the social, environmental and economic pillars. In addition to substantially reducing carbon emissions, the production of bioethanol, biodiesel, and other modern biofuels also promotes the generation of jobs and income, especially in rural regions, where the largest concentrations of poverty and extreme poverty are found around the world. Job posts generated in agro-energy farmlands are better paid than in other plantations and the logistical investments necessary for the development of bioenergy stimulate the production of foodstuff and of other agricultural and livestock products. Furthermore, investments in bioenergy can also be beneficial for the electrification of isolated regions and fosters the substitution of traditional kitchen fuels, such as logwood and charcoal, which two billion people still depend on, and which contribute to the deaths of almost two million people annually, especially children in less developed countries.

The Brazilian Government, through its Ministry of External Relations, has acted to prioritize not only the recognition of the environmental, social and economic benefits of bioenergy, but also the assurance of conditions for the establishment of a free international market. The greatest objective is to promote the "commoditization" of biofuels. In other words, the aim is to create a global market for these products, with multiple producers and consumers, and prices determined by market forces. Such policy is based upon the understanding that bioenergy is an energy alternative that is both sustainable and more easily accessible to developing countries, which could therefore increase their energy security in the medium and long term, while generating revenue, especially through exports of liquid fuels such as bioethanol and biodiesel and the substitution of imported fossil fuels.

Due to the lack of international fora dedicated to this issue, Brazil has sought, over the last few years, to develop initiatives of various forms to promote international understanding of the theme.

One of the approaches that Brazil's Ministry of External Relations has adopted in this effort to assure the recognition of the benefits of bioenergy for sustainable development focuses on active participation in international debates, contributions to processes of public consultation, technical and political contributions to official reports on the theme, and the organization of missions to exchange information on the Brazilian experience.

The Global Bioenergy Partnership (GBEP) has thus far been a privileged forum in this sense. It was created in 2007 by the G8+5 (G8 + Brazil, China, India, Mexico and South Africa) and constitutes a partnership for dialogue on bioenergy, which is open to all countries, on a volunteer and non-binding basis, whose main objective is the creation of sustainability indicators which help in the formulation of public policies toward the sustainable production of bioenergy. During the process in which these indicators, which were recently agreed to, were negotiated, the Brazilian Government, working together with representatives of the academy and the private sector, emphasized the importance of the environmental, economic and social benefits brought by bioenergy, being valued and adequately estimated by the Governments of countries which, at the moment in which local policies for the sector are defined, are not yet producers. The set of indicators agreed can be seen as a benchmark, as it was signed by a group of countries that can be considered a sample of developed and developing countries, and it considers the three pillars of sustainable development in a balanced manner, instead of simply listing the potential problems linked to bioenergy.

Another example in this endeavour was the intense dialogue held with the EPA (the United States' Environmental Protection Agency), which culminated, in February 2010, with the recognition that sugarcane bioethanol produced in Brazil reduces the emission of greenhouse gases by 61%, as compared to emissions produced by gasoline. Even though this value is below estimates that indicated that emission reductions would be around 80% relative to gasoline, the EPA's recognition granted Brazil's bioethanol an "advanced biofuel" classification, given to those which produce reductions of at least 50% in greenhouse gas emissions. The granting of this classification can bring commercial advantages to Brazil's sugarcane bioethanol over the next few years, as US law determines increasing goals in the consumption of advanced biofuels as of 2011. The joint and coordinated efforts made by the Brazilian Government, scientific community and private sector, since the beginning of debates on the new US legislation for the energy sector, in 2007, contributed to the EPA's decision.

A similar effort is being carried out by the International Organization for Standardization (ISO), whose resolutions, can serve as a basis for the establishment of technical and commercial barriers for biofuels at the World Trade Organization. Brazil's Ministry of External Relations' efforts are aimed at assuring that only physical and chemical characteristics of the final product, not means and base products used in its composition, are taken into consideration in certification processes. The same undesirable tendencies observed early on in GBEP's process can be observed in the ISO's. These are exemplified by extensive discussions, sponsored by European countries based on biased and preliminary studies on ILUC (indirect Land Use Change) and other aspects related to the lifecycle of products.

Additionally, on this front, one must also single out the Brazilian Government's efforts, also coordinated with scientists and the private sector, in public consultations relating to the implementation of the European Union's Directives on Renewable Energy and Fuel Quality. These Directives seek to establish sustainability criteria for the production and use of biofuels with reference to, among others, indices of reduction of greenhouse gas emissions. Brazil has actively participated in this process, so as to dispute any provisions that constitute technical barriers to the free trade of bioethanol and to highlight social sustainability aspects of the production of bioenergy. The European Commission recognizes that the Brazilian contributions to the debate have promoted a better understanding of the national production of biofuels and have led to reviews of assessments and data on which new rules to be implemented will be based.

In addition to actively taking part in several fora, Brazil has sought to create new unbiased spaces for debate on the subject. In 2008, when bioenergy was under constant and, often, unfair criticism by countries and groups that did not favour its international expansion, Brazil's Ministry of External Relations organized the I International Biofuels Conference, in São Paulo. The event gathered 93 foreign government delegations (36 of which headed at the ministerial level), representatives from 23 international organizations and 38 high-level specialists from Brazil and abroad, attending six thematic round tables. The transparent and scientifically-based debate over then-controversial aspects, such as food security and tropical forest devastation, was a benchmark by which agreements were reached and where myths on the sustainability of bioenergy were uncovered. Even today, the event is still cited by foreign delegations as the turning point in international discussions on the subject. It was then that it became clear that developing countries had a great interest in modern bioenergy alternatives and that there was an urgent need to increase international cooperation in that area.

In this context, Brazil began to develop projects to share its experience in the biofuel sector, especially with countries in Africa, Latin America and the Caribbean. An example of this is the Structured Programme in Support of Other Developing Countries in the Area of Renewable Energies (Pro-Renova), launched in 2009, as an initiative by Brazil's Ministry of External Relations. The Programme is an important instrument of Brazil's policy to promote South-South cooperation and aims at creating a lasting basis for a wide range of projects with developing countries in the renewable energies sector, while administering the employment of human and material resources that the country holds. One of the themes highlighted by Brazil is the opportunity that developing countries have to use clean development mechanisms (CDM's) in the production of biofuels.

Among Pro-Renova's activities, the following can be singled out: i) the sending of Brazilian specialists to administer on-site courses in African countries to capacitate local populations (since 2009, 16 countries on the Continent have already been hosts to seminars on different technical and political aspects of the production and use of biofuels); ii) the realization of short courses in Brazil on the specific aspects of the production and use of biofuels; and iii) the constant sending of Brazilian specialists to take part in international events on the subject. Following the positive results obtained during its first phase in Africa, a second phase is being planned to potentially be applied in countries in the Americas and in Asia.

Another direction in which Brazil's Government is pointed internationally is the bilateral relation with countries that hold positions similar to Brazil's. An example of this is the partnership with the United States – the world's largest producer of bioethanol, launched by the signing of the Memorandum of Understanding Between the United States and Brazil to Advance Cooperation on Biofuels, in 2007. The instrument envisages bilateral cooperation in research and development, global efforts to harmonize standards and technical norms and joint efforts to encourage the production and use of biofuels in third party countries. Among its main results are the publication of the White Paper on Internationally Compatible Biofuels Standards, during the International Biofuels Forum, in November 2008, and the development of viability studies on bioenergy in seven Latin American and Caribbean countries (El Salvador, Dominican Republic, Haiti, Honduras, Saint Kitts and Nevis, Guatemala and Jamaica) and two African countries (Senegal and Guinea-Bissau). The studies, provided by Brazil, are carried out by technical experts and specialists from the Getúlio Vargas Foundation and aim at aiding local governments to define the best investment alternatives in bioenergy production, based on their local specific characteristics.

In 2011, during President Obama's visit to Brazil, both countries also signed the Partnership for the Development of Aviation Biofuels. This Partnership is part of international discussions on contributions to mitigate climate change caused by the aviation sector, where the search for new alternatives to Aviation Kerosene is a strategic priority. The development of biokerosene has been a relevant part of scientific research and private investments in several countries. The Brazilian Government seeks to ensure that the country does not become a mere supplier of raw material for the new fuel, by trying to guarantee that the country controls technological production routes.

With respect to lignocellulosic bioethanol, Brazil's longstanding experience in the development of biofuels and the country's historic leadership in the sector result in a responsibility toward further development and technological innovation, which leads the Brazilian Government to promote research in the area. Work carried out by the National Lab for Bioethanol Science and Technology (CTBE) serves as an example. Nevertheless, while the goal of scientific advancement is never forgotten, it is important to highlight that Brazil's international position seeks to point out the social, environmental and economic benefits ensuing from any biofuel production technology, as long as its production is carried out in a sustainable fashion. This counters the view that new technologies, such as lignocellulose, are necessarily superior to traditional production, based on the extraction of sucrose. In any case, Brazil internationally maintains an active policy with a view to develop these alternatives. The Brazil-Germany partnership, for example, whose main framework is the Agreement on Cooperation in the Energy Sector with an Emphasis on Renewable Energies and Energetic Efficiency, has the development of lignocellulosic bioethanol as one of its main themes.

In essence, Brazil, in all of its international efforts aimed at sustainable development, seeks to contribute toward an open and balanced dialogue regarding the recognition of the environmental, social and economic benefits of bioenergy as a renewable source of energy. It also recognizes that each reality requires a specific solution, where the production of bioenergy will not always be the most suitable. It defends, however, its role not only as a source of clean, secure and accessible energy, but also as an alternative to the generation of jobs and income, whilst also addressing climate change.

As Brazil prepares itself to host the United Nations Conference on Sustainable Development (Rio+20), bioenergy presents itself as an energy alternative, which, like few others, demonstrates advantages in all areas of sustainable development and can be applied in the most diverse regions and situations. The example of Brazil's experience, a country that synthesizes the challenges of sustainable development, shall inspire the continuity of the expansion of bioenergy around the world and sustain a more complete understanding based on the evidence of its advantages over other forms of energy.

Chapter 2

Main trends on sustainability of sugarcane production systems

Isaias C. Macedo

The development of sustainability concepts

The concepts related to process sustainability have evolved in the last forty years to include new issues, to consider new technology options and in general to work with a broader perspective, although the changes still have a long way to go. Initial concerns (at the time of the first oil shock) were focused on the depletion of natural resources by a growing and more affluent world population. The Limits to Growth (Meadows *et al*, 1972) presented the results of modeling the interactions between the Earth's and the human systems, in this context, looking for possibilities of sustainability with suitable growth trends for world population, food production, industrialization, pollution and resource depletion. The search for economic/technological solutions produced new ideas, opening discussions on world economics; an example is Small is Beautiful: Economics as if People Mattered (SCHUMACHER 1973), ranked among the 100 most influential books published since World War II (The Times Literary Supplement). It suggested the use of small scale production systems and "appropriate" technologies (with decentralization); that workplaces should firstly be meaningful, and secondly, efficient; and that natural resources are priceless. The strong inclusion of social factors, and acknowledging that the underlying problem was of an unsustainable economy, were his significant contributions.

Technological solutions to energy supply / utilization sustainability was a dominant subject in the seventies; and much of the concepts used today were considered at that time. One of the pioneers was A. Lovins (LOVINS 1975; LOVINS 1977); Lovins advocated " soft" energy paths (efficient energy use, renewable energy sources, scale and quality matched to the end use).

The UN First World Environment Conference (1972, STOCKHOLM) recognized the need to fight for actions concerning both the quality of environment and human exploitation. Twenty years later, at the UN Conference on Environment and Development (RIO DE JANEIRO, 1992), the decision was made to promote a “sustainable development”; actions and responsibilities were detailed in *Agenda 21*, adding environmental protection to the list of basic conditions for human development. The implementation of this has been considerably delayed but there has been progress in many fields both by governments and by "bottom to the top” actions. Ten years after the Conference an outstanding report edited by J.C Dernbach, Stumbling Towards Sustainability, (DERNBACH 2002), with 42 scientists, addressed the progress in the U.S. towards the objectives stipulated by Agenda 21, and the possibilities for the coming years. It gives a very comprehensive idea of the difficulties in the paths to sustainability; and it makes clear, once again, that the efforts should not only shape the path for developing regions, but significantly change processes in "developed" regions.

The "sustainable development" addressed in *Agenda 21* evolved to cover a wide range of aspects of our civilization. These include demographic policies, consumption of materials and energy; international trade, development financing and support; preservation and management of natural resources, including water; air pollution; climate changes; biodiversity conservation; land use; control of toxic waste and chemicals; education; institutions and infrastructure. Since the second half of the nineties a number of methodologies have been proposed to advance the life cycle assessments of many expected environmental impacts of human actions; and the concern with work conditions, health care and general human welfare were included in the analyses. Also, the economic analyses started (although not with the same depth) to look comparatively at the externalities involved in both the conventional and the "new" processes.

One specific topic among the environmental impacts has been discussed by many governments and scientists worldwide. The growing concern for Global Warming problems has led, in the last 15 years, to actions proposed among the nations to mitigate the emissions of GHG. The distribution of the costs of mitigation is still far from being established, and the methodologies to quantify emissions (and their mitigation) are treated at different levels (national, regional). At the same time, dozens of initiatives for the "certification" of some technological solutions (biofuels being the most striking example) fight to be accepted by energy providers and users. The effort has contributed to considerably increasing the knowledge in many areas; but in some cases the pressure to reach quantitative impact evaluations has led to propositions lacking the support of sound scientific data and methodologies (as in the ILUC associated GHG emissions, a few years ago).

Sustainability concepts will continue to evolve; impact evaluation methodologies (environmental, social or economic) will need more specific, regional data and sounder criteria; but their utilization will be the basis for the design of the pathways for development.

Biofuels and sustainability

Biofuels and Energy Conservation have been considered the two most important groups of technologies to mitigate GHG emissions in the present decade. Biofuels hold a special place in sustainability considerations, because they address a variety of areas with potential problems. They are based on agriculture; agriculture will grow together with the global demand, and today (after the "green revolution") the sustainability of agriculture is an open-ended question in the best of cases.

Many of the “modern agriculture” paradigms of twenty five years ago are now contested from the sustainability standpoint. Agriculture (as well as urban concentrations) breaks natural ecological functions, leading always to some conflict with the “environmental” part of sustainability. Modern agriculture frequently relies on price and income subsidies (in many cases, with subsidized irrigation or drainage systems) and growing utilization of pesticides, herbicides and fertilizers. It has helped to destroy almost all the native vegetation in large areas of developed nations. However, food supply for human development, and environmental protection should not be exclusive of each other; how can we evolve into sustainability?

An important part of the answer is: technology (the right choices) and investment.

Agricultural lands occupy nearly 1.5 billion ha, but an additional 3.5 billion ha are used as pasturelands. An important fraction of the latter consists of degraded (or en route for degradation) pasturelands; even for the food production areas, economic distortions frequently lead to high cost, low efficiency (non sustainable) systems. The most optimistic IEA Scenario for Biofuels (Blue Scenario in IEA 2008) leads to the need for 100 million ha in 2030. Even a very small (2%) increase in the pastureland and crop productivity worldwide would be sufficient to supply all the area needed for biofuels in this period. If done right, this would also help in recovering low efficiency areas, increasing soil Carbon stocks, increasing water resources in the associated protection areas and creating jobs. Actually, in this way biofuels could provide what will eventually be required from agriculture in general: to be both internally and externally sustainable, while serving as an available resource with which to assist other sectors of the economy and society. The questions raised about the biofuel versus food "dilemma", or the indirect Land Use Change effects in GHG emissions, may consider the numbers above and lead to changes in the non sustainable food production systems.

Although starting with quite different drivers in 1975 (essentially, at that time, helping to alleviate the heavy burden of imported oil, and promoting job creation) the Brazilian bioethanol program today follows very closely the “virtuous” path described in the paragraph above.

Trends in the sustainability of sugarcane based production processes

Sustainability depends on policies and legislation; its implementation needs technology and investment. Being the first large scale commercial biofuel, bioethanol from sugarcane in Brazil has been the subject of much discussion. The pathways followed (drivers, technology options) and the levels of sustainability achieved have been analyzed by scientists, economists, engineers, and social science professionals (MACEDO 2005) and from there, updates in most topics were prepared; this book brings some of the results. Bioethanol from sugarcane, among all biofuels, holds the best position today in environmental performance (notably, in GHG mitigation) and economic sustainability, and has gained approval in social issues.

What will be the trends for the next ten years? We must look at the policies and legislation, since they are essential for the investments; and to the technology perspectives.

Although it is clear that some needed policies in Brazil (mostly leading to regulation in production, commercialization and taxes) have not been fully stated and regulated, the main problems are well known and it is expected that solutions will be implemented in the near future. A look at the trends, in the following text, assumes that this is the case.

Some environmental and social policies, both at federal and state levels, have advanced in a very positive way; examples are:

The Agro-Ecological Zoning (national) for sugarcane, identifying the areas suitable for production expansion, essentially for non irrigated cane, and forbidding the use of areas with native vegetation.

The (national) policies and legislation to promote the insertion of sugarcane bagasse generated electricity surpluses in the national grid

The State of São Paulo's policies and legislation to accelerate the phasing out of the practice of sugarcane burning; the regulation of vinasse disposition; and the gradual reduction of licensing for water uptake for the mills.

A large number of social programs, beyond the legal requirements for working conditions, being implemented by the mills.

The technology component for increased sustainability shows very important prospects for the next ten years; some items in the expected scenario, considering only proven technologies (or fairly advanced developments) are shown below. All are being used (or will be, in the next few years). Some of the impacts expected in sustainability are indicated.

Cane production

Optimized variety allocation (a,c):

Detailed soil mapping for Edaphoclimatic Environment classification: about 300 thousand ha /year being mapped (DONZELLI 2010)

Main variety breeding programs with regional selection

Need: much higher (quality and quantity) seed cane supply

Agricultural operations:

Equipment and systems for soil preparation, conservation (b) and low compaction (a)

Much better water management for "salvation" irrigation (stillage and residual) avoiding full irrigation; localized solutions (a, b).

Full use of precision agriculture technology to reduce and optimize inputs: fertilizers, herbicides, pesticides, lime (d).

Mechanical harvesting of green cane, with some trash recovery (c) (need equipment improvement)

Optimized use of residues (stillage, filter cake, boiler ash) including stillage distribution systems with no open channels (d) Increased reforestation of Environmental Protection Areas (e) Varieties for crop rotation / inter cropping (g)

Cane processing

Conversion efficiencies:

Minimize sugar losses; recovery of by-products (d)

Energy production

> Energy generation for 11 months of the year, with high pressure steam systems and 40% waste; lower heat and electricity self consumption (d)

New products

> Bioethanol and sugar streams (juice, syrup, sugar) as inputs to new processes (plastics, oils, other); matching surplus power to the new processes needs; combined with products. (f)

Most processes lead to impacts in more than one category; the letters are used to indicate the most important categories in each case.

(a) : impacts in cane productivity, leading to positive results in Agricultural Land Use, overall GHG emissions, economic sustainability
(b): impacts on water conservation; reduced run off of agricultural inputs; increased soil carbon stocks, impacting on GHG mitigation
(c): economic sustainability; reduced net GHG emissions (positive from cane burning and from surplus energy use); increased soil Carbon stocks
(d): economic sustainability and GHG mitigation
(e): GHG mitigation (increased carbon stocks), water and biodiversity conservation
(f): economic sustainability; GHG mitigation with the new systems
(g): economic sustainability; mitigation of Land Use Change

Social issues: labor quality

Experience over the last ten years clearly shows that the professionals required by the new processes (in cane production and processing) have to receive a much higher education and more specific training than before. In almost all the technologies listed above the lack of suitable workers has led to some failure in attaining the objectives. A great effort has been made by equipment manufacturers, mill owners and associations of cane producers to provide training; but still most of the problems, when looking for higher performance, come from the low skilled manpower available, not from the equipment alone. The solution to this problem will take time, but it will add to the sustainability of the production system: the upgrading of the workers education, leading to better living conditions and higher productivity.

Land Use Change effects on GHG emissions

The expansion of cane areas in Brazil has been closely observed, and it provides substantial information to help correcting / improving the modeling of emissions from direct and indirect LUC. A brief summary of the findings is as follows:

Since 2002 the cane expansion has substituted pasture and crop lands, with a very small (< 2%) area coming from native vegetation areas (RUDORFF 2010). The federal decree including the Agro-Ecological Zoning indicates that future expansion will not reach any areas of native vegetation.

Recent reports on Soil Organic Carbon mapping covering more than 1.3 million ha of sugarcane lands since 1990 (JOAQUIM, 2011) show that the carbon stock down to 30 cm, is compatible with the IPCC based estimates for perennial crops for the same regions (soil texture, climate), even for the burned cane practices used in this period. Green cane and higher productivity will lead to even higher SOC stocks, in the next few years.

Data for the last 20 years (PAES, 2011) show that the above ground biomass stock in sugarcane, in Brazil, averages 8.8 t C/ha.

The agricultural expansion areas in Brazil are expected to come from areas released from pasturelands, with increases in cattle raising productivity. This has occurred in the last few years (pasturelands decreased from 200 million ha in 1996 to 170 million ha in 2006, while increasing beef production); this future trend is supported by planning (governmental and private sectors).

When the correct parameters are used in the (suitably modified) models for simulated land use changes worldwide (both general or partial equilibrium models), or when stronger models (direct allocation) are used, the ILUC effects indicated on GHG emissions are very small (see Chapter XII, A.NASSAR *et al*).

References

DERNBACH, J.C. Stumbling toward sustainability. John C. Dernbach, ed., Environmental Law Institute, Widener University, 2002

DONZELLI, J.L et al. Ambientes de produção edafoclimáticos para a cultura da cana-de-açúcar. Revista Opiniões, p. 20-21, 2010.

IEA. Energy technology perspectives: scenarios and strategies to 2050. IEA – OECD, 2008.

JOAQUIM, A.C. et al. Organic carbon stocks in soils planted to sugarcane in the mid-south region of Brazil: a summary of CTC's data, 1990 -2009. Centro de Tecnologia Canavieira, Brazil, Tech. Report Sept. 2011. Acesso em: <www.ctcanavieira.com.br>

LOVINS, A. World energy strategies: facts, issues, and options. London: Friends of the Earth Ltd for Earth Resources Research Ltd, 1975.

____. Soft energy paths: towards a durable peace. San Francisco: Friends of the Earth International, 1977.

MACEDO, I.C. Sugarcane's energy – twelve studies on Brazilian sugarcane agribusiness and its sustainability. São Paulo: Berlendis & Vertecchia: UNICA, Brazil, 2005 (2nd Ed. 2007)

MEADOWS et al, The Limits to Growth. Universe Books, England, 1972. An updated version was published in 2004: Limits to Growth: The 30-Year Update, Chelsea Green Publishing Company and Earthscan.2004.

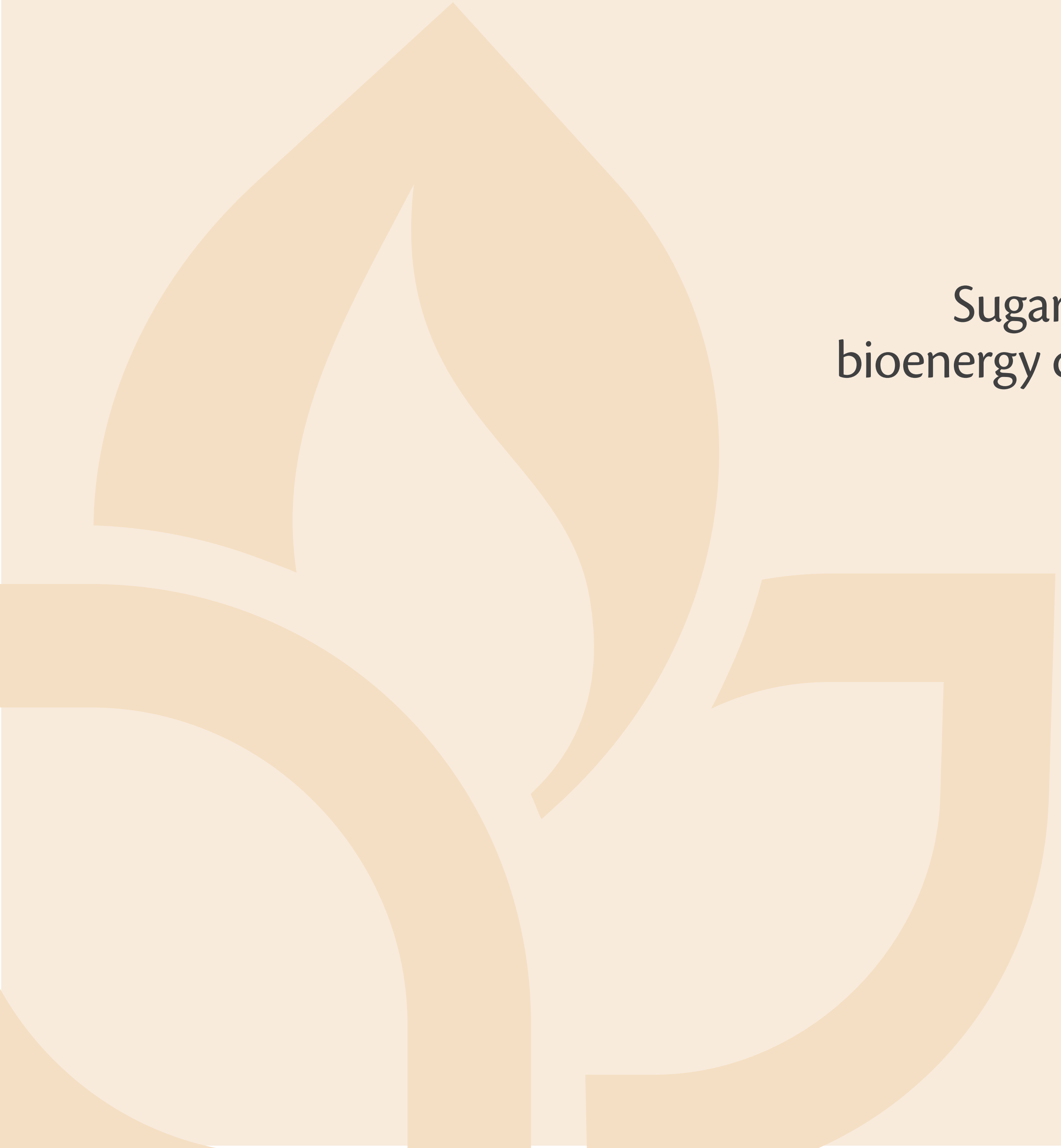
PAES, L.A. et al. Carbon storage in sugarcane fields of Brazilian South-Central region. Centro de Tecnologia Canavieira, Brazil, Tech. Report Sept. 2011. Acesso em: <www.ctcanavieira.com.br>

RUDORFF, B.F.T. et al. Studies on the rapid expansion of sugarcane for ethanol production in São Paulo State (Brazil) Using Landsat Data. INPE, Brazil Remote Sens. 2010, v. 2, p. 1057-1076; doi:10.3390/rs2041057.

SCHUMACHER, E.F. Small is beautiful: economics as if people mattered. England: Blond & Briggs, 1973.

Part II

Sugarcane bioenergy chain



Chapter 3

Agro-industrial technological paths

Paulo Sérgio Graziano Magalhães
Luiz Augusto Horta Nogueira
Heitor Cantarella
Raffaella Rossetto
Henrique C. Junqueira Franco
Oscar Braunbeck

A) Aspects of sugarcane production

Identification of relevant parameters

Significant changes in the sugarcane agricultural sector have been observed in recent years with increasing mechanization of the planting and harvesting processes. In São Paulo state the mechanized harvest increased from 35% in 2002, 20% being green, to about 70% in 2007/08 (SILVESTRIN 2008) with more than 49% green harvest (GESP - Secretaria do Estado do Meio Ambiente. 2009). These values are reflected on a smaller scale in other regions of the country, mainly in the Southeast and Midwest. One reason for this is that federal and state laws set deadlines for the elimination of the practice of straw burning, but it is mainly due to the Green Protocol in São Paulo State. This protocol is an agreement between UNICA, the Brazilian Sugarcane Industry Association (with voluntary participation of its members) and the São Paulo state government to end straw burning, in areas where mechanization is feasible, by 2014, and other areas by 2017. A Similar protocol was signed in the state of Minas Gerais, between representatives of the private sector and the state government.

While mechanized harvesting has brought clear benefits to the system, some studies show that the intensive use of agricultural machines also cause damage to the soil, compromising sustainability. Braunbeck and Magalhães (2010) show how the current model of sugarcane mechanization is characterized by the annual traffic of over 15 wide and heavily loaded wheels belonging to harvesters, tractors and wagons that cover about 60% of the field surface, with negative effects on soil structure and wheel performance, mainly under wet conditions.

Despite the availability of cane straw (10 to 20 Mg.ha^{-1} of dry matter basis) resulting from green harvesting, it is just beginning to be considered as a fuel for the cogeneration process. Keeping the straw on the soil surface brings clear benefits to the production of sugarcane, such as protection against soil erosion, reduction in the variation of soil temperature, protection from direct radiation, increased biological activity, better water infiltration rate, increased availability of water due to lower evapotranspiration, and better control of weeds (ROSSETTO *et al.* 2008). Straw also has its drawbacks, such as the increased incidence of pests that reduces cane quality and productivity, the increased risk of accidental field burning and the fact that mechanical cultivation is made more difficult during the growing season. These negative factors point in the direction of a partial recovery of straw lefting its excedent still being a significant source of energy for the cogeneration process.

Part of the residual straw left on the soil is incorporated into the soil as organic matter after the humification process, increasing carbon stock. Several authors (WOOD 1991; BLAIR, 2000; and NOBLE *et al.*, 2003, in Australia; DOMINY *et al.*, 2002, and GRAHAM *et al.*, 2002; in South Africa, and VILLEGAS, 1998, in Cuba) cited by Luca *et al.* (2008) showed that maintaining the straw on the soil surface, rather than burning the straw, resulted in a higher concentration of organic matter, comprised mainly of 50% organic carbon.

The sugarcane planting process also changed substantially during this period, mainly due to the introduction of required mechanized planting, resolving labour shortages. In addition, mechanized operations that precede the planting process have received special attention in recent years, mainly because of their high costs and energy demands. The soil preparation required for plantation reform occurs at intervals of five to seven years, and may reach up to ten years. The tillage system varies among producers, but traditionally begins with the stubble eradication process. This operation is performed mechanically (by shallow harrowing or using a stubble eliminator implement) or chemically (using herbicide Glyphosate). Due to the intense traffic of heavy equipment between the rows of sugarcane through the production cycle, the degree of soil compaction is usually high, requiring the use of deep tillage by means of subsoilers pulled by high power tractors. It is then necessary to mobilize the soil profile using mouldboard ploughs or heavy disc harrows, followed by light harrowing in order to break soil clods and even the surface for planting.

The traditional sugarcane planting system involves three distinct steps: harvest and transportation of cane setts from different locations of the plantation; opening the furrows with the application of fertilizers; distribution of setts, fumigation with fungicide and covering the setts at the bottom of the furrow. Until the mid-90's all the sugarcane was planted manually or using a semi-mechanized system where furrowing was performed mechanically; distribution and chopping of stalks was performed manually, while insecticide application and the furrow closing was done mechanically. During the 1996-97 season, a more intense process of planting mechanization began in Brazil through the acquisition of imported equipment or development of local solutions, such as was done by the Copersucar Technology Center, CTC (PINTO & MORAES, 1977ab). In the mechanized planting system all operations from sett harvesting to furrow closing are performed mechanically, increasing operational capacity of the system with significant reduction of manpower cost. The introduction of mechanized planting associated with precision agriculture has contributed to reduce some operational problems such as lack of row parallelism, improving the harvesting operation, especially at night, and also has some environmental benefits associated with the reduction of soil preparation, and water and wind erosion.

However, the machines available on the market today for seed harvesting and planting inflict high levels of mechanical damage to the cane setts. The greater quantity of seed cane required for mechanical planting, together with the sugarcane expansion process in Brazil, has created a seed cane demand that outweighs the available seed fields free from diseases and pest infestation with a negative impact on the quality of the new established areas.

The mechanical concept of depth tillage for soil physical conditioning is being replaced by the concept of minimum tillage. It is a way of growing crops under low soil disturbance keeping the surface covered with crop residues. In this system the biological activity, the incorporation of organic matter and the reduction of traffic allow for sustainable crop production with significant reductions in erosion, costs and water losses. Despite no-till farming being a well-established approach for grain production in Brazil, it is still an unusual practice for sugarcane. The intense machine traffic during the sugarcane cycle ends up hindering the popularization of no-till farming for sugarcane.

The main residues of sugarcane industrialization are stillage, filter cake and ashes. According to the composition of these wastes, field applications were developed in the form of solid or liquid fertilizer, always focused on the reduction of fertilization costs and environmental impacts.

Stillage is a liquid residue from the distillation of wine to obtain alcohol. Produced at a rate of approximately 11 litres per litre of bioethanol, it is the most important liquid effluent from the sugarcane industry. Positive factors such as the recovery of potassium, organic matter and water, along with negative factors such as the pollutant potential, give the vinasse issue a high economic and environmental importance. Among the effects of vinasse in the soil over time, Mutton *et al.*(2010) point out that it raises the pH, increases the cation exchange capacity (CEC), provides and increases the availability of some nutrients, improves soil structure, increases water retention, and improves biological activity promoting greater numbers of small animals, fungi and bacteria, and possible harmful effects caused to the soil or the plants are usually due to the application of excessive doses.

According to Braunbeck and Albrecht Neto (2010), the use of stillage in fertigation systems requires transportation, storage, and distribution systems with feasible investment and operating costs that could reach remote areas of the plantation, thus reducing the need for high doses and the corresponding impact to the environment.

The filter cake (press mud) is obtained from the sugar clarification process, equivalent to 3 to 4% of the weight of sugarcane crushed. It is an organic compound in 85% of its composition, rich in calcium, nitrogen, potassium and phosphorus, having its composition dependent on the raw material. According to Korndorfer (2004) cited by Santos (2009), some independent distilleries have introduced the system for clarification of juice, thus obtaining the filter cake. The same author also reports that the filter cake produced at the distilleries is rich in phosphorus, but the P_2O_5 content is variable, and the amount of filter cake generated by the distilleries is half of that produced by the sugar mills.

Filter cake is used as a mineral fertilizer supplement. It can be applied in the form of wet cake in dosages ranging from 15 to 35 $Mg.ha^{-1}$ when applied in the planting furrow. Higher rates are applied to ratoons, varying from 80 to 100 $Mg.ha^{-1}$ when distributed in the total area and 40 to 60 Mg.ha-1 when distributed between the rows of ratoons (CORTEZ, *et al.*, 1992). The application and storage processes of filter cake require adequate control, as its high oxygen biochemical demand may become a source of pollution. Also the levels of heavy metals that are not absorbed by the plant tend to percolate the soil, risking groundwater contamination (RAMALHO & AMARAL, 2001, cited by BRAUNBECK and ALBRECHT_NETO, 2010). The authors point out that even though there is economic viability in the use of the filter cake to supplement fertilizers, especially for planting, there is still room for improvement in the way of reducing costs, soil compaction and environmental risks, or increasing the sustainability of sugarcane agriculture by improving logistics in the distribution process.

Included among the relevant parameters related to the sustainability of the sugarcane agricultural production, should be the planting and harvesting processes, the level of soil compaction, the use of straw as an energy source, soil protection and carbon sequestration, and of course the rational use of fertilizers and waste from the sugar industry itself, which will be presented and discussed in other chapters of this book.

Reference values

Sugarcane planting

Within this parameter it is observed today in the production of sugarcane, that 30 to 40% of the planting is done mechanically and the rest is semi-mechanized, being the no-till farming used only experimentally in some mills.

Equipment used for mechanized planting has low technological development. It is not capable of performing precise intra-row spacing of setts, inducing the use of a larger density of buds per linear meter of furrow. Between 18 and 25 $Mg.ha^{-1}$ of seed cane are used in mechanized planting (Janini 2007). Garcia (2008), in a comparative study between the costs of mechanized and semi-mechanized planting systems, found that the operating costs are substantially lower for the mechanized, with a total cost of 121,00 $R\$.ha^{-1}$ against 216.24 $R\$.ha^{-1}$ for the semi-mechanized system, not considering the cost of cutting, loading and transportation of seed cane. However, mechanized planting uses higher quantity of setts per hectare, and the increase in mass planted is not accompanied by a corresponding increase in productivity, highlighting the weakness of this system.

Syngenta has recently launched a new concept in the market to plant sugarcane, using single budded setts with a length of 3 or 4 centimetres, called "plene", pre-treated with specific technologies to maximize early plant development. This technique promises significant advances in the cultivation system, potentially reducing costs for the producer by reducing the amount of seed cane used in mechanized planting. The “plene” system also offers the opportunity for greater varietal purity. Figure 1 illustrates the results of the distribution of setts for the three systems currently available for sugarcane planting in Brazil.

Semi mechanized whole stick

Mechanized 2 to 3 bud setts

Mechanized single bud setts (Plene)

Figure 1. Distribution of planting setts in the semi-mechanized and mechanized systems

Soil preparation

From the stand point of soil preparation for planting, the sustainability of sugarcane production can be improved through changes in agricultural practices such as traffic control, and no-till and precision farming. Whereas the technologies for conservation agriculture are being employed on almost 88 million hectares worldwide, one wonders why the sugarcane sector still doesn't use these technologies as part of a strategy to reduce costs, conserve soil and water, and achieve a more sustainable agricultural production.

The potential advantages of direct seeding in the case of sugarcane do not differ from those of other crops for which the results have been successful. It should be emphasized that to make possible the no-till system, it becomes necessary to drastically reduce traffic of the conventional mechanization system currently in use.

Soil compaction

The principle of mechanical harvesting currently used in Brazil is not meeting satisfactorily the current technical requirements in terms of efficient recovery of biomass and sustainable use of soil. The harvester capable of harvesting only one row, represents a high, non-renewable fuel consumption and low operational efficiency, requiring heavy machinery and equipment trafficking on more than 60% of the acreage, with consequent damage to the soil structure and plant growth.

The number of machinery passes between the rows of sugarcane is now excessive, and has reduced the longevity of the sugarcane plantation, inducing the use of soil subsoiling to reform the area. Without doubt, it is environmentally and economically necessary to reduce soil compaction during harvest, which together with green cane harvesting can minimize the problem, because the presence of crop residues on the soil surface reduces runoff and contributes to the structural stability of the soil.

Furthermore, the controlled traffic system (CT) used on some mills, is also contributing to the reduction of compaction. This technique consists of changing the gauge of the tractors and transfer equipment, and adjusting it to the rows spacing in order to create distinct areas for plant growth and vehicle traffic, in order to avoid traffic of the tires on the stubble. This technique of controlled traffic proved to be a successful innovation in Australia. According to Tullberg *et al.* (2007) traffic control leads to increased productivity, reduced operating costs and investments, makes more efficient use of rainwater, generates less runoff and surface erosion, and improves the physical condition and fertility of the soil. But these are only stopgap measures, because the reduction of soil compaction would only be possible if harvesters capable of harvesting two or more lines were available, or by using an entirely new concept for the harvesting system.

Mechanical harvesting

About 80% of the sugarcane in São Paulo state was harvested mechanically in 2011, but due to climate changes and harvester losses there was a drop in productivity (DATAGRO, 2011). Currently, for the 2011/12 harvest season in the South-Central region there is a projection for processing 490 million tonnes, which is 11.9% lower than the 556.88 million tonnes from the previous season.

A second challenge to overcome is the limitation of the harvesters to operate on slopes above 12%. Susceptibility to overturning and lack of directional stability are the main restrictions for operation on steeper slopes. To achieve 100% mechanization, equipment must be able to work on areas with a much greater slope.

The development of harvesters able to operate on steeper slopes may bring about some advantages. One possibility is associated with the harvester operating in two rows, requiring, in principle, increasing the wheel track, improving stability and enabling the crop in currently restricted areas. Two row harvesters increase operational capacity and reduce traffic on the area, bringing positive effects with respect to soil compaction and harvesting cost. There are difficulties to overcome such as development of increased capacity for gathering and cleaning processes of the harvester (weight of sugarcane per unit of time), associated with cane losses, both visible and invisible, as well as adequate quality of the harvested material (straw and cane).

The harvesters available on the market today use inadequate technology to handle green cane plantations with continuously increasing productivity, needing to harvest both stalks and straw, with much lower levels of losses and extraneous matter. The development of a semi-mechanized harvesting system to facilitate the work of man power may be a trend in areas where mechanical harvesting is not yet an adequate solution. This will help to minimize the social problems arising from the rapid advance of the totally mechanized harvest. In the prospective 10 to 15 years there must be advances in technology, enabling the harvest in currently restricted areas and a trend to improve rather than replace existing technologies.

Straw recovery

Currently there is a question in the sugarcane sector: how much straw can be removed from the field for cogeneration? Trying to answer this question, Manechini, Adhair Ricci_Júnior, and Donzelli (2005), in a study conducted by CTC, found that about 7.5 $Mg.ha^{-1}$ of dry matter should remain on the field in order to generate maximum agronomic benefits such as the chemical herbicide effect for weed control. However, field management under straw blanket is not that simple; other technological and economical challenges related to handling, transportation and cleaning require solutions to make it feasible.

The great difficulty lies in the handling and transportation of this material from the field to the power plant, because investments required for straw transportation are high, according to the price paid for electricity fed back into the grid. There are already some initiatives and developments in this direction, with some successful experiences.

To remove the straw from the field and take it to the industry, several systems were tested, and the best options are presented in Figure 2. Studies conducted by the College of Agriculture "Luiz de Queiroz" (ESALQ), in partnership with the Cosan group (currently Raizen), indicated that the best system was an integral harvesting approach (conventional chopper harvesters dump into the wagons both stalks and straw with their cleaning devices, primary and secondary extractors turned off) (MICHELAZZO 2005). Similar results were obtained by Rodrigues_Filho (2005), comparing the recovery cost of baling straw, as well as integral harvesting, with total and partial recovery of straw. The results showed that the best advantage from the viewpoint of sustainability was the partial recovery of straw. However, for the adoption of a straw recovery system, it is also necessary to install a pre-cleaning process at reception at the mill, in order to separate stalks from straw as well as to reduce the levels of mineral and vegetable impurities before processing.

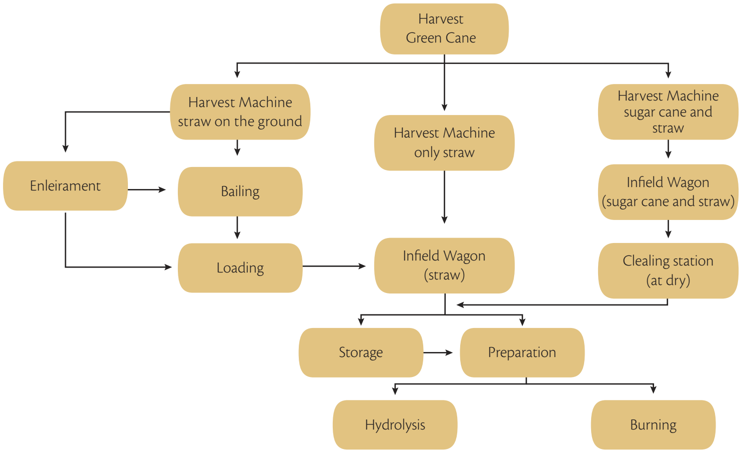


Figure 2. Possible routes for sugarcane straw recovery for energy.

Use of residues

Of the three main residues, namely stillage, filter cake and ashes, stillage is the most important one, from both the stand point of output quantity and pollutant potential. About as much tonnage of stillage comes out of bioethanol production as cane goes into the mill. The amount of sugarcane fields that can be economically reached by "fertigation" depends on the soil topography, as well as on the distribution system and management approach adopted. There are mills currently applying stillage on 70% of the production area and others reaching values much smaller (NOGUEIRA et al, 2008).

The distribution of stillage on the soil involves four phases that are quite distinct: primary transport from the industry to the storage tanks, storage, secondary transport from the tanks to the field, and distribution on the soil surface. Each phase involves equipment, infrastructure, manpower and management techniques focused on specific economic and environmental goals (BRAUNBECK & ALBRECHT NETO, 2010).

The main stillage distribution systems can be grouped into furrow infiltration, tank-trucks and spraying. The application by furrow infiltration requires large areas with suitable topography for its rational application, which has restricted its use (Silva, 1992). Application by tank-trucks, with gravitational or forced flow, was the most used system in the past due to its simplicity and versatility for application on variable field conditions, with adequate uniformity of distribution; however, it is limited by the transportation cost between the point of loading and the application areas. Spraying became a commercial option with the development of irrigation equipment such as the semi fixed moto-pump system that captures the stillage from main channels to feed the main and side pipes, to which sprinklers are connected. Currently, São Paulo state has popularized the combined sprinkler system, mainly through the channel and spool reel (BRAUNBECK & ALBRECHT NETO, 2010).

According to Mutton *et al.* (2010), continued use of vinasse in the same soil, even at low dosages, can cause saturation of cations, mainly potassium in the CEC of the soil, causing problems of leaching of their constituents to the groundwater. The leaching of K for the subsurface is not an environmental problem, since this element does not contaminate clean water. Nevertheless, the high concentration favours the formation of chemical complexes that are easily leached with a neutral change . The complex formed between the (K)+ and (NO_3)- is a particular concern from the environmental point of view, since nitrate is a major water pollutant. In São Paulo state, regulation P 4.231/2005 (Cetesb) regulates the criteria and procedures for the application of vinasse, setting standards for the storage, transportation and disposal on the soil. This regulation is forcing industry to carry stillage to greater distances and/or consider other solutions, such as its concentration.

Rossetto *et al.* (2008), considering the main residues from the sugarcane chain, estimated the potential for nutrient recycling on the whole area of production, estimated at 6.9 million hectares, without burning. Table 1 shows the estimated amounts of N, P_2O_5 and K_2O saved and which can potentially be added to the soil through the application of residues.

Table 1 – Nutrients recycled annually by the sugarcane agro industry

Residue	Nutrients			Volume of residues	Recycled Nutrient		
	N	P_2O_5	K_2O		N	P_2O_5	K_2O
	% of dry residue				*(ton year^{1})*		
Filter Cake1	1.4	1.94	0.39	3.03 million ton of dry filter cake year^{1}	42.400	58.800	11.820
Straw2	0.46	0.11	0.57	40.0 million ton of dry straw year^{1}	184.000	44.000	228.000
				(g m^{3} of vinasse)			
Vinasse3	375	60	2.035	360 billion L year^{1}	135.000	21.600	732.600
Total					292.750	99.550	755.230

[1] Sugarcane production in 2010/2011 season was 624 million tons, in 8 million ha, 288.7 million tons were used in sugar production producing 35 kg of filter cake per ton of crashed cane with 70% moisture content (CONAB 2011)

[2] 5 ton.ha^{-1} of dry straw considering 100% of the harvested area with green cane.

[3] Bioethanol production: 27.7 billion liters; vinasse production 13 L.L^{-1} of bioethanol produced.

Conclusion

The mechanical system for planting sugarcane still has serious problems that hinder its adoption and negatively affect some sustainability parameters. The planting equipment available uses low-level technology for handling and distribution of setts, using a high density of buds in the furrow and requiring larger areas for seed production, generating additional costs. The no-till system has not yet been adopted as a soil management practice. Scientific research emphasizes the benefit of this technique, but also warns about management problems that may arise under trash blanket agriculture. The great risk of adopting this management technique is associated with the intense equipment traffic at harvesting, causing soil compaction, suggesting that alternative technologies such as controlled traffic and/or new harvesting equipment should be developed to ensure sustainability of production. The production chain of sugarcane has an important differential against other cultures represented by the great potential for saving fertilizer by the recycling of nutrients. However, it must be remembered that there is only legislation on the disposal of stillage, and only in the state of Sao Paulo.

B) Impact of sugarcane green harvest on carbon sequestration and greenhouse gases (GHG) emissions.

Introduction

The sugar and bioethanol sector in Brazil presents important technological dynamics, with a permanent process of appropriation of innovations in the agricultural production, transportation of raw materials, processing and managing the entire supply chain, seeking complementary goals of increased productivity and reduced costs, mitigation of environmental impacts and increased sustainability. Indeed, particularly with reference to the latter point, several studies aimed at assessing the sustainability of bioethanol production from sugarcane, especially considering the conditions observed in South-Central Brazil, have clearly shown how this supply chain has positive indicators from the environmental, social and economic points of view (see, for example, Macedo 2005, and Macedo *et al.* 2008). However, as a result of recent developments in agricultural and industrial activities, new improvements have been suggested or effectively introduced, enabling further efficiency gains, reducing the environmental impacts associated with the agricultural industry and justifying further studies such as those presented in this chapter.

Soil carbon sequestration

Concerning the main reservoirs of C, the ocean is the largest, with 38,000 Pg of C. The second largest is composed of geological reserves of fossil fuels (4,130 Pg C). The third largest reservoir is soil, with approximately 2,500 Pg C up to 1 m deep, consisting mainly of organic carbon (1,550 Pg) and relatively inert charcoal. The atmospheric reservoir with 760 Pg C is the fourth largest, and biotic the smallest, with 560 Pg C (Lal, 2008). Therefore, the amount of C stored in soils is two times higher than that of the atmosphere, where the increase in the form of CO_2 is responsible for global warming.

Soils can either be a source of atmospheric CO_2 (especially through the mineralization of organic matter) or sink, which occurs when organic residues are incorporated into the stock of organic matter or the inorganic phase of the soil C. The C stock is the result of the balance between the supply of organic material, its C:N ratio, and climate. Cultivated soils generally have lower soil C stock than the same soils in natural ecosystems - usually between 50 and 70% of the original organic C - due to the effects of agricultural practices such as plowing, harrowing and cultivation, among others (LAL, 2008).

Figure 3 illustrates the behaviour of soil C stocks over time in different situations. Soils under natural vegetation tend to lose C when cultivated. The speed and magnitude of loss increases with the changes caused by soil cultivation, and depends on soil type and climate. Conservation management may decrease the loss of C or partially/totally reverse the downward trend in the stock of this element. The new system tends towards equilibrium, eventually reaching new values for the maximum capacity of the soil C storage, that depends on soil characteristics, climate and agricultural management. These factors also affect the time required to reach the new equilibrium.

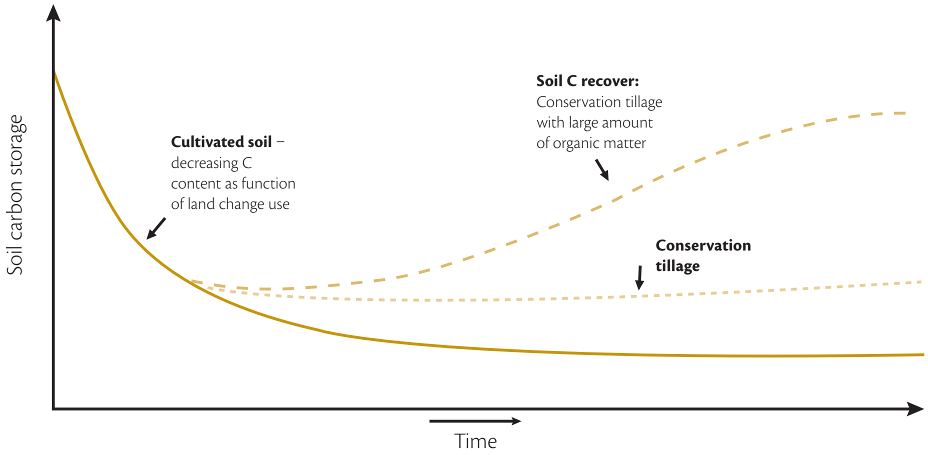


Figure 3. Conceptual framework of soil C stocks change as a function of cultivation. (Based on CANTARELLA, 2007)

The C sequestration in soils has an inverse curve when compared with mineralization of organic matter. It is a process with an asymptotic increase, which will cease when the new equilibrium is reached. This means that any management aiming to sequester atmospheric C in soil is not permanent. The average potential rate of C sequestration in the soil was estimated at around 0.4 to 1.2 Gt C yr^{-1}, or 5 to 15% of global fossil fuel emissions (LAL, 2004). Those values are relevant, but insufficient to mitigate a significant proportion of GHG. However, the ability to cause changes in soil C stocks - and to sequester C - can vary greatly depending on the farming system.

The stabilized soil organic matter has a C:N ratio of between 10:1 and 13:1. This means that the C sequestration must be accompanied by N fixation, a limiting nutrient in many ecosystems. In long-term studies on tillage in southern Brazil, Bayer *et al.* (2006) found that the organic matter content in soil was higher in areas where crop rotations included leguminous plants - fixing atmospheric N and straw with the highest N content, being the average rate of carbon sequestration 0.35 Mg ha^{-1} per year , similar to that reported by other researchers in regions of temperate soils (CORAZZA *et al.* 1999 and OLIVEIRA *et al.* 2005), and less than 0.48 Mg ha^{-1} estimated for subtropical soils of southeastern Brazil (CASTRO FILHO *et al.*, 1998).

Sugarcane straw usually has a C:N ratio of between 80:1 and 100:1, which in principle should make it difficult to incorporate C into the soil for lack of N. The C stock may decline in areas of burnt sugarcane harvesting because of low replenishing of organic C in the system, leading to soil degradation. Graham *et al.* (2002), in a study conducted in South Africa in an area with more than 60 years experience of a system of green sugarcane harvesting, compared with areas of burned sugarcane, observed that maintaining coverage with sugarcane straw was an effective way to increase the amount of soil organic matter (SOM), not only in the surface layer, but also the concentration of various fractions of SOM unstable at a depth of 300 mm . These changes, according to the author, affect other soil properties such as structural conditions, aggregate stability, soil N and activities of the microfauna and microorganisms, which improve the sustainability of the production of sugarcane. Figure 4 shows results observed in the same experimental area, displaying the benefits of the sugarcane harvest without burning 60 years after the beginning of this practice (GRAHAM *et al.*, 1999).

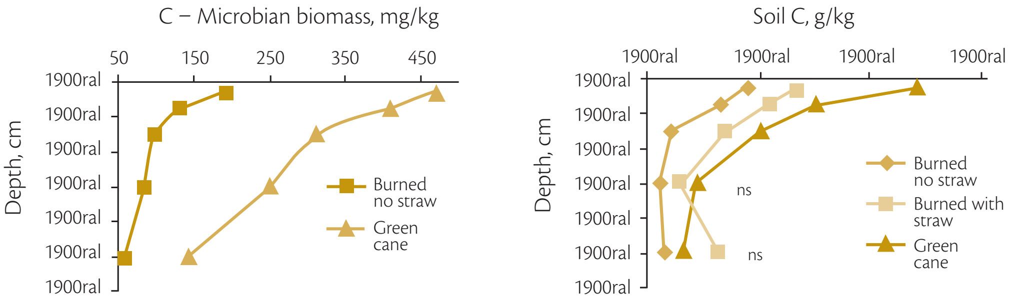


Figure 4. Variation in total content of C and C of the soil microbial biomass in burnt sugarcane and sugarcane after 59 years of differential management in South Africa The soil is a Vertisol and the region receives about 950 mm of rain per year.

Source: Graham *et al.* (1999).

Similar work was conducted by Canellas *et al.* (2003) in the northern state of Rio de Janeiro, Brazil, evaluating the properties of the soil in the area of sugarcane in a report of 55 years without burning and with maintenance of straw. The results showed that the maintenance of straw on the soil promoted improvements in soil chemical properties (increased CTC, reducing the point of zero salt effect-PZSE, increased levels of micronutrients and accumulation of SOM). Changes were also seen in the humification process, which included the accumulation of humic acids in the areas of preservation of straw. Using modelling software (Century), Galdos et al (2009) found that in all evaluated scenarios there is a trend in the gradual increase of the accumulation of C in soil, ranging from 2.3 gm^{-2} to 22.8 gm^{-2} , depending on the type of soil and climatic conditions, noting that the program had a high sensitivity employed to predict the simulation results (Figure 5).

Results obtained in the sugarcane plantations of Sao Paulo state indicate accumulations of C in the soil between 0.32 Mg ha^{-1} y^{r-1} and 0.8 Mg ha-1 yr^{-1} , with the adoption of mechanical harvesting (CARVALHO *et al.* 2010). The lower figure quoted seems more representative, because it refers to a period of 12 years. Moreover, the sugarcane crop is renewed every six or seven years, usually with great movement of the soil for planting, which can promote the oxidation of part of the C accumulated in the soil due to the management of sugarcane (CERRI *et al.* 2009). Under the conditions of the Sao Paulo state, Brazil, Faroni *et al.* (2003) observed that 40 to 50% of dry matter of straw remained in the soil after one year. The C:N ratio, however, decreased gradually from 85 in the recently deposited straw to 34 after one year. Oliveira et al (1999) obtained rates of decomposition of the straw after one year between 20 and 70%, depending on the trial site.

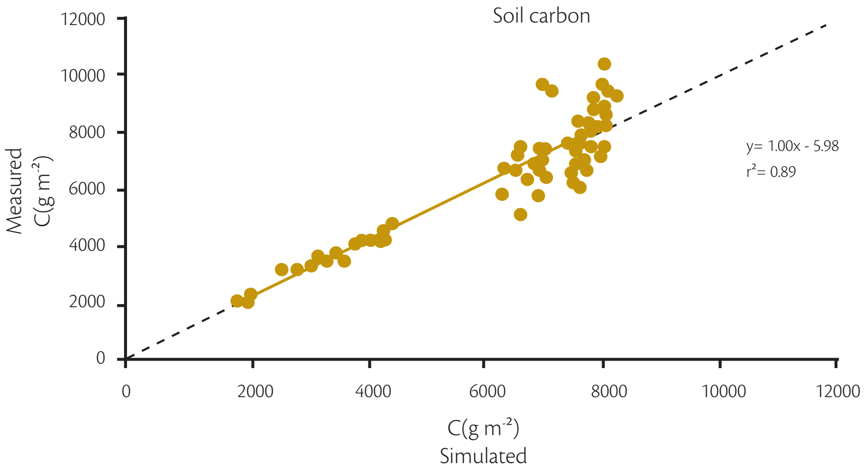


Figure 5. Linear regression between simulated and experimental values of C stock using the CENTURY model.

Source: Galdos *et al.* (2009).

Any change in use or soil management induces a change in carbon stocks, even in agricultural systems considered to be stable (SIX *et al.* 2002; LAL, 2008). The green sugarcane harvesting returns a large amount of C to the soil which would otherwise be lost during the burning of pre-cleaning (RAZAFIMBELO *et al.* 2006). Table 1 presents the results of Razafimbelo *et al.* (2006), in which is evidenced the benefits of green harvesting on the soil C and N (increases of up to 15% compared to the area with burning).

Galdos *et al.* (2009) point out that in addition to the carbon stock, other parameters can be used to measure the impact of residues management in the MOS. In order to evaluate the effect of sugarcane straw from the green harvest in the carbon dynamics, the authors studied two chronosequences in areas where sugarcane was replanted 2, 6 and 8 years earlier, and harvested with and without burning in Oxisols (currently 60% of the sugarcane in the South Central region of Brazil is planted in this soil type). The area with 8 years of planting had more total carbon (TC) than the areas with burned sugarcane, an increase of 1.2 Mg.ha^{-1} per year in the first 200 mm. Whereas the sugarcane is grown on about 5 million hectares of Oxisols in Brazil, the potential for carbon sequestration assuming that 100% of the area will be harvested without prior burning could be 6 Tg.C year^{-1}. The authors also pointed out that the system of tillage during the planting needs to be revised, because during the conventional tillage (subsoiling, ploughing and harrowing) the carbon stored in soil can be lost, leading to a rapid oxidation of MOS.

Table 2 – Total carbon (g kg^{-1}), total nitrogen (g kg^{-1}) and C/N ratio in sugarcane areas, burned (BUR) and unburned (MUL), in the respective soil layers. Values represent the mean of six replicates (RAZAFIMBELO *et al.* 2006)

Soil Depth	Carbon (g kg^{-1} C)		Nitrogen (g kg^{-1} de N)		C/N ratio	
(mm)	BUR	MUL	BUR	MUL	BUR	MUL
0-50	21.0±1.7Aa	25.2±2.4Ba	1.6±0.2Aa	1.9±0.2Ba	13.5±1.5Aa	13.5±0.6Aa
50-100	20.5±2.3Aa	22.3±1.2Ab	1.6±0.2Aa	1.7±0.1Aa	13.0±1.5Aa	13.1±0.4Aa
0-100	20.7±1.9A	23.7±1.7B	1.6±0.2A	1.8±0.2A	13.2±1.5A	13.3±0.5A

For a given depth layer, capital letters mark significant differences between treatments ($p<0.05$). For a given treatment, lowercase letters mark significant differences between depth layers ($p<0.05$).

Greenhouse Gases Emission (GHG)

Many agronomic effects of the presence of straw on the soil are known and have been cited in previous topics; however, replacement of burnt sugarcane field also prevents the emission of methane and other greenhouse gases.

The reduction of SOM implies the emission of gases into the atmosphere (especially CO_2, CH_4 and N_2O) and increased global warming (CERRI *et al.* 2007). Macedo *et al.* (2008), based on emissions factors proposed by the IPCC (2006), showed that 2.7 kg of CH_4 and 0.07 kg of N_2O are released for each Mg of dry matter burned. Considering that the straw represents 11 to 17% of sugarcane yield (PAES and M.A. OLIVEIRA 2005), and that the average productivity in Brazil is 81 Mg ha^{-1}, the harvesting of green sugarcane provides an emission reduction of approximately 30 kg of CH_4 and

0.80 kg of N_2O ha^{-1}. However, according to Cerri *et al.* (2010), these values can vary depending on weather conditions at the time of burning and conditions of the plantation. Other authors propose different methods for calculating the GHG emissions, but independently of the method adapted the methane emission lies in the range of 35-38 kg CH4 ha^{-1}. The same does not apply to nitrous oxide emissions which vary widely: from 0.5 to 3 kg ha^{-1} (Cerri *et al.* 2010). Macedo *et al.* (2008) also show that the increase in the harvested area without burning will bring significant changes in the pattern of GHG emissions in the coming years. In the scenario analyzed, emissions not resulting from the use of fossil fuels will be reduced from 19.5 kg of CO_2 Mg of sugarcane^{-1} (in 2005/2006) to 11.6 kg CO_2 Mg of sugarcane^{-1} in 2020 (Table 3).

According to Cerri *et al.* (2010), the fluxes of CH_4 can be positive (produced by soil) or negative (consumed into the soil), and are dependent on the microorganisms and environmental conditions. As an example, Figures 6 and 7 show the results of measurements performed in the systems of sugarcane burning (BC) and unburned (UBC) during the 1999/2000 crop season. It is observed that the average annual consumption of CH_4 in burning sugarcane is higher than in unburned sugarcane. However, observations made in one week after the harvest of sugarcane in an unburned system have noted an oxidation rate 56% higher than that of a burned sugarcane system (Figure 6). Regarding the daily flux of N_2O in the soil (Figure 7), from the microbial processes of nitrification and especially denitrification, BC showed an annual average value of 11 g N_2O ha^{-1} day^{-1}. In the UBC, daily flux had an average of 15.7 g N_2O ha^{-1} day^{-1}. For a year and BC systems USC emitted on average 4 kg N_2O ha^{-1} and 5.7 kg N_2O ha^{-1} respectively.

Table 3 – Emissions not related to the use of fossil fuels (kg CO_2 eq Mgc^{-1}) (adapted from Macedo *et al.*, 2008)

GEE	Crop Season		Scenario
	2002	**2005/2006**	**2020**
	___________________kg CO_2 eq Mgc^{1} ___________________		
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	9.9	8.6
CO_2 (urea, lime)	____	3.4	3.0

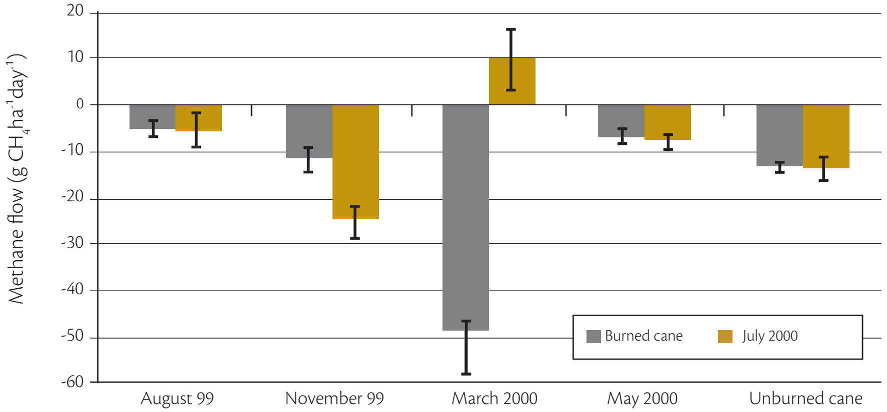


Figure 6. Methane flow in burned and unburned cane systems. The bars represent the standard error (standard deviation divided by the number of observations) (CERRI *et al.* 2010).

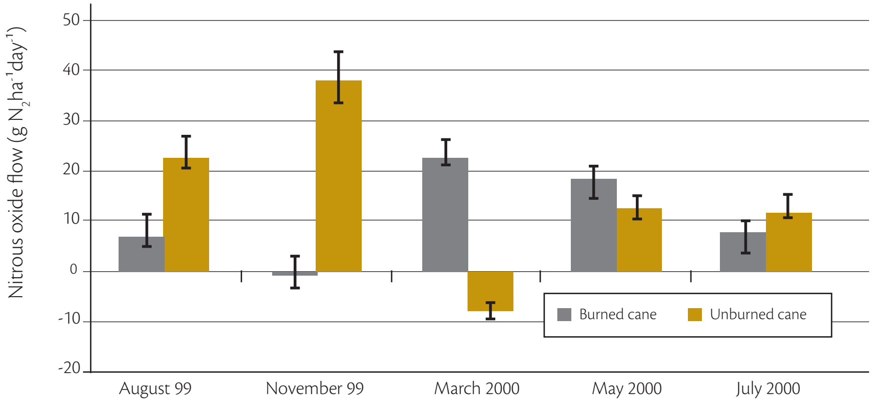


Figure 7. Nitrous oxide flow in burned and unburned cane systems. The bars represent the standard error (standard deviation divided by the number of observations), (CERRI *et al.* 2010).

Although the practice of maintaining the straw on the ground helps restore soil C stock, the impact of the method of tillage on C loss is not fully defined for sugarcane crop. A study conducted by La Scala Jr. (2006) in the area of sugarcane spanning 6 years of green sugarcane harvesting, found that a no-till system of the sugarcane contributed to reducing the crop residue emissions by 30% compared with the conventional tillage during soil preparation for sugarcane planting. Therefore, there is no doubt that further studies should also address this focus aimed at mitigating GHG emissions.

Other effects

Covering the soil with straw also has effects on soil physical properties that interfere indirectly with the management of N. Graham, Haynes, and Meyer (2002) reported the increase in microbial activity and the accumulation of surface organic matter causing increases in soil aggregate stability, water infiltration and nutrient cycling, improving the overall soil conservation. Beneficial effects on soil physical properties were also observed by Thorburn *et al.* (2002) in Australia and by (SOUZA *et al.* 2005) in Brazil. The latter, in a study evaluating the effects of 3 years after harvesting without burning, observed a significant increase in average pore diameter and a decrease in penetration resistance, especially when straw was incorporated into the soil.

There are doubts whether the maintenance of the straw affects productivity compared to the burning system. The effects on productivity are complex and involve factors such as adaptation of varieties, ratoon sprouting under the straw, pressure from pests and diseases, water availability, and nitrogen nutrition. Orlando Filho *et al.* (1994) reported that the presence of straw caused significant reduction in the production of stems, but the problem seemed to be related to the variety used. Gava *et al.* (2001) and Basanta *et al.* (2003) also reported lower production of sugarcane in areas without burning in relation to burn sugarcane in clay soils. Although, in this study, the reasons may have been excessive rain in the summer and N immobilization by straw. On the other hand, in sandy soil, Trivelin *et al.* (2002a,b) found no differences in stalk productivity in areas with or without burning. In some studies, the yields were not affected after three years of adoption of green harvesting (SOUZA *et al.*, 2005), or after 15 years (THORBURN *et al.*, 1999), while Oliveira *et al.* (1994) and Urquiaga *et al.* (1995) achieved higher yields in green sugarcane in most of the nine cycles evaluated.

All breeding programs currently operating in Brazil test the varieties budding under straw. Therefore, it is possible that the reduction in yield of sugarcane due to problems with straw sprouting will be solved in a short time. For the conditions in Australia, a simulation model for 35 years shows that 86% of the straw N that would be lost by burning would be stored in SOM or be exported with the harvested stems (THORBURN *et al.* 2001a).

In the medium and long term, the soil can accumulate organic C and N when the sugarcane is managed without burning, but in the short term, the contribution of residues with high C: N ratio can increase the demand for mineral N. Moreover, the reduced evaporation of water through straw cover may favour leaching losses and denitrification (WEIR *et al.*, 1998), although simulation models suggest that denitrification may not be affected by the presence of straw due to increased immobilization of N by microorganisms that act on carbon mineralization of straw, offsetting the excess water (THORBURN *et al.*, 1999).

The demand for N in green harvests can also be higher due to increased production of stems due to higher water availability (VAN ANTWERPEN *et al.*, 2002). Thorburn *et al.* (2002) state in their model, that the level of N in green sugarcane should be 60 kg N ha^{-1} higher than in the burning sugarcane to take advantage of excess water. The authors predicted that the response to N is stabilized only after 30 to 40 years. These numbers should be analysed with caution in Brazil because in the region where the data has been collected, rainfall is only 950 mm $year^{-1}$. On the other hand, Meier *et al.* (2002) predict that it will be possible to reduce nitrogen by 40 kg ha^{-1} in places with green harvesting after many years, when the system has reached a new equilibrium with accumulation of organic N in soil. Similar results were obtained by the team of Dr. Trivelin in the state of São Paulo, where the straw N recovery by regrows of the culture was assessed for 4 consecutive years (FORTES, 2010). Using a simulation tool, the researchers found that the N cycling of straw in a soil-plant system can reduce N fertilization (unpublished data), similar to that observed by Meier *et al.* (2002).

Production of coal as an alternative for C storage

An alternative to mitigate the greenhouse gas emission through the long-term storage of C in the soil is the use of coal (biocharcoal) from the carbonization at low O_2 vegetable residues. In this case, C is very stable and can remain in the soil for decades or even hundreds of years. For coal, the maximum storage of C discussed above does not apply. In fact, the addition of coal may even increase that limit for retention of organic C in soil. The viability of this practice depends mainly on the economic advantages of the use of coal (the doses necessary to produce benefits in the soil from the agricultural point of view are of the order of tens of tons per hectare) and the environmental balance. The production of biocharcoal releases greenhouse gases, whose evaluation must also be accounted for.

In many ecosystems where fire is a frequent or occasional part of management of the natural cycle, coal is a component of the soil. In the forest soils of Sierra Nevada ,California USA, coal content in a layer of 60 mm of mineral soil varies from 1000 to 5000 kg ha^{-1} (MACKENZIE *et al.*, 2008). Coal, although not constituted in a substrate easily oxidizable by heterotrophic organisms of the microbial flora of the soil, may have an important role in the SOM. It affects the formation and stabilization of humus and thus affects various microbial processes. Polyphenolic compounds can be adsorbed on coal, contributing to the fixation of additional quantities of C in soil (MACKENZIE & DE LUCA, 2006).

Coal is a highly resistant source of C in soil, which can not only affect soil fertility, but can eventually be counted for the purpose of obtaining C credits. Although coal cannot be considered an inert form of C, there is strong evidence that this material is also mineralized in the soil and does not constitute, therefore, a permanent sink for atmospheric CO_2 (GLASER *et al.*, 2002). The oxidation of coal can occur by abiotic or biotic processes, although the former is extremely slow under normal conditions of soil temperature. The role of microorganisms in the decomposition of coal is not well established, but there are several reports that soils with higher microbial activity release more C coal. The process is usually slow and occurs with the gradual oxidation of aromatic structures on the surface of the material. These reactions result in carboxylic groups, which are responsible for the formation of organ mineral complexes and increased cation exchange capacity of soils (GLASER *et al.* 2002).

Although subject to mineralization, much of the C coal can remain in soil for thousands of years, especially when stabilized with the SOM, demonstrated in several reports by the dating of C, even in the black soils of Brazilian Amazonia (Glaser, *et al.* 2002). Thus the C added to soil can help to mitigate the GHG by C sequestration for extended periods of time, and improve various characteristics of agricultural soils. But apparently, the addition of coal does not help to reduce the emission of N_2O from N added to soil (CLOUGH *et al.* 2010). The extent and magnitude of these effects depend on the feedstock and the mode of production of charcoal (GLASER *et al.* 2002).

Soils cultivated with sugarcane are potential sites of application of pyrolysed coal, because this crop generates large amounts of carbonaceous residue that can be used for the production of coal. This can help the environmental balance of the biofuels industry and enhance the productivity of agricultural soils, especially in sandy soils and soils with low fertility. However, significant effects of the application of coal are only observed with heavy applications of the product, usually above 10 Mg ha^{-1}. Thus, the technical and economic feasibility of using coal in sugarcane is yet to be proven. Assessments of long-term agronomic effects must still be performed, as well as costs of production and application of this material. An important factor is that the coal left in the ground leaves off generating energy, which may have other uses in an associated value, and may be relevant to an industry that produces bioenergy.

Straw recovery

The replacement of hand cut & burned sugarcane harvesting by mechanical green harvesting results in a large amount of biomass residue left on the ground. It is estimated that 8 to 30 Mg ha^{-1} of dry matter are added depending on the sugarcane yield (Vitti *et al.*, 2011); although the amount of straw that must remain in the soil to prevent erosion problems, to keep moisture and to ensure the recovery of soil C, is not yet known. There is a consensus that the amount of biomass residue produced in the green harvest is excessive, depending on the amount generated, and could be partly recovered for use in energy production, either by direct combustion or by hydrolysis to produce second-generation bioethanol.

An important point to consider is that the ability to retain soil organic C is dependent on soil characteristics, climate and management. This means there is a maximum potential to increase the C content in soil and that, once this point of balance has been reached, extra inputs of straw will not bring additional benefits. On the other hand, the removal of straw from the field and its transport to the industry is not a trivial operation. Several systems were tested, as previously mentioned, and are shown in Figures 8 and 9. In addition to differences in the cost of biomass recovery, each system differs in the form and quality that this material provides, plus the number of operations required and, consequently, the demand for fuel and CO_2 emissions.

To draw attention to the difficulty in collecting vegetable residues in the fields, the biomass from corn harvest (corn stove) is approximately of the same magnitude, and presents similar problems to those faced by sugarcane farmers. Since this is a widely available and reasonably concentrated product which does not compete with food, it has been used as a model of raw materials in research and development of processes for the production of biofuels at the National Renewable Energy Laboratory (NREL) (DENKE *et al.*, 2007 cited in TEMPLETON *et al.* 2009). However, the recovery of straw as corn stove has several limiting factors related to sustainability. Sokhansanj *et al.* (2008) investigated the cost, energy demand and emissions during the recovery process for cereal straw in Canada in five different scenarios, which showed that the energy demand and emissions was proportional to the recovery cost of straw in each system. Emissions from equipment used ranged from 20.3 to 40 kg CO_2 Mg^{-1} of dry matter. The sensitivity analysis of the productivity effect on the cost of production showed that the 33% increase in productivity represented a reduction of 20% in the cost of collection. These values are consistent with those presented by Braunbeck & Albrecht Neto (2010) and by the project developed in CTC (RODRIGUES_FILHO 2005) and Michelazzo (2005) all of them studies of recovering sugarcane straw.


Windrowing

Bailing

Loading

Figure 8. Baling sugarcane straw system.

Loading and transport of whole straw from green Harvest

Trash and Cane Harvest System with Dry Cleaning Station

Figure 9. Other systems for straw recovery: integral harvesting and bulk transport.

Use of biofuels (bioethanol and biodiesel) in agriculture and transport of sugarcane

During the decade of 1975-1985, which saw the first phase of the Pro-Alcohol program and a great expansion in the production of sugarcane agribusiness, the adoption of bioethanol as a substitute for diesel was evaluated, and was widely used in agricultural activities and transportation of sugarcane to the mills. In this evaluation, two technologies were studied the most: 1) the bioethanol use, pure or in mixtures with diesel, in Diesel cycle engines, using additives to increase the cetane number and lubricity of bioethanol, and 2) the so-called "ottolization" diesel engines, corresponding to their conversion to Otto cycle, reducing the compression ratio and incorporating spark ignition systems for use with hydrous bioethanol (SOPRAL, 1985). Especially because of the reduced energy advantage of bioethanol, since this biofuel in Diesel engines does not provide a higher efficiency as in Otto engines, and due to the more competitive prices of Diesel derived from petrol compared to bioethanol, these technologies have made little progress and were practically abandoned in the early eighties.

After more than two decades, in the last few years a revival of interest in the use of bioethanol in heavy-duty engines was observed, especially considering the use of Diesel engines with high compression ratio, or Otto engines that were supercharged and of high performance. The Swedish manufacturer Scania, has achieved significant advances in their Diesel engines and in 2007 launched a third generation of commercial engines using a hydrous bioethanol additive with 9 litres of displacement, 270 horsepower and a high compression ratio (28:1), taking into account the new European standards for vehicle emissions (Euro 5) (SCANIA, 2007). These engines have been adopted in 138 buses of an experimental program, the Bioethanol for Sustainable Transport Project, which promotes the use of bioethanol for transportation in many cities around the world (Brandenburg, Stockholm, La Spezia, Madrid, Nanyang, São Paulo, Somerset and Rotterdam). In addition to these engines, China has also been using flex engines with dual tanks, where the engine start-up is initiated with gasoline and after heating of the motors, uses only hydrous bioethanol. Particularly in Sweden, public transportation using biofuels has been widely adopted. Since 1989 there are buses that use hydrous bioethanol in Stockholm, currently amounting to a fleet of 400 vehicles; future targets being that bio-fuelled buses make up 50% of the fleet in 2011, and from 2025, that all vehicles run on biofuels (BEST, 2010). It is also known that the MWM have developed in Brazil, along with AGCO and Delphi, the design of an bioethanol based engine to replace diesel engines for use in trucks, commercial vehicles and agricultural machinery.

Besides bioethanol use, biodiesel should be considered. Since January 2010, it is mandatory in Brazil to blend 5% of biodiesel in all diesel sold for vehicular purposes. Biodiesel was introduced in the Brazilian market in 2003 and since then its production capacity has expanded dramatically, based primarily on soybean oil and beef tallow as raw materials, transesterified by the methyl alkaline process. The perspectives are that gradually other raw materials, such as palm, become predominant. Also, it is expected the improvement of the process to replace methanol by bioethanol from sugarcane.

Estimation of diesel consumption in the sugarcane industry

In order to evaluate the impact of biofuel use on the consumption of fossil energy and GHG emissions of bioethanol industry, the next few paragraphs present an estimate of regular diesel consumption in agricultural activities and transport in sugarcane. Following, the biofuels adoption is studied, considering the use of biodiesel in three scenarios, and the use of hydrous bioethanol scenarios are established.

To estimate the consumption of diesel in the sugarcane industry the values presented by Seabra (2008) were adopted, referring to the 2005/2006 harvest in the Centre-South region of Brazil, based on results of the "Agroindustrial Mutual Control" developed by the Sugarcane Technology Centre, CTC, which tracks 40 mills in this region, responsible for a significant fraction of national production. According to this survey, the consumption of diesel in these activities ranged from 68 to 285 litres per hectare ($L.ha^{-1}$), with a dispersion that confirms the sensitivity of this consumption to agricultural practices and modals of transportation adopted, and the possible inclusion of consumption of activities not related to the production of bioethanol.

Adopting the procedure of Seabra (2008), which conservatively considered only the cases with consumption above 160 $L.ha^{-1}$, weighted by the crushing of these mills and adding a consumption of 15 $L.ha^{-1}$, for the transportation and distribution of stillage and filter cake, an average consumption of 230 $L.ha^{-1}$ was obtained. In a previous study, developed from the characterization of the operations and determining their specific consumption in agriculture activities and transportation, a consumption of 164 $L.ha^{-1}$ was estimated (MACEDO *et al.*, 2004). The difference between these two estimates was attributed to other activities and services performed in the production of sugarcane (SEABRA, 2008).

Table 4 presents a breakdown of diesel consumption, relative to the cultivated area, which allows the calculation of the total consumption of diesel, as a function of the production cycle and the partial adoption of mechanical harvesting. For this estimate, for the 2005/2006 harvest, the average yield of 87.1 Mg.ha-1 and 86.3 litres of bioethanol per ton of cane processed were adopted as representative conditions: production cycles with five cuts, with mechanized harvesting in 50% of the harvested area (SEABRA, 2008). Further on in this chapter these parameters are used in the scenarios considered for the introduction of biofuels.

Under these conditions it was estimated that in total consumption of diesel, 31% corresponds to agricultural operations, 40% to the harvesting, loading and transport, and 29% to other activities related to the production of bioethanol and unidentified activities. Interesting additional information can be obtained from the study of Capaz (2009), which estimated from CTC data and the work of Seabra (2008) that the transport of stillage and filter cake corresponds to 34.6 L.ha^{-1}, therefore under the assumption that 67.0 L.ha^{-1} is consumed for other uses.

Table 4 – Diesel consumption in sugarcane industry, 2005/2006 season (SEABRA, 2008)

Activity	Unit	Diesel consumption
Agriculture operations		
plant cane	L.ha^{-1}	102.6
ratoon cane	L.ha^{-1}	9.1
Harvesting, loading and transportation[1]		
harvester	L.ha^{-1}	91.4
loader[2]	L.ha^{-1}	14.2
tractor and infield wagon	L.ha^{-1}	32.7
Other activities	L.ha^{-1}	67.0

[1] Considering 87.1 Mg of sugarcane harvested per hectare.

[2] Loaders are used in manual harvesting only

Scenarios considered for the use of biofuels

To consider the introduction of biofuels in agricultural activities and transport, without changes in the machinery and truck fleet, four different scenarios were evaluated, considering the use of hydrous bioethanol and biodiesel, with the following conditions, to be compared with the scenario reference corresponding to pure mineral diesel:

Scenario 1: B5 (5% biodiesel in diesel), considering the current mix of raw materials for biodiesel (85% from soybean oil and 15% from beef tallow, methyl route);

Scenario 2: B5, considering an improved mix of biodiesel production (85% from palm oil and 15% from beef tallow, methyl route);

Scenario 3: B100, considering an optimized mix of biodiesel production (85% from palm oil and 15% from beef tallow, ethyl route);

Scenario 4: E100, hydrous bioethanol additive in high performance Diesel engines (fuel injection and high compression ratio).

From the standpoint of the adequacy of these engines to use biofuels, the first two scenarios correspond to the situation existing in the Brazilian market since January of 2010, so they do not require any change in the engines, because the specification for biodiesel was established to ensure that parameters such as viscosity, lubricity, stability, etc. of the mixture of biodiesel/diesel (at low levels) are the same as those found in diesel fuel. Under these conditions, most manufacturers of Diesel engines give the guarantee of their products to operate with B5 and in some cases to levels of up to B20. For the other two scenarios in which it is assumed that the tractors, harvesters and trucks of the mills are using pure biodiesel or bioethanol additive, engine modifications are required. In Scenario 3 these changes could be relatively simple, essentially those related to materials used in the engines, and have been implemented by some manufacturers such as Deutz, Germany, which is offering engines from 10 to 500 kW for road and off-road vehicles, using only biodiesel, a product marketed in some places in that country. For Scenario 4, the technology being used is still under development, but currently some Diesel engines are now sold by Scania, capable of burning hydrous bioethanol, as mentioned earlier.

Besides the possibilities characterized in these scenarios, alternatives of combined use of bioethanol and diesel has also been explored, either through co-solvent mixtures, or using special motors with double injection in which the diesel acts as the igniters in the mixture of bioethanol/air. Despite the fact that these technologies are under study, the proposed scenarios can be assumed as the boundary cases for biofuel use, starting from the current frame, exploring the effect of changes in the system of biodiesel production and considering the exclusive use of hydrous bioethanol and biodiesel to totally replace diesel .

Modelling the impacts of the adoption of biofuels: fuel consumption and emissions

Although significant effort has been applied in the analysis of Brazilian biofuel agroindustry in its various dimensions and aspects, there are still relatively few studies on the energy balances for biodiesel, based on regional data and using a significant database of production units. Therefore, in the present study, the values of the demand for inputs and information about the production and processing of raw materials for biodiesel were determined from different studies conducted in actual farms in Brazil, translated into energy values with the help of the same energy coefficients. Data for soybean biodiesel, for the cultures of northern Paraná, were obtained from Gazzoni *et al.* (2006), data for palm biodiesel were obtained from the work of Costa *et al.* (2006), who studied this agroindustry in Pará, and data for beef tallow for biodiesel were taken from the dissertation of Lopes (2006), which evaluated cattle slaughterhouses in São Paulo. Although not necessarily corresponding to average values for the Brazilian market, these studies refer to real production systems and can be considered to be representative.

For the coefficients of fossil fuel energy associated with energy inputs, the non-energy inputs (fertilizers, chemicals, etc.) and the equipment used, as well as anhydrous bioethanol for sugarcane, in the context of studies of energy production ethylic route for biodiesel and hydrous bioethanol suggested to be used in Diesel engines, the reference used was the work of Seabra (2008), based on a broad base of data obtained from the sugarcane industry in the South-Central region of Brazil. From this survey data from real production systems, converted to fossil energy consumption using a standardized energy coefficients base, it was possible to develop a comprehensive and relatively homogeneous energy balance, considering agricultural production and industrial processing, and allowing emissions estimates in each case. Table 5 presents the main results of this study for pure diesel and biofuels adopted in the scenarios studied.

Table 5 – Properties and parameters adopted for diesel and pure biofuels

Fuel	Lower calorific value (MJ/kg)	Density (kg/L)	Energy consumption fossil (MJ/L)	GHG emission factor (kg CO_2/L)
Conventional diesel	42.3	0.84	41.22	2.489
Soya biodiesel (methyl)	39.5	0.92	11.16	1.019
Beef tallow biodiesel (methyl)	37.5	0.92	5.50	0.469
Palm oil biodiesel (methyl)	39.8	0.92	10.53	0.796
Palm oil biodiesel (ethyl)	39.8	0.92	7.40	0.250
Beef tallow biodiesel (ethyl)	37.5	0.92	2.25	0.135
Hydrous bioethanol	26.4	0.79	2.71	0.257

An important aspect for evaluating the energy cost of biodiesel is the partition of the common costs between co-products, made in this study based on the energetic value of each product, such as cake produced in the extraction process of vegetable oils and glycerine resulting in the transesterification process. Particularly in the case of soy processing, where 82% of the raw material is transformed into cake for animal feeding, the distribution of common costs resulted in a significant reduction in the cost of biofuel. More details on the procedures and assumptions adopted for the complementary energy balance of these production systems and the determination of values in this table are available in CCAP (2008).

Energy impact of biofuels use in bioethanol production

The substitution of diesel for biofuels has a direct effect of reducing the use of fossil energy, in a proportion that depends on this new fuel consumption and demand of fossil energy required in its production. To estimate the variation of volumetric consumption of fuel in fleets of mills to adopt bioethanol and biodiesel, it is reasonable to assume that the work to be performed by the engines of agricultural equipment and trucks is the same for all fuels, and depends on the fuel characteristics and performance of these engines. For Diesel engines operating with biodiesel, a change in the performance is not considered, since the engines are virtually the same; however, for engines with higher compression ratio, as must occur with bioethanol, the relative gain performance was evaluated using the expressions of the theoretical efficiency of air power cycles, based on engine compression ratios (20:1 assumed for diesel or biodiesel and 28:1 for bioethanol engines), which should be considered a first approximation. Under these conditions, the relationship between the thermal efficiencies with conventional diesel and hydrous bioethanol additive was estimated at 0.95. Thus, it is possible to estimate the consumption of biofuels according to the following expression:

$$C_{biofuel} = C_{diesel}\left[\frac{(PC_i.\rho)_{diesel}}{(PC_i.\rho)_{biofuel}}\left(\frac{\eta_{diesel}}{\eta_{biofuel}}\right)\right] \qquad (1)$$

where:

C : biofuel consumption, (L.ha^{-1})

PCi : lower calorific value, (MJ.kg^{-1})

ρ : density, (kg.L^{-1})

η : engine thermal efficiency, (-)

After estimating the consumption of biofuels in agriculture and transportation of sugarcane, as well as the demand for fossil energy in its production, it is interesting to evaluate the relative impact of this replacement on the energy performance of agroindustry. In other words, it means to evaluate how the adoption of biodiesel in the agricultural stage of production processes can affect the efficiency of the production of bioethanol from sugarcane. With this purpose the following expression can be used for the energy ratio, ER, indicating the total energy production per unit of fossil energy consumption:

$$ER = \frac{EP_{ref}}{EC_{ref} - \frac{1}{Y_{ref}}\left[(FC.FE)_{diesel} - (FC.FE)_{biofuel}\right]} \qquad (2)$$

where:

ER : energy ratio, ($MJ_{renewable}/MJ_{fossil}$)

EP : renewable energy production, ($MJ.Mg^{-1}$)

EC : fossil energy consumption, ($MJ.Mg^{-1}$)

Y : yield, ($Mg.ha^{-1}$)

FC : fuel consumption, ($L.ha^{-1}$)

FE : fossil energy consumption in the production and consumption of the fuel, ($MJ.L^{-1}$)

To evaluate the relationship of energy through equation (2), the reference parameters were taken from Seabra's work (2008). Thus, for the 2005/2006 season, an average agricultural productivity of 87.1 $Mg.ha^{-1}$ was considered, the consumption of fossil fuels in bioethanol production (EC_{ref}) was valued at 234.2 $MJ.Mg^{-1}$ (90% in the agricultural phase and 10% in the industrial phase), and renewable energy production (EP_{ref}) was estimated at 2198.4 $MJ.Mg^{-1}$ (88% as bioethanol, 4% as a surplus of electricity and 8% as surplus bagasse), corresponding to a energy rate of 9.4.

Table 6 presents, for the scenarios studied, the weighted averages of the variables of interest in assessing the energy impact, and Table 7 shows the major results in the evaluation of the energy impact resulting from the use of biofuels: the specific volumetric consumption, according to equation (1) and the ratio between energy production and consumption of fossil fuels, according to equation (2).

Table 6 – Properties and parameters adopted for diesel and biofuels

Fuel	Lower calorific value (MJ.kg^{-1})	Density (kg.L^{-1})	Fossil energy consumption (MJ.L^{-1})
Reference scenario, conventional diesel	42.3	0.84	41.2
Scenario 1: Current B5 (85% methyl soy biodiesel and 15% tallow)	39.2	0.92	10.3
Scenario 2: B5 improved (85% methyl palm biodiesel and 15% tallow)	39.5	0.92	9.78
Scenario 3: B100 optimized (85% ethyl palm biodiesel and 15% tallow)	39.5	0.92	6.63
Scenario 4: E100 (hydrous bioethanol with additive)	26.4	0.79	2.71

Table 7 – Consumption of biofuels and energy ratio considering the use of biofuels

Fuel	Consumption (L.ha^{-1})	Energy ratio ($MJ_{renewable}/MJ_{fossil}$)
Reference scenario, conventional diesel	230	9.4
Scenario 1: Current B5 (85% methyl soy biodiesel and 15% tallow)	227	9.6
Scenario 2: B5 improved (85% methyl palm biodiesel and 15% tallow)	225	9.6
Scenario 3: B100 optimized (85% ethyl palm biodiesel and 15% tallow)	225	15.4
Scenario 4: E100 (hydrous bioethanol with additive)	392	16.0

According to these results and as expected, the use of biofuels can to an appreciable extent improve the energy productivity of the production chain of bioethanol from sugarcane. Indeed, the demand for diesel in agricultural activities and transportation of raw materials accounts for about 70% of energy consumption in the agricultural phase and 63% of total energy consumption observed in bioethanol production. Replacing a fossil fuel with relevant demand brings significant impacts, proportional, of course, to the fraction replaced and characteristics of the biofuel adopted. Thus, the scenarios considering the adoption of B100 and E100 corresponded to most relevant results, increasing the energy ratio observed in the reference scenario by 64% and 70%, respectively. The small difference observed in this parameter between Scenarios 1 and 2 (0.03%) is basically due to the similarity of the energy costs of biodiesel in each case, primarily due to the partition of energy costs in the processing of soybean oil and cake, resulting for the biodiesel from soybean an energy cost similar to the estimated cost of palm biodiesel.

Impact of adoption of biofuels on emissions in bioethanol production

It should be observed that the reduction of GHG emissions associated with the production of bioethanol from sugarcane due to partial or total replacement of diesel used in the production processes depends directly on the effective reduction of fossil energy consumption. To estimate this reduction is relatively simple when information is available on the GHG emissions in the production of these fuels and their consumption. In this sense, considering the introduction scenarios of biofuels and the GHG emission factors shown in Table 4, it is possible to estimate emission factors for biofuels to be adopted in each scenario, through the use of equation (3).

$$EGHG = EGHG_{ref} - \frac{1000}{AP_{ref}} [(FC.EF)_{fossil} + F(C.EF)_{biofuel}] \qquad (3)$$

where:

EGHG: GHG emissions (kg CO_2eq.m^{-3} of anhydrous bioethanol)

AP: agro-industrial productivity (m^{-3} anhydrous bioethanol.ha^{-1})

FC: fuel consumption (L.ha^{-1})

EF: GHG emission factor (kg CO_2eq.L^{-1} biofuel)

In this case, the reference parameters (baseline) were also taken from the study of Seabra (2008) for the 2005/2006 harvest, which estimated total net emissions of 269 kg CO_2 eq.m^{-3} anhydrous bioethanol, with inputs in GHG of 493 kg CO_2 eq.m^{-3} of anhydrous bioethanol (53% due to fossil fuels, 17% due to burning of sugarcane and 30% attributed to emissions from soil) and credits CO_2 eq.m^{-3} 224 kg of anhydrous bioethanol. For agro-industrial productivity of bioethanol, 7,517 litres of bioethanol per hectare was used (SEABRA, 2008). The values obtained for the emission factors of biofuels in each scenario, total GHG emissions and its reduction as regards to the baseline scenario are presented in Table 8.

Table 8 – Emission factors, total emissions and reduced percentage of total emissions associated with the adoption of biofuels in agriculture and transport

Fuel	GHG emission factors (kg $CO_2.L^{-1}$)	Total emissions (kg $CO_2.m^{-3}$ bioethanol anhydrous)	GHG emission reduction (%)
Reference scenario, conventional diesel	2.489	269.0	0.0%
Scenario 1: Current B5 (85% methyl soy biodiesel and 15% tallow)	0.937	266.7	0.9%
Scenario 2: B5 improved (85% methyl palm biodiesel and 15% tallow)	0.747	266.7	0.9%
Scenario 3: B100 optimized (85% ethyl palm biodiesel and 15% tallow)	0.233	222.8	17.2%
Scenario 4: E100 (hydrous bioethanol with additive)	0.293	244.9	8.9%

The results presented in Table 8, as would be expected, show impacts whose magnitudes are related to the energy ratio (ER) of the biofuel used, favouring: a) the use of biodiesel from beef tallow and palm facing the biodiesel from soybean, b) ethyl route in relation to methyl and c) the use of hydrous bioethanol additive. Thus, while reductions of GHG emissions for Scenarios 1 and 2 are very small, the other two scenarios showed substantial impacts. Currently, despite these favourable prospects, only the methyl route is actually in use and the production of biodiesel from soybean largely predominates, imposing significant efforts for improving ethyl biodiesel production processes and Diesel engine technology. These studies should continue in order to achieve the effective potential of biofuels in the context explored here, extending and consolidating the sustainability in the production of bioethanol from sugarcane.

Increase in the scale (milling capacity) of the sugar and bioethanol mills

Induced by the scale factor in the cost of capital, which has promoted the reduction of unit costs in the industrial phase while increasing the capacity of mills, the expansion of sugarcane production in new agricultural areas has been associated with intensification of the cultivated areas in the vicinity of production facilities and increased annual crushing of the mills (called field densification). Considering the recent two seasons (2007/2008 and 2008/2009), the average capacity of mills in the South-Central region rose by 9.5% and the average crushing capacity of the three major units increased from 6.66 to 7.41 million tonnes per year (MAP, 2010).

However, transport of raw materials is one of the relevant items in the energy cost of bioethanol and consequently of the GHG emissions associated with their production. According to the study by Seabra (2008) for the Centre-South region, in the 2005/2006 harvest season, the transportation of sugarcane represented 17.5% of energy consumption in the agricultural stage (36.8 $MJ.Mg^{-1}$) and 15.7 % of total energy consumption in bioethanol production. To illustrate the magnitude of this problem, the energy value of the diesel used (lower calorific value and energy consumed in its production and logistics) was 41.2 $MJ.L^{-1}$, with an industrial output of 86.3 litres of anhydrous bioethanol per ton of cane (values adopted earlier in this study), which resulted in a consumption of 10.3 litres of diesel per thousand litres of bioethanol.

For an assessment of the energy demand above, adopted as a reference condition for the transportation of raw materials from the sugarcane fields to the mill, a sample was considered (44 mills at the Centre-South of Brazil) in which the average raw material transportation distance was 23 km (SEABRA, 2008). Assuming for these mills an annual grinding of 2.27 million tons of sugarcane (estimated from the total grinding in mills presented in the survey, Seabra, 2008) and considering an agricultural yield of 87.1 $Mg.ha^{-1}$, with a cycle of cutting of 5 or 6 years, it was possible to estimate an area of 31.275 ha occupied with sugarcane, for a mill of that survey.

To explore the impact of scale and densification of mills on the energy consumption in sugarcane transport and associated emissions, a simplified model can be based on the fraction of sugarcane in the area around the plant. Thus, based on circular areas around the mill and recalling that the average radius of a circle is 2/3 of its radius , the fraction or the average densification can be defined by the following equation:

$$AM = \frac{\text{sugar cane field area}}{\text{total area by the transportation mean radius}} = \frac{0{,}01.AC_{ref}}{\pi.\left(\frac{3.\bar{R}_{transp}}{2}\right)^{2}} \qquad (4)$$

where:

AM: average densification, (-)

AC: area occupied by sugarcane (ha)

$\bar{R}_{transp}$: mean radius of transport (km)

Under the conditions described as references, the results indicated an average densification of 7.0%, meaning that in principle sugarcane plantation can be expanded, with a reduction in the average distance of transport and consequently, lower energy cost. Equation (4) also determines the mean radius of transportation, known as the area of sugarcane and the average densification. Using this tool, values of the mean radius as a function of densification and annual crushing were constructed in Figure 10. Current data indicates that there is a clear increase of the transportation distance of raw materials with increased mill capacity, imposing the densification of sugarcane fields to keep this distance at a reasonable level.

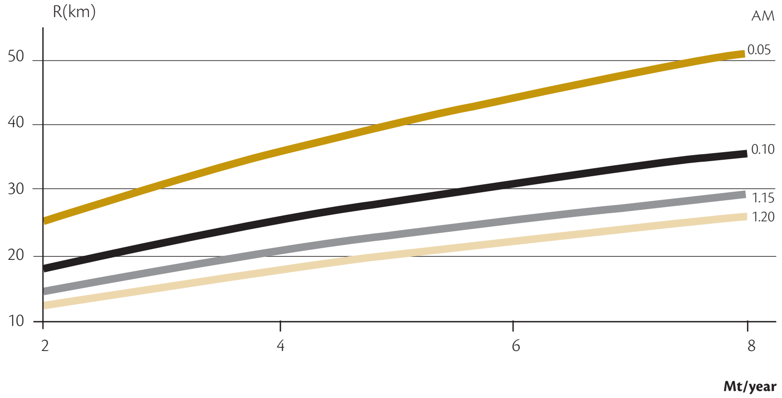


Figure 10. Average radius of transport in the capacity of the mill and densification of the fields

The average distance of raw material transport, observed in the 2008/2009 season in São Paulo, Goiás and Mato Grosso were respectively 25.1 km, 22.8 km and 22.7 km, which seem to indicate that the new, relatively larger mills, located in the last two states, are achieving the objective of planting sugarcane close to the mill (MAP, 2010). For example, in a mill crushing 4 million tons in a season, the goal is to densify the sugar canes fields to maintain a mean transportation radius of less than 25 km, keeping the transport energy cost at a competitive level (CHIARINELLI, 2008).

The efficiency of sugarcane transportation, measured in litres of diesel per Mg.km^{-1} , directly depends on the type of vehicle used (Table 9). For the whole sugarcane harvested manually flatbed trucks are used that can be simple (currently rarely used), or with several other trailers coupled to a main truck, depending on the traction capacity and road transport law to be observed. For the sugarcane harvested mechanically, the truck bodies must be closed to prevent loss of billets during transportation.

Table 9 – Parameters of vehicles used to transport sugarcane (CTC and CGEE, 2005)

Type	Load (Mg)	Specific consumption ($L.Mg^{-1}.km^{-1}$)
Single truck	15	0.030
Romeo and Juliet	28	0.022
Treminhão	45	0.019
Road-train	58	0.016

Considering the values calculated for the transport radius, adopting the specific consumption corresponding to the composition type Romeo and Juliet (truck plus trailer), it is possible to estimate the consumption of diesel in the transportation of raw materials for bioethanol production for different values of field densification and capacity. This consumption can be translated into units of energy and GHG emissions per tonne of cane produced, as shown in Tables 10 and 11.

The results of this evaluation may also be presented in relative terms, compared to the reference mill (with annual crushing of 2.27 Gg and 7% of densification, with total emissions of 269 $kgCO_2eq.m^{-3}$ anhydrous bioethanol), considering Seabra's results (2008), allowing to infer how they vary depending on the total emissions of the mill's capacity and density of the fields.

Table 10 – Impact of milling capacity and density of the plantations in the energy consumption and GHG emissions associated with transporting sugarcane for bioethanol production

Densification	Milling capacity ($Gg.year^{-1}$)							
	2.0		4.0		6.0		8.0	
	$J.Mg^{-1}$	$kg.CO_2.Mg^{-1}$	$J.Mg^{-1}$	$kg.CO_2.Mg^{-1}$	$J.Mg^{-1}$	$kg.CO_2.Mg^{-1}$	$J.Mg^{-1}$	$kg.CO_2.Mg^{-1}$
0.02	46.2	4.08	65.4	5.78	80.1	7.08	92.5	8.17
0.04	32.7	2.89	46.2	4.08	56.6	5.00	65.4	5.78
0.06	26.7	2.36	37.7	3.34	46.2	4.08	53.4	4.72
0.08	23.1	2.04	32.7	2.89	40.0	3.54	46.2	4.08

The present analysis is preliminary and indicative, not including secondary effects associated with the variation of densification. For example, the sugarcane transport distance affects also by-products, like stillage and filter cake, which should be transported from the mill to the field. Similarly, an important aspect of increasing capacity is to increase the performance of industrial systems, due to reduced losses and improved design and operation that is usually more available in larger systems. These aspects should be explored in further analysis of this problem.

Table 11 – Impact of milling capacity and densification of sugarcane in greenhouse gas emissions associated with transporting sugarcane for bioethanol production, compared to the observed emissions at the mill of 2.27 Gg.yea^{r-1}, with 7% of densification

Densification	Milling capacity (Gg.year^{1})			
	2.0	4.0	6.0	8.0
0.02	2%	9%	15%	19%
0.04	-3%	2%	6%	9%
0.06	-6%	-1%	2%	4%
0.08	-7%	-3%	-1%	2%

References

BASANTA, M.V.; DOURADO-NETO, D.; REICHARDT, K.; BACCHI, O.O.S.; OLIVEIRA, J.C.M.; TRIVELIN, P.C.O.; TIMM, L.C.; TOMINAGA, T.T.; CORRECHEL, V.; CASSARO, F.A.M.; PIRES, L.F.; MACEDO, J.R.. Management effects on nitrogen recovery in a sugarcane crop grown in Brazil. Geoderma (Amsterdam), v. 116, n. 1-2, p. 235-248, 2003.

BAYER, C.; MARTIN-NETO, L.; MIELNICZUK, J.; PAVINATO, A.; DIECKOW, J. Carbon sequestration in two Brazilian Cerrado soils under no-till. Soil and Tillage Research, v. 86, n. 2, p. 237-245. 2006. doi:10.1016/j.still.2005.02.023

BEST. Bioethanol for sustainable transport. Disponível em: http://www.best-europe.org/. Acesso em: jun 2009.

BRAUNBECK, O.A.; MAGALHÃES, P.S.G. Avaliação tecnológica da mecanização da cana-de-açúcar. In: BIOETANOL de cana-de-açúcar: P&D para produtividade e sustentabilidade. p. 413-424. 2010.

BRAUNBECK, O.A.; ALBRECHT_NETO, E. Transport logistics of raw material and waste of sugarcane. In: CORTEZ, L.A.B. (Ed.), Sugarcane bioethanol R&D for productivity and Sustainability, São Paulo: Blucher & Fapesp. p. 487-504. 2010.

CANELLAS, P.; VELLOSO, A.C.X.; MARCIANO, C.R.; RAMALHO, J.F.G.P.; RUMJANEK, V.M.; REZENDE, C.E.; SANTOS, G.A. Propriedades químicas de um cambissolo cultivado com cana-de-açúcar, com preservação do palhiço e adição de vinhaça por longo tempo. R. Bras. Ci. Solo, v. 27, n. 5, p. 935-944. 2003. doi:10.1590/S0103-90162001000300018

CAPAZ, R.S. Estudo do desempenho energético da produção de biocombustíveis: aspectos metodológicos e estudos de caso, Dissertação (Mestrado). Programa de Pós-Graduação em Engenharia da Energia, Universidade Federal de Itajubá, 2009.

CARVALHO, J.L.N.; AVANZI, J.C.; SILVA, M.L.N.; MELLO, C.R. de; CERRI, C.E.P. Potencial de sequestro de carbono em diferentes biomas do Brasil. R. Bras. Ci. Solo, v. 34, n. 2, p. 277-289. 2010.

CASTRO FILHO. C.; MUZILLI, O.; PODANOSCHI, A.L. Estabilidade dos agregados e sua relação com o teor de carbono orgânico num latossolo roxo distrófico, em função de sistemas de plantio, rotações de culturas e métodos de preparo das amostras. R. Bras. Ci. Solo, v.22, p.527-538, 1998.

CENTRO DE GESTÃO DE ESTUDOS ESTRATÉGICOS – CGEE. Estudo sobre as possibilidades e impactos da produção de grandes quantidades de etanol visando à substituição parcial de gasolina no mundo – Fase 1. Campinas: Nipe/Unicamp e Centro de Gestão de Estudos Estratégicos, 2005.

CHIARINELLI, M.D. Logística de transporte da cana-de-açúcar: desafios para um processo just in time. Opiniões sobre o setor sucroenergético, Piracicaba, abril-junho de 2008.

CERRI, C.C.; MAIA, F.; GALDOS, M.V.; CERRI, E.P.; FEIGL, B.J.; BERNOUX, M. Brazilian greenhouse gas emissions : the importance of agriculture and livestock. Scientia Agrícola, v. 66, n. 6, p. 831-843. 2009.

CERRI, C.E.P.; SPAROVEK, G.; BERNOUX, M.; EASTERLING, W.E.; MELILLO, J.M.; CERRI, C.C. Tropical agriculture and global warming: impacts and mitigation options. Scientia Agrícola, v. 64, p. 83-99. 2007.

CERRI, C.C.; FEIGL, B.J.; GALDOS, M.V.; BERNOUX, M.; CERRI, C.E.P.C. Carbon stock in soil and greenhouse gas flows in the sugarcane agro-system. In: CORTEZ, L.A.B. (Ed.), Sugarcane bioethanol R&D for productivity and Sustainability, São Paulo: Blucher & Fapesp. p. 203-216. 2010.

COMPANHIA NACIONAL DE ABASTECIMENTO – CONAB. Safra 2010 / 2011 Terceiro Levantamento Janeiro / 2011 Brasília, p. 19, 2011.

COSTA, R.E.; LORA, E.E.S.; ANGARITA, E.Y.; TORRES, E.A. Balanço energético preliminar da produção do biodiesel de óleo de palma para as condições do Brasil e da Colômbia. In: CONGRESSO INTERNACIONAL sobre Geração Distribuída e Energia no Meio Rural, 6., AGRENER, UNICAMP, Campinas. 2006.

CORAZZA, E.J.; SILVA, J.E.; RESCK, D.V.S.; GOMES, A.C. Comportamento de diferentes sistemas de manejo como fonte ou depósito de CO em relação à vegetação de Cerrado. Rev. Bras. Ci. Solo v. 23, p. 425–432. 1999.

CORTEZ, L.; MAGALHÃES, P.S.G.; HAPPI, J. Principais subprodutos da agroindústria canavieira e sua valorização. Revista Brasileira de Energia, v. 2, n. 2. 1992.

DECKER S.R.; SHEEHAN J.; DAYTON, D.C.; BOZELL, J.J.;,ADNEY, W.S.; HAMES, B,; THOMAS, S.R.; BAIN, R.L.; CZERNIK, S.; ZHANG, M.; HIMMEL, M.E. Biomass conversion. In: KENT, J.A. (ed) Kent and Riegel's handbook of industrial chemistry and biotechnology, vol 2. Springer-Verlag, New York: p. 1449–1548, 2007.

DOMINY, C.S.; HAYNES, R.J.; VAN ANTWERPEN, R. Loss of soil organic matter and related soil properties under long-term sugarcane production on two contrasting soils. Biology and Fertility of Soils v. 36, p. 350–356. 2002.

FARONI, C.E.; VITTI, A.C.; GAVA, G.J.C.; MANZONI, C.S.; PENATTI, C.P.; TRIVELIN, P.C.O. Degradação da palha (15N) de cana-de-açúcar em dois anos consecutivos (Compact disc). In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 29, 2003, Ribeirão Preto. Anais... Ribeirão Preto: Unesp/SBCS, 2003.

GALDOS, M.V.; CERRI, C.C.; CERRI, C.E.P. Soil carbon stocks under burned and unburned sugarcane in Brazil. Geoderma, n. 153, p. 347-352. 2009. doi:10.1016/j.geoderma.2009.08.025

GAVA, G.J.C.; CESAR, P.; TRIVELIN, O.; OLIVEIRA, M.W.D. Crescimento e acúmulo de nitrogênio em cana-de-açúcar. Pesq. Agropec. Bras., v. 36, n. 11, p. 1347-1354. 2001.

GAZZONI, D.L.; FELICI, P.H.N.; CORONATO, R.M.S. Balanço energético das culturas de soja e girassol para produção de biodiesel. In: CONGRESSO DA REDE BRASILEIRA DE TECNOLOGIA DO BIODIESEL, 1., v.1, p. 12-17, Brasília, 2006.

SÃO PAULO. Secretaria do Estado do Meio Ambiente - GESP. Relatório Ambiental Estratégico Etanol Verde. p. 1-8, 2009.

GRAHAM, M.H.; HAYNES, R.J.; MEYER, J.H. Green cane harvesting promotes accumulation of soil organic matter and an improvement in soil health. In: SOUTH AFRICA SUGAR TECHNOLOGIST ASSOCIATION, Proceedings… v.73, p.53-57, 1999.

____. Soil organic matter content and quality: effects of fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. Soil Biology & Biochemestry, v. 34, n. 1, p. 93-102. 2002. doi:10.1016/S0038-0717(01)00160-2.

GLASER, B.; LEHMANN J.; WOLFGANG Z. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review. Biol Fertil Soils n. 35, p. 219–230, 2002. doi 10.1007/s00374-002-0466-4.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE – IPCC. Guidelines for national greenhouse gas inventories, prepared by the National Greenhouse Gas Inventories Programme. In: EGGLESTON, H.S.; BUENDIA, L.; MIWA, K.; NGARA, T.; TANABE, K. (Eds.), Japan: IGES, 2006. N2O emissions from man- aged soils, and CO2 emissions from lime and urea application. Chapter 11, Generic methodologies applicable to multiple land-use categories. Chapter 2

JANINI, D.A. Análise operacional e econômica do sistema de plantio mecanizado de cana-de-açúcar (Saccharum spp .). São Paulo: USP. 2007.

KORNDORFER, G.H. Fósforo na cultura da cana-de-açúcar. In: YAMADA, T.; ABDALLA, S.R.S. (Eds.). Fósforo na agricultura brasileira. Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fosfato, 2004. p. 290-306.

LAL, R. Carbon sequestration. Philosophical Transactions of the Royal Society n. 363, p.815-830, 2008.

LOPES, E.M. Análise energética e da viabilidade técnica da produção de biodiesel a partir de sebo bovino. Mestrado (Dissertação). Programa de Mestrado em Engenharia da Energia, Universidade Federal de Itajubá, Itajubá, 2006.

LUCA, E.F. de; FELLER, C.; CERRI, C.C.; BARTHÈS, B.; CHAPLOT, V.; CAMPOS, D.C.; MANECHINI, C. Avaliação de atributos físicos e estoques de carbono e nitrogênio em solos com queima e sem queima de canavial. Revista Brasileira de Ciência do Solo, v. 32, n. 2, p. 789-800. 2008. doi:10.1590/S0100-06832008000200033

MACEDO, I.C.; SEABRA, J.E.A.; SILVA, J.E.A.R. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. Biomass and Bioenergy, v. 32, n. 7, p. 582-595. 2008. doi:10.1016/j.biombioe.2007.12.006

MACEDO, I.C. (org). A Energia da cana-de-açúcar - doze estudos sobre a agroindústria da cana-de-açúcar no Brasil e sua sustentabilidade. São Paulo: UNICA - União da Agroidústria Canavieira do Estado de São Paulo, 2005.

MEIER, E,A,. THORBURN, P.J.; WEGENER, M.K.; BASFORD, K.E. A conceptual analysis of nitrogen trash blankets in the wet tropics. Sugar Cane International, Maio-Junho, p.8-11, 2002.

MANECHINI, C.; RICCI_JÚNIOR, A.; DONZELLI, J.L. Benefits and problems of trash left in the field in Biomass power generation: sugar cane bagasse and trash. In: HASSUANI, S.J.; LEAL, M.R.L.V.; MACEDO, I.D.C. (Eds.), Biomass power generation, Sugar cane bagasse and trash. 1st ed.

Piracicaba: CTC - Centro de Tecnologia Canavieira, PNUD - Programa das Nações Unidas para o Desenvolvimento. p. 27-34. 2005.

GARCIA, M.A.L. Avaliação de um sistema de plantio mecanizado de cana-de-açúcar. São Paulo: ESALQ. 2008.

MICHELAZZO, M.B. Análise de sensibilidade de seis sistemas de recolhimento do palhiço da cana-de-açúcar (saccharum spp.). Campinas: Universidade Estadual de Campinas. 2005.

MUTTON, M.A.; ROSSETTO, R.; MUTTON, M.J.R. Agricultural use of stillage. In: CORTEZ, L.A.B. (Ed.), Sugarcane bioethanol R&D for productivity and sustainability São Paulo: Blucher & Fapesp. p. 423-440. 2010.

NOBLE, A.D.; MOODY, P.; BERTHELSEN, S. Influence of changed management of sugarcane on some chemical properties in the humid wet tropics of north Queensland. Aust. J. Soil Res. v. 41, p. 1133–1144. 2003.

NOGUEIRA, L.A.H.; SEABRA, J.E.A.; BEST, G.; LEAL, M.R.L.V.; POPPE, M.K. Bioetanol de cana-de-açúcar: energia para o desenvolvimento sustentável. Rio de Janeiro: BNDES, 2008, v. 1. 316 p.

OLIVEIRA, M.E.D.D.; VAUGHAN, B.E.; RYKIEL JR., E.J. Ethanol as fuel: energy, dioxide balances and ecolog footprint. BioScience, v. 57, n. 7, p. 593-602. 2005. doi:10.1641/0006-3568(2005)055

OLIVEIRA, J.J.; CHAVES, L.H.G.; QUEIROZ, J.E.; LUNA, J.G. Variabilidade espacial de propriedades químicas em um solo salino-sódico. R. Bras. Ci. Solo, v. 23, p. 783-789, 1999.

ORLANDO FILHO, J.; CARMELLO, Q.A.C.; PEIXE, C.A.; GLÓRIA, A.M. Adubação de soqueiras de cana-de-açúcar sob dois tipos de despalha: cana crua x cana queimada. STAB, v.12, n.4,p. 7-11, 1994.

PAES, L.A.D.; OLIVEIRA, M.A. Potential trash biomass of the sugar cane plant. In: HASSUANI, S.J.; LEAL, M.R.V.L.; MACEDO, I.C. (Eds.), Scientia Agrícola Piracicaba: PNUD - Programa das Nações Unidas para o Desenvolvimento CTC - Centro de Tecnologia Canavieira. p. 19-23. 2005.

PINTO, A.C.; MORAES, E.E. Equipamento distribuidor de cana-de-açúcar. In: SEMINÁRIO DE TECNOLOGIA AGRONÔMICA, 7, Copersucar, Piracicaba, novembro de 1977. Anais..., 1977. p. 213-222

____. Plantadora de cana. In: SEMINÁRIO DE TECNOLOGIA AGRONÔMICA, 7, Copersucar, Piracicaba, novembro de 1977. Anais..., 1977. p. 223-231

RAMALHO, J.F.; AMARAL SOBRINHO, N.M. Metais pesados em solos cultivados com cana-de-açúcar pelo uso de resíduos agroindustriais. Revista Floresta e Ambiente, v. 8, n 1, jan./dez. 2001.

RAZAFIMBELO, T.; BARTHES, B.; LARRELARROUY, M.; LUCA, E.F.D.; LAURENT, J.-Y.; CERRI, C.C.; FELLER, C. et al. Effect of sugarcane residue management (mulching versus burning) on organic matter in a clayey oxisol from southern Brazil. Agriculture, Ecosystems & Environment, v. 115, n. 1-4, p. 285-289. 2006. doi:10.1016/j.agee.2005.12.014

RODRIGUES_FILHO, J.P. Trash recovery cost. In In: HASSUANI, S.J.; LEAL, M.R.V.L.; MACEDO, I.C. (Eds.), Biomass power generation sugar cane bagasse and trash. 1st ed., Piracicaba: CTC. p. 74-85. 2005.

ROSSETTO, R.; CANTARELLA, H.; DIAS, F.L.F.; LANDELL, M.G. de A.; VITTI, A.C. Manejo conservacionista e reciclagem de nutrientes em cana-de-açúcar tendo em vista a colheita mecânica. INFORMAÇÕES AGRONÔMICAS, p. 8-13. 2008.

SANTOS, D.H. dos. Adubação fosfatada no plantio da cana-de açucar a partir de torta de filtro enriquecida com fosfato solúvel. S.l.: Universidade do Oeste Paulista. 2009.

SCANIA. New highly efficient diesel-ethanol engine - ready to cut fossil CO2 emissions by 90%. Scania Press Info, P07503EN, maio 2007.

SEABRA, J.E.A. Avaliação técnico-econômica de opções para o aproveitamento integral da biomassa de cana no Brasil:a avaliação técnico-econômica de opções para o aproveitamento integral da biomassa de cana no Brasil. Campinas: UNICAMP, 2008.

SILVA, E.T. Solo-cimento e solo-vinhaça no revestimen- to de canais de irrigação para transporte de vinha- ça: adequação física e parâmetros hidráulicos. 1992. 108 f. Dissertação (Mestrado em Engenharia Agrícola – Construções Rurais e Ambiência) – Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas, 1992.

SILVESTRIN, C.R. Bioeletricidade. In: Congresso Brasileiro de Agribusines,7. São Paulo: UNICA, p. 24, 2008.

SIX, J.; FELLER, C.; DENEF, K.; OGLE, S.M.; SA, J.C.D.M.; ALBRECHT, A. Review article Soil organic matter , biota and aggregation in temperate and tropical soils – effects of no-tillage. Agronomie, v. 22, p. 755-775. 2002. doi:10.1051/agro

SOKHANSANJ, S.; TURHOLOW, A.F.; STEPHEN, J.; STUMBORG, M.; FENTON, J.; MANI, S. Analysis of five simulated straw harvest scenarios. Canadian Biosystems Engineering, v. 50, n. 2, p. 27-35. 2008.

SOUZA, Z.M.D.; PRADO, R.D.M.; CLARET, A.; PAIXÃO, S.; CESARIN, G. Sistemas de colheita e manejo da palhada de cana-de-açúcar. Pesq. agropec. bras., v. 40, n. 3, p. 271-278. 2005.

TEMPLETON, D.W.; SLUITER, A.D.; HAYWARD, T.K.; HAMES, B.R.; THOMAS, S.R. Assessing corn stover composition and sources of variability via NIRS. Cellulose, v. 16, n. 4, p. 621-639. 2009. doi:10.1007/s10570-009-9325-x

TRIVELIN, P.C.O.; VITTI, A.C.; OLIVEIRA, M.W.; GAVA, G.J.C.; SARRIÉS, G.A. Utilização de nitrogênio e produtividade da cana-de-açúcar (cana-planta) em solo arenoso com incorporação de resíduos da cultura. Revista Brasileira de Ciência do Solo, Viçosa, v. 26, n. 3, p. 636-646, 2002.

TRIVELIN, P.C.O.; OLIVEIRA, M.W.; VITTI, A.C.; GAVA, G.J.C.; BENDASSOLLI, J.A. Perdas do nitrogênio da uréia no sistema solo-planta em dois ciclos de cana-de-açúcar. Pesquisa Agropecuária Brasileira, Brasília, v. 37, n. 2, p. 193-201, 2002.

THORBURN, P.J.; PROBERT, M.E.; LISSON, S.; WOOD, A.W.; KEATING, B.A., Impacts of trash retention on soil nitrogen and water: an example from the Australian sugarcane industry. In: SOUTH AFRICAN SUGAR TECHNOLOGISTS' ASSOCIATION, 72., p. 75–79. 1999. Proceedings… 1999.

THORBURN, P.J.; PROBERT, M.E.; ROBERTSON, F.A. Modelling decomposition of sugar cane surface residues with APSIM-Residue. Field Crops Research, v.70, p.223-232, 2001.

TULLBERG, J.N.; YULE, D.F.; MCGARRY, D. Controlled traffic farming—from research to adoption in Australia. Soil and Tillage Research, v. 97, n. 2, p. 272-281. 2007. doi:10.1016/j.still.2007.09.007

VILLEGAS, R.; CHANG, R.M.; GONZÁLES, M. Sostenibilidad del agroecosistema y evolución de características biogeoquímicas en estudios de larga duración con caña de azúcar. Cuba Caña, v. 2, p. 11-17, 1998.

VITTI, A.C.; COUTINHO, H.; FRANCO, J.; CESAR, P.; TRIVELIN O. Nitrogênio proveniente da adubação nitrogenada e de resíduos culturais na nutrição da cana. Planta. v. 1, p. 287-293, 2011.

WEIR, K.L. Sugarcane fields: Sources or sinks for greenhouse emissions? Australian Journal of Agricultural Research, v. 49, 1998.

WOOD, A.W. Conservation tillage and management of crop residues management of crop residues following green harvesting of sugarcane in north Queensland. Soil and Tillage Research v. 20, p. 69-85. 1991.

Chapter 3A

Fertilizer concerns

Heitor Cantarella
Raffaella Rossetto

Nutrient and fertilizer needs of sugarcane

Introduction

Mineral nutrients are essential components of plants; they make up about 5% of their dry mass and cannot be replaced by other elements. The classification as macronutrients (N, P, K, Ca, Mg and S) and micronutrients (B, Cl, Cu, Fe, Mn, Mo, Zn, and Ni) relates only to the quantities in which elements are present in plants. In addition to the minerals absorbed from the soil, plants contain carbon (C), oxygen (O) and hydrogen (H), representing approximately 96% of their mass, and are absorbed from air in the form of CO_2, and from water.

Micronutrients, used by plants in smaller proportions, are increasingly important to guarantee high yields of sugarcane, but are less relevant in the supply chain of raw materials for agricultural production and generally are not part of the crop production statistics. Silicon (Si) is not essential, but is considered a useful element; sugarcane absorbs large amounts of soil Si from the soil.

The average quantities of nutrients contained in the stalks of sugarcane plants are shown in Table 1 and give an idea of the exports of these elements with the harvested portions of the crop. The relatively wide ranges of variation reflect differences in varieties, growing conditions and soil types. For some nutrients, particularly potassium, there may be a luxury consumption, i.e., plants accumulate the nutrient in amounts above their needs, depending on nutrient availability in the soil. The requirements of plants are greater than those presented in Table 1, because the nutrients are also part of other plant structures such as leaves, roots and rhizomes. However, the quantities of nutrients in the stalks have more relevance to this discussion, as these are removed from the field and need to be replaced to maintain soil quality and the preservation of its productive capacity.

Table 1 – Mineral nutrients content per 100 tonnes of fresh harvested sugarcane stems(1).

Macronutrient	Content	Micronutrient	Content
	kg		g
N	80-140	B	235
P_2O_5	12-25	Cu	339
K2O	85-250	Fe	7.318
S	18-49	Mn	2.470
CaO	16-50	Cu	590
MgO	20-53		

(1) For some nutrients contents are traditionally expressed as oxides. Data for macronutrients are averages of several published studies compiled by Rossetto et al. (2008a). Data for micronutrients are from Orlando Filho (1993).

Sugarcane fertilization

Limestone and gypsum are important inputs for the production of sugarcane. Limestone is used to correct soil acidity, which is a characteristic of most Brazilian soils, to supply Ca and Mg, and to increase the availability of several nutrients. Gypsum aims at improving the chemical environment in the subsoil by providing calcium and reducing the activity of aluminum, thereby promoting deep rooting that facilitates water absorption, especially in drier periods and in areas with prolonged drought. Periodic applications of lime to sugarcane fields are made to raise the soil pH to at least 5.5 or the base saturation to 60% of the cation exchange capacity. Average gypsum application rates in Brazil range from 1 to 3 t ha^{-1} (SPIRONELLO *et al.*, 1997).

Fertilization of sugarcane in Brazil bears some differences from those practiced in other countries, denoting the peculiarities of soil, climate and management of each location. The recommendations of N in Brazil are generally lower and those of P and K, higher than in other regions, reflecting the low fertility of most Brazilian soils with respect to those nutrients.

The rates of N fertilizer used in Brazil are relatively small, especially in the cane plant cycle (30 to 60 kg ha^{-1} N). In the ratoon cycles, rates vary from 60 to 120 kg ha^{-1} N, depending on pending yield (CANTARELLA AND ROSSETTO, 2010). These recommendations were based mostly on data from cane crops burned before harvest. In other sugarcane growing countries with comparable yields, the rates of N are usually higher than 120 kg ha^{-1} N, and, in some cases, reach 200 kg ha^{-1} N (DONZELLI, 2005; GARCIA *et al*, 2003; RICE *et al.*, 2006). A recent network of field experiments conducted by Rossetto et al (2010b) in areas harvested without burning, in which 8 to 15 t ha^{-1} of trash is maintained on the soil surface, showed that maximum and economical yields were obtained with 148 and 120 kg ha^{-1} N, respectively. It is likely that with unburned cane and higher average yields, N requirements of sugarcane in Brazil will be higher than present fertilization. However, in the long term (> 15 years) trash preservation tends to increase the pool of soil organic N so that N fertilization rates are likely to decrease (THORBURN *et al.*, 1999; ROBERTSON AND THORBURN, 2007).

It is believed that biological nitrogen fixation (BNF) may play a role in supplying N for sugarcane under conditions in Brazil, which may explain the current N fertilizer rates used. There are various estimates for the N contribution of BNF for sugarcane but it seems that a realistic value for Brazil is around 40 kg ha^{-1} N (HERRIDGE et al. 2008). This issue will be further discussed in this chapter.

The average P rate used in Brazil is approximately 120 kg P2O5 ha^{-1} in plant cane and 30 kg P_2O_5 ha^{-1} in ratoons (DONZELLI, 2007; ROSSETTO *et al.*, 2008a). Corresponding figures for plant cane and ratoons in Australia are 58 and 57 kg P_2O_5 ha^{-1} (DONZELLI, 2007, HARTEMINK, 2008), in México 60 and 60 kg P_2O_5 ha^{-1} and in Costa Rica 150 and 75 kg P_2O_5 ha^{-1} (ROSSETTO *et al.*, 2008a).

Potassium is the element which is extracted and exported in higher amounts; therefore sugarcane usually requires high K fertilization rates. In Brazil K recommendation varies from zero up to 200 kg K_2O ha^{-1} depending on soil type, expected yields and recycling of by-products such as vinasse (SPIRONELLO *et al.*, 1997).

The mean doses of K applied to plant cane and ratoons, respectively, are 120 and 145 kg K_2O ha^{-1} in Australia, and 175 and 150 kg ha^{-1} of K_2O in Costa Rica (ROSSETTO *et al.*, 2008c). In Florida, USA doses range from 0 to 280 kg ha^{-1} K_2O plant cane and from 0 to 170 kg ha^{-1} K_2O in ratoons (RICE *et al.*, 2006), but in Louisiana the doses used are lower - up to 55 and 67 kg ha^{-1} of K_2O and plant cane and ratoon, respectively (LEGENDRE, 2001), reflecting the K supply capacity of soils from different locations.

Responses of sugarcane to micronutrients are usually less frequent than for macronutrients. In the sandy flatlands of the Northeastern region of Brazil, high responses to Cu and Zn are common, but not in the South-center region, where most sugarcane is grown and yield increases due to micronutrient application are scarce (CANTARELLA AND ROSSETTO, 2010). However, recent studies (BECARI, 2010) showed a high frequency of response to Zn and Mo, and medium responses to Mn and Cu application in the state of São Paulo in sugarcane fields grown in low fertility soils that are being increasingly used as this crop expands to new areas.

Sugarcane can produce high amounts of biomass with the same or even less fertilization than many other crops, indicating that sugarcane is relatively efficient in using nutrients. Nevertheless, about

17% of the fertilizer used in Brazil goes to sugarcane production; for nitrogen, the proportion is 23.3% (Table 2).

Table 2 – Fertilizers used in Brazil to produce sugarcane (2006/2007). Figures refer to fertilizers for sugar and ethanol.

Nutrients	Amounts of nutrient (1000 t)	Percentage of fertilizer used in Brazilian agriculture
N	535	23.3
P2O5	274	8.7
K2O	713	20.6
Total	**1.522**	**17.1**

Source: Heffer & Prud'homme (2008).

Fertilizers and the environment

The production of fertilizers worldwide currently consumes about 1.2% of the total energy use. Fertilizers account for 2-3% of GHG emissions: 0.93% in the manufacturing process, 0.07% in the transport, and 1.5% after field application. Agriculture accounts for 10 to 12% of total GHG emissions (SNYDER *et al*, 2009; WANG *et al*, 2007).

The use of nitrogen fertilizers, essential for crop production, contributes to the environmental liability of crops used for bioenergy production because of the environmental costs attached in terms of emission of GHGs (FIELD *et al.*, 2007, SCHARLEMANN AND LAURANCE, 2008). The major GHG emissions are associated with nitrogen fertilizer (Table 3). In the emissions that occur during manufacturing, CO_2 and CH_4 (methane) have some weight, but, overall, N_2O (nitrous oxide) emissions are crucial, especially those arising from the use of fertilizers in the field: 30 to 40% of the GHG generated for sugarcane production and transportation is solely caused by N fertilizer use (GALDOS *et al.*, 2010, LISBOA *et al.*, 2011).

Nitrous oxide is produced by natural processes of soil N cycle, mainly by reactions mediated by microorganisms. Although this represents a small fraction of the losses, this gas is a potent greenhouse gas, equivalent to 296 times the effect of CO_2 in terms of amount of substance (mol). N_2O emissions associated with the use of fertilizers were brought to the center of discussions about the environmental balance of crops for biofuel production. For example, Crutzen *et al.* (2008) argued that N_2O emissions from the use of nitrogen fertilizers alone could offset the environmental benefits of replacing fossil fuels with biofuels.

Table 3 – Energy and green house gases (GHG) emissions associated with the production and use of fertilizers and limestone

	NH3 (N)	Urea (N)	Ammonium nitrate (N)	Phosphate (P_2O_5)	Potassium (K_2O)	Limestone ($CaCO_3$)
----- per kg of nutrient (in parenthesis)						
Fertilizer and limestone production phase						
Energy used	45	53	65	14.0	9	8
CH_4 emission g	2.5	3.7	4.2	1.8	1.0	0.9
N_2O emission, g	0.02	0.03	19.7	0.02	0.01	0.01
CO_2 emission, kg	2.6	3.1	3.8	1.0	0.7	0.6
GHG, kg CO_2 eq	2.6	3.2	9.7	1.0	0.7	0.6
Emissions after field application						
N_2O emission, kg	0.016	0.016	0.016	-	-	-
CO_2 emission, kg	0.40	0.40	0.40			0.44a
GHG, kg CO_2 eq	5.05	5.05	5.05			0.44
Total GHG emission due to production and use						
kg CO_2 eq	5.65	8.32	14.75	1.0	0.6	1.04

a: CO_2 emission associated with limestone use to correct soil acidification by N fertilizers

Source: Snyder *et al.* (2009); Wang (2007)

Other losses related to the use of nitrogen fertilizers are important, especially those of NH3 volatilization and nitrate leaching. The environmental impact of volatilized NH_3 is relatively small, but this gas is considered the main source of atmospheric N deposition, which, in some countries, has been related to soil acidification and changes in natural ecosystems (CANTARELLA, 2007).

Ammonia losses in acidic soils such as the ones that prevail in Brazil are only relevant when urea is the choice of nitrogenous fertilizer and is surface-applied to soils. Under such conditions, the loss of NH_3 reported in Brazil may reach 40 to 60% of N; however, the most common values of measurements in the field are around 20 to 40% (CANTARELLA, 2007). If urea is incorporated into the soil, NH_3 losses are negligible. When sugarcane is burned before harvest, incorporation of fertilizer is a common practice. However, when trash is preserved, the thick mulch that remains on top of the soil makes it more difficult to mechanically bury urea. As urea comprises about 60% of the N fertilizer in the Brazilian market, NH_3 volatilization losses deserve attention.

Nitrate leaching is considered one of the most important routes of N losses in agricultural systems, compromising the quality of surface and groundwater. Meisinger *et al.* (2008) suggest that leaching of nitrate represents an average of 10 to 30% of N added to soils, but the magnitude of loss is very variable and depends on the presence of nitrate and excess water to percolate into the soil profile. N losses by NO_3 leaching in Brazil have been relatively modest. Contamination of surface and deep waters in Brazil with NO_3 doesn't seem to be a widespread problem. Several studies done in Brazil with nitrogen fertilizer labeled with ^{15}N showed that, in general, little N fertilizer has been moving to the subsoil in sugarcane fields (CANTARELLA *et al.*, 2007)

Phosphorus is also a nutrient that can cause environmental problems, and is often associated with eutrophication of surface waters. However, there are few reports of problems of excess P in areas of sugarcane in Brazil, because tropical soils are P deficient and have great capacity to retain this nutrient. In such soils, the primary means of surface water pollution is by laminar erosion because P hardly moves in depth. But runoff losses of P are not favored in sugarcane fields because P is applied in the planting furrow in cane plant and little P is employed in ratoons, where it could be surface-applied. In addition, conservation practices commonly used in areas cultivated with sugarcane are relatively efficient in preventing laminar erosion. Therefore, the main environmental concerns regarding fertilizer are related to gaseous losses and the energy used to produce N compounds.

World nutrient supply

FAO (2009) predicted that food supply will have to increase by 70% from 2009 to 2050 to meet the demand of an increasing world population. The global food vs fuel debate involves disputes over land and water. Localized problems of food shortage and the sharp increase of fertilizer prices in 2008 led some countries to temporarily halt food exports and raise barriers to fertilizer exports. Although these measures were reversed afterwards, the possibility that fertilizer supply may be of strategic value was reinforced. With the foreseen expansion of biofuel production in the world and particularly in Brazil, the question arises of the availability and supply of a key feedstock such as fertilizer.

The proportion of fertilizer consumed for sugarcane in Brazil is relatively high (13 to 17%) (Table 2) but worldwide it is much smaller. Of approximately 170 million tonnes of nutrients ($N + P_2O_5 + K_2O$) consumed worldwide in 2006/2007, only 4.1 million, or 2.4% of the total, were applied to crops for biofuels production, a very low proportion. Of this amount, most was consumed in Brazil and the United States for the production of ethanol from sugar cane and corn, respectively (Table 6). Brazil imports approximately 70%, 50%, and 90%, respectively, of the N, P, and K fertilizer or feedstock for fertilizer production but Brazil's share of the world fertilizer market is only 5.3% (HEFFER, 2009), although it is growing. The Brazilian Ministry of Agriculture forecasts an annual growth rate of fertilizer consumption of 4.3 to 4.5% up to 2020 when fertilizer demand shall be 59 to 62% higher than that of 2009 (GASQUES *et al.*, 2009).

Table 4 – Estimated amounts of fertilizer for crops used in biofuel production worldwide in 2007/2008. The data from Brazil and the United States are for ethanol(1) and do not include sucrose or corn for other purposes.

Nutrients	Fertilizer consumption		
	World	Brazil (sugarcane)	USA (Corn)
	------------- Mt of N, P2O5 e K2O ---------		
N	2,1	0,32	1,57
P2O5	0,8	0,16	0,58
K2O	1,2	0,43	0,65
Total	4,1	0,91	2,80
Ethanol production (billion liters)	**22,5**	**24,7**	

(1)Calculated from Heffer & Prud'homme (2008). It was assumed that about 28% of the fertilizer used for corn in the USA was purposed for first generation ethanol production.

The forecast of fertilizer use in sugarcane in 2022 varies from 1552 Mt of NPK to 2496 MT of NPK, depending on different scenarios. The highest number is based on a 1.8% annual increase in cropping area and a 10% increase in N fertilization due to wide adoption of unburned harvesting; the lowest estimate takes into account a strong effort of nutrient recycling in the sugarcane industry and biological N fixation advances, which can lead to reduced N fertilizer use (scenarios discussed in other chapter of this book).

Whichever scenario, fertilizer use for sugarcane production in Brazil will continue to be high due to the large area cultivated: 18% of the fertilizer consumption in Brazil in 2020 (ANDA, 2009). As most of this fertilizer is imported nowadays, fertilizer for biofuel production in Brazil deserves attention.

Limestone is abundant in Brazil and its supply for the production of sugarcane is not at risk. According to a recent survey conducted by Lopes *et al*. (2009), the total reserves of limestone in Brazil in 2005 – both measured and inferred - are of the order of 106 billion tons, which, at the current rate of consumption of Brazilian agriculture, 70 million tons per year (approximately 20 Mt for agriculture and 50 Mt for industrial uses, especially cement), are sufficient for 1500 years. Brazil also has large deposits of gypsum. The reserves, including those measured and inferred, are of the order of 1,700 million tons (RAIJ, 2008). However, most of the gypsum used in agriculture in the South, Southeast and Center west is a residue from the production of phosphoric acid in the fertilizer industry, known as phosphogypsum. About 11 tons of gypsum is generated per ton of phosphoric acid-P (RAIJ, 2008). There are large deposits of gypsum near the phosphate fertilizers plants. In addition, the increased production of phosphate fertilizers by the route of the phosphoric acid will also result in increased production of phosphogypsum. Therefore, the supply of both limestone and gypsum is not a limitation for the future expansion of sugarcane production.

In terms of strategic fertilizer supply, the important elements are N, P, and K. Although internal production of NPK has been growing steadily in Brazil (Lopes *et al*., 2009), fertilizer and feedstock are increasingly being supplied by imports, as discussed. For N there are limitations of industrial plants and feedstock. For K, presently the major limitation is the low availability of easily explored minerals resources. Brazil presents a relatively large production of phosphate fertilizers but high consumption causes the need to import both fertilizers and phosphate rock feedstock (LOPES *et al*., 2009).

Increasing the internal supply of fertilizer is a complex issue. Mining and fertilizer industries are capital-intensive, deal with bulky and low unit-value feedstock, and depend on long term investments. Only large private enterprises or government companies are capable of investing in this sector. Small and medium-size industries usually participate in the fertilized formulations and distribution side but they do not affect the overall offer on a national scale. The availability of feedstock is an important factor for local production. In general, mineral deposits are concentrated in a few countries (FIXEN, 2009).

There is no limitation in nature of N supply for fertilizer production because most of the N is taken from the atmosphere. However, the industrial reduction of N_2 to NH_3 requires large amounts of energy: 1,200 to 1,400 m^3 of natural gas per tonne of NH_3-N. About 99% of the N fertilizers worldwide are based on NH_3 (LOPES *et al*., 2009). Presently, natural gas accounts for 75 to 85% of the energy feedstock for NH_3 production and is the most cost-efficient technology for this application (FIXEN, 2009). Other sources include other petroleum fractions, such as naphtha (used in Brazil), coal, electricity etc. Therefore, the availability of N fertilizers will depend on energy supply. Data on the world stock of natural gas indicate that there are large reserves available, sufficient for about 100 years at the present consumption rate; most of the known reserves are in Russia and in the Middle East (FIXEN, 2009); Therefore, N fertilizer supply for cultivation of biofuel crops is not at risk to the extent that only about 5% of the natural gas used in the world goes to N fertilizer production. However, the price of energy will ultimately determine the cost of N fertilizers. In addition, the environmental cost of N fertilizer manufacture and utilization, already discussed in this text, may be an issue for bioenergy production.

Brazil imports around 70% of the N fertilizer consumed. This is likely to change in the near future. Recent discoveries of oil and gas in the Pre-Salt put Brazil in a more comfortable situation regarding medium term N fertilizer production. Petrobras is planning to build three new ammonia plants, which will decrease the dependence on imported fertilizer and will probably reduce internal price fluctuations.

Phosphorus supply is by far the most relevant topic regarding nutrient accessibility for agricultural production and many authors consider that the risk of P scarcity in the future should be recognized and addressed in order to avoid food-related crises (CORDELL *et al.*, 2009; ELSER AND BENNETT, 2011). Obviously the same applies for biofuel production. In 2004 the United States signed a free-trade agreement with Morocco that included phosphate rock. Although the USA is one of the largest phosphate producers, this agreement was seen as a strategic maneuver to secure future fertilizer and food supply (GILBERT, 2009).

Approximately 99% of the phosphate fertilizers in the world are produced from rock phosphates and a small proportion derives from residues of the iron industry.

The most important reserves of rock phosphates are found in the North of Africa, China, and the United States (Table 5), which are also the largest producers. Although phosphate production in Brazil is of intermediate scale, the known reserves are relatively small.

There have been concerns about the medium and long term supply of P because the world reserves are considered small. This issue is controversial. Information on known reserves must be viewed with care because it is based on limited data and the owners of the mining rights regard it as confidential (FIXEN, 2009; Lopes *et al.*, 2009). In addition, 2/3 of the P reserves are in Morocco, Western Sahara and China, which gives these countries great power regarding this subject (ELSER AND BENNETT, 2011). At present consumption rates, the estimated longevities of the economically exploitable reserves and of the base reserves are of 93 and 291 years respectively (FIXEN, 2009). Therefore, the scenario seems not to be as negative as previously thought but the uncertainties are great. Several authors cited by Fixen (2009) concede the existence of much larger reserves, with longevities of over 690 years. Recently the US Geological Survey increased the world's reserve estimates almost fourfold from 15,000 Mt (Table 5) to 65,000 Mt because of reevaluation of Morocco reserves, although uncertainties about the data still remain (ELSER AND BENNETT, 2011). There are also more pessimistic scenarios that foresee that the exploitation of present reserves will reach a peak by 2030 with a decline thereafter (CORDELL *et al*., 2009).

It is certain, however, that the cost of P fertilizer will increase as reserves with low P concentration and greater mining difficulties come into use. On the other hand, Isherwood (1999 apud LOPES *et al*., 2009) considers that price increase will make possible the exploitation of more difficult reserves such as those in the oceans, thus increasing the P resources.

Table 5 – Mineral production and phosphate reserves in the world.

Country	Mineral production 2007(1)	Reserves(2)	Base reserves(3)	Reserve lifetime(4)
		----------------- Mt ----------------- *Years*		
Morocco and Sahara	27,0	5.700	21.000	207
China	45,4	4.100	10.000	86
USA	29,7	1.200	3.400	40
South Africa	2,6	1.500	2.500	605
Jordan	5,5	900	1.700	163
Australia	2,2	82	1.200	36
Russia	11,0	200	1.000	18
Brazil	6,0	260	370	43
World Total	**156,0**	**15.000**	**47.000**	**93**

(1) P_2O_5 concentration: 23% to 39% with an average of 32% in 2007, de 32%. The average P_2O_5 content of phosphate rock in the USA is 29%; (2) Reserves that can be economically exploited at time of measurement; (3) Base reserves: economically- marginally economically- and some under economically-exploitable resources; (4) Reserve lifetime for the world is estimated at 291 years.

Source: Fixen (2009)

Brazil is the forth greatest consumer of phosphates in the world. Therefore, both long term supply and self-sufficiency are matters of interest. The known reserves in Brazil are sufficient for 43 years at the present consumption rates (LOPES *et al*., 2009). But Brazil has areas with great potential for occurrence of phosphate rocks so that the reserves may increase. On the internal supply side, the Brazilian Government is working on new legislation to stimulate the fertilizer and mining companies to exploit the areas to which they have mining rights and to curb speculation over these rights (MME, 2010). According to the Brazilian Department of Mineral Research (LOPES *et al*., 2009) new mining activities are projected so that the dependence on imported P fertilizer and phosphate feedstock shall reduce from 45% in 2009 to 24% in 2015.

The most common minerals used for the production of potassium fertilizers are sylvite (KCl), sylvinite (KCl + NaCl), and langbeinite ($K_2SO_4.MgSO_4$), most of them from sedimentary salt deposits (FIXEN, 2009). The situation of the world's potassium supply is more comfortable because the known reserves that can be economically mined are of 8.3 billion tonnes, enough for 230 years. If the base reserves are included, there is enough potassium for 500 years (Table 6). Most of the reserves are located in Canada (57%) Russia (22%), Belarus and Germany (9% each).

Brazil is the third largest consumer of K fertilizers in the world but produces only about 10% of its needs. Potassium minerals in Brazil come from the Taquari/Vassouras deposits in Sergipe. The reserves in that region are relatively small; although mining activities in that region can be expanded, it will probably not be sufficient to significantly reduce Brazilian imports of K. The largest reserves in Brazil are in the Amazon, close to Nova Olinda do Norte, by the Madeira River. The reserves estimated by Petrobras are of the order of 1.1 billion tonnes of potassium ores. However, the deposits are deep, located in a remote area of difficult operation, and as such, costs should be high. Although the Brazilian Government is pressing companies such as Petrobras and Vale to exploit the Amazonian K deposits, it is not clear whether this will happen in the near future. Vale, which mines the Sergipe deposits, has recently acquired the mining rights of two sites in Argentina and intends to supply the Brazilian K market from there.

The large reserves around the world and their locations in countries more open to free trade make Brazilian dependence of K imports less critical than that of P in the long run. It should be noted that countries such as USA, China, and India, which are important food producers, do not have significant reserves of K (Table 6).

While it is desirable to reduce dependence on fertilizer imports, there is little possibility of autonomy in the production of fertilizers and their raw materials in most countries, because the natural resources - oil and mineral deposits - are concentrated in different regions of the world. In general, even countries well endowed with natural resources do not have all the nutrients necessary. Thus, even large exporters of a given nutrient are importers of others. For instance, China is a great exporter of N and P but imports 63% of K (FAOSTAT 2010).

Table 6 – World mineral production and reserves of potassium.

Country	Mineral production 2007(1)	Reserve(2)	Base of reserve(3)	Reserve lifetime(4)
		----------------- *Mt* --------------- *Years*		
Canada	11,10	4.400	11.000	398
Russia	6,60	2.800	2.200	267
Belarus	4,97	750	1.000	149
Germany	3,60	710	850	197
Brazil	0,41	300	600	719
Israel	2,20	40	580	17
Jordan	1,09	40	580	35
China	2,00	8	450	4
United States	1,10	90	300	78
World Total	34,06	8.300	18.000	235

(1) Estimated; (2) Reserves that can be economically exploited at time of measurement; (3) Base reserves: economically- marginally economically- and some under economically-exploitable resources; (4) Lifetime of reserve based on 2007 – 2008 production.

Source: Fixen (2009)

Brazil has reserves for the production of N, P and K, but they all have limitations, as discussed in the text. Investments in exploration, mining and industry can alleviate the problem of external dependence but not rid Brazil of it.

Fixen (2009) observed that global reserves and resources for N, P and K appear adequate for the foreseeable future. Phosphorus may or may not be an exception. The costs of nutrients will increase over time as more easily extracted mineral resources are depleted. As currently there is great capillarity in foreign trade, including the fertilizer market, the supply of fertilizers seems not to threaten the production of biofuels. In case of supply shortages, other sectors of agriculture will also be affected. In this case, perhaps the scarce nutrients may be preferentially used in more sensitive areas such as food production.

Alternative sources

Increasing the nutrient use efficiency of the whole bioenergy production system may reduce the need for synthetic fertilizers in sugarcane. One way of doing this is by improving the recycling of sugarcane's agricultural or industrial wastes that contain nutrients. Other options include the use of organic fertilizers or wastes of urban areas or other industries and of low grade minerals less suitable for fertilizer production at present prices. The cost of transportation is crucial to the viability of using such products. Biological nitrogen fixation (BNF) may also be an important source of N for sugarcane.

Recycling of sugarcane by-products

The sugarcane industry exports mainly sucrose and ethanol, which contains only C, H, and O, that is to say, all the mineral nutrients carried from the field to the mill can theoretically be recycled. When sugarcane stalks are processed to produce sugar and/or ethanol, large quantities of by-products are generated (Figure 1). The first by-product is the bagasse, resulting from crushing the stalks to extract the cane juice: about 250 kg (50% moisture) per tonne of cane. Bagasse is seldom used as an organic fertilizer because of its low nutrient and high energy content; therefore, this by-product is usually burned to produce heat and electricity in the mill. In this process, about 6 kg of ashes (dry basis) are produced. The ashes contain oxides of most of the cations present in bagasse, plus portions of the N, S and other elements that are partially lost as gases during combustion. The ashes are returned to the fields either singly or mixed with other by-products.

Sludges and small pieces of bagasse are vacuum-filtered in the process of cane juice clarification in the sucrose production route, yielding a mud, known as filter cake. Nowadays, many distilleries also clarify the juice and generate filter cake. On average, 30 kg of filter cake (70% moisture) are produced per tonne of cane crushed. Filter cake presents high amounts of compostable organic matter (> 50%), and variable amounts of nutrients, including those from the lime and phosphates added to help in the clarification process. Usually phosphorus (10 to 20 g P_2O_5/ kg dry filter cake) is the nutrient of interest when filter cake is applied on the fields, but it carries other nutrients as well and its easily mineralizable organic matter is highly beneficial as a soil conditioner. Sugar mills and distilleries generally have large areas and equipment to prepare filter cake compost. Other by-products such as vinasse, gypsum, and ashes may be added to enrich the compost. This product is applied in several ways to the sugarcane fields, the most common is in the planting furrow at rates that vary from 10 to 20 t/ha (wet basis). Usually, yield responses to filter cake compost go beyond its nutrient value, especially in sandier, low fertility soils, and include greater tolerance of the crop to increased sugarcane longevity and soil pests such as nematodes and termites (ROSSETTO *et al.*, 2010a).

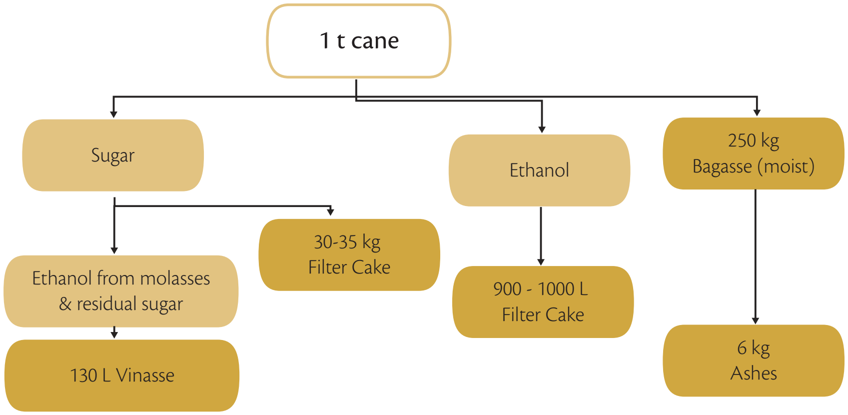


Figure 11. By-products or residues produced when 1 tonne of sugarcane stalk is processed for sugar or ethanol.

Vinasse is a liquid residue of ethanol production, generated in large amounts (10 to 13 L/L ethanol). Presently about 300 billion liters of vinasse are produced in Brazil. The composition of vinasse is quite variable and depends on the fermented material; nutrient richer vinasse is produced when ethanol is made out of molasses, whereas the opposite happens when cane juice is fermented directly (Mutton *et al.*, 2010). Vinasse is a relatively diluted effluent but has basically all the chemical elements present in the cane juice (and in the fermentation additives), plus organic matter. Potassium is the nutrient of the highest concentration: about 1 to 3 g K_2O per liter, or an average of 2 kg K_2O/m^3 vinasse, and usually determines the rate of application of this by-product to the fields.

Because of the large volumes of vinasse generated in the mills during the harvesting season, it is commonly applied in the sugarcane fields at rates that vary from 50 to 200 m^3/ha. The cost of transport and distribution often limits the distance where it is economically feasible to apply vinasse – usually no more than 30km. Concentrated vinasse, prepared by removing part of the water, makes it possible to distribute the residue at longer distances from the mill, but the energy cost of concentration must be balanced against the benefits of spreading it to additional fields.

In the state of São Paulo, Cetesb, the Environmental Agency, regulates the maximum rate of vinasse to be applied in a field in order to prevent contamination of ground water; the rule is that no more than 5% of the soil cation exchange capacity, to a depth of 0.8 m, should be occupied with K+ (CETESB, 2006). Normally, where vinasse is applied mineral K fertilization can be dispensed with.

Bagasse, ashes, filter cake, filter cake compost, and vinasse, besides being sources of nutrients to be returned to the fields, can also replenish the soil with organic matter. These materials are basically of plant origin and practically no harmful products are added during industrial processing. Therefore, none of these industrial by-products carry heavy metals or chemicals in concentrations that can deteriorate soil quality.

Burning of sugarcane is being increasingly restricted, as discussed previously, resulting in large amounts of trash (8 to 20 t/ha of dry matter) on the field after harvesting. The amounts of nutrients in this material are around 64, 7, 66, 25, 13 and 9 kg/ha of N, P, K, Ca, Mg, and S, respectively (OLIVEIRA *et al*, 1999a). Usually more than 70% of the organic mass and of the N content of leaves and tops are lost after a fire in a standing sugarcane field (MITCHELL *et al.*, 2000). Losses of other nutrients when trash is burned are equally high (MITCHELL et al., 2000). On the other hand, when trash is preserved, so are the nutrients. However, not all the elements are readily available for plant use. After almost one year, only 20% of the N contained in the trash was released, but corresponding values for K were above 80%; for the other nutrients the mineralization ranged from 50 to 68% (OLIVEIRA et al., 1999b). Using trash marked with ^{15}N, Vitti *et al.* (2008) observed a much higher mineralization of trash N: 50 to 70% in 13 months. Therefore, trash preservation contributes to the recycling of nutrients and, in the long term, will allow for the reduction of fertilizer application.

Considering the main by-products and residues of the sugarcane industry (vinasse, filter cake, trash) it is possible to estimate the nutrient recycling potential and the corresponding savings in fertilizer use. For a cultivated area of 8 million hectares in 2010, if the whole area is not burned before harvest, about 352, 116 and 952 thousand tonnes of N, P_2O_5, and K_2O could be recycled (Table 7). In 2006/2007, Brazil had approximately 6 million ha of sugarcane and consumed 535, 274 and 713 thousand tonnes of mineral fertilizers for this crop (Table 2). It must be noted that the mineral fertilizer used for sugarcane in Brazil already takes into account that vinasse and filter cake are already reasonably efficiently recycled, although there is room for improvement.

Table 7 – Nutrients recycled annually by the sugarcane industry.

Residues	Nutrients			Quantity of residues/yr	Nutrients recycled		
	N	P_2O_5	K_2O		N	P_2O_5	K_2O
		- % in dry matter -				*---------- t/yr ----------*	
Filter cake *	1.4	1.94	0.39	2.63 million t dry filter cake	36,820	51,022	10,257
Trash **	0.46	0.11	0.57	40 million t dry straw	184,000	44,000	228,000
		---- g/m3 vinasse----					
Vinasse***	375	60	2035	351 billion L	131,625	21,000	714,285
Total					352,445	116,022	952,542

*Assuming: 8 million hectares and 624 Mt of sugarcane produced, 250 Mt used for sugar production, generating 35 kg filter cake (70% moisture content) per tonne of sugarcane;

**Trash: 5 t/ha of dry matter, considering that 100% of the sugarcane area in Brazil will not be burned.

***Ethanol production: 27 billion L, yielding 13 L vinasse per liter of ethanol;

Alternative sources of mineral fertilizers

Aside from the traditional sources of fertilizers, there are other possibilities which may not be economically feasible at today's prices, but that can be considered of some strategic value.

For potassium, Brazil has large reserves of various rocks that are alternatives to conventional feedstock, among them the serpentinites, mica schist, and phlogopite wastes of emerald mines of Campos Verdes (GO), Itabirito/Nova Era (MG) and Campo Formoso (BA). Also important are the "Verdete de Abaeté", Abaeté (MG) and nepheline syenite, of Poços de Caldas, MG (LOPES et al., 2009).

The technology to make these rocks usable in agriculture has been investigated for many years at the Federal University of Lavras (Alfredo Scheid Lopes, personal communication) and much data is available. However, the low K concentration and the cost of processing and transport make fertilizers made from these materials too costly. Eventually, they may be used in areas near the site of fertilizer production. These materials can serve as strategic reserves, but due to huge stocks of cheap potassic rocks which are easily processed throughout the world, it is unlikely that products of low solubility and concentration will become an option under normal circumstances.

Phosphate rocks are processed for use as natural phosphate fertilizers or for the production of soluble fertilizers such as superphosphate, triple superphosphate, diammonium phosphate, etc. However, the restrictive legislation in some countries, as to the minimum water solubility of phosphate fertilizers, causes much mineral material to be discarded as waste. In addition, some non-apatite rock phosphates are not suitable for the production of water soluble fertilizer (CHIEN *et al.*, 2009). Therefore, many phosphate rocks of low quality are set aside and not used as fertilizer. Given the relative scarcity of phosphate rock in the world in the medium term, there is interest in the use of these materials.

Chien *et al.* (2009), in a review on the subject, showed that there are several options for the use of phosphate fertilizers with low water solubility, including the mixture of water soluble P and phosphate rock, use of calcined non-apatite rock phosphate for direct application and phosphate fertilizers with non-conventional acidulation. In some cases, legislation changes are needed. Nevertheless, the data of Chien *et al.* (2009) show that there are options to make better use of natural resources available as a source of P. In this case, Brazil would have additional stocks of materials for use as sources of P in agriculture.

Few of the studies with non-conventional fertilizers were done with sugarcane; however, by having a long cycle and deep and abundant root system, sugarcane may be efficient in the use of low solubility P. Cantarella *et al.* (2002) found that mixtures of reactive phosphate rock from North Africa (DAOIU) with triple superphosphate were as efficient a P source for sugarcane as the soluble fertilizer. Therefore, there are possibilities for phosphate fertilizers, in addition to the traditional ones; however, the appropriate use of some of these P sources of low solubility in sugarcane should be preceded by further studies.

Enhanced efficiency fertilizers

Increasing fertilizer use efficiency is also a way of both increasing biomass output per unit of nutrient applied and of reducing environmental impact of excess nutrients transferred to other ecosystems.

In addition to the conventional fertilizers, there is a class of Enhanced Efficiency Fertilizers, composed by the Slow or Controlled Release Fertilizers (SCRF) and by the Stabilized Fertilizers (TRENKEL, 2010). The SCRF products are designed to supply the nutrients as synchronized as possible with plant uptake so as to avoid excess of soluble chemicals that may be lost to the environment. This is done by having low water solubility compounds as opposed to highly soluble fertilizers (this applies mostly to

N fertilizers) or by encapsulating conventional fertilizers with sulfur, resin or polymers so that the rate of release of the nutrients can be controlled. The Stabilized Fertilizers (EF) are conventional fertilizers amended with compounds that interfere with nutrient loss mechanisms. The most common EFs are those containing urease or nitrification inhibitors; the first aims at reducing NH_3 volatilization losses from urea and the second at retarding the nitrification of amide- or ammonium-containing fertilizers in order to reduce nitrate leaching - two important routes of loss of nitrogen fertilizers.

Many SCRF fertilizers have been created and tested with mixed success (CHIEN *et al*., 2009; TRENKEL, 2010) but generally they can increase fertilizer efficiency under conditions favorable to losses. However, the price of SCRF is 2 to 8 times higher than that of conventional fertilizers, which has restricted their use so far in most agricultural crops including sugarcane; less than 0.5% of the fertilizers consumed in the world are SCRF (TRENKEL, 2010).

The market for EFs is broader and their cost is more competitive than that of conventional fertilizers. Urea containing NBPT, an urease inhibitor, have been tested and commercialized with relative success for some time in several countries, including Brazil. Studies conducted in Brazil showed that NBPT caused an average reduction in NH_3 volatilization losses of 60% for summer crops and 35% for sugarcane harvested without burning (CANTARELLA *et al*. 2008). The use of NBPT in sugarcane has not shown results as favorable as those with grain crops.

Several nitrification inhibitors have been developed and three have reached the global market (TRENKEL, 2010), but they have not been widely tested with sugarcane in Brazil, probably because leaching losses are not a recognized problem in sugarcane in this country (CANTARELLA *et al*., 2007). A renewed interest in nitrification inhibitors has been prompted by the findings that this compounds can reduce the emission of N_2O from N fertilizers (TRENKEL, 2010). Since N_2O is a potent green house gas, reducing its emission may improve the environmental balance of sugarcane used for biofuel; however, it is not clear whether growers will spend money on nitrification inhibitors for that purpose.

Biological nitrogen fixation in sugarcane

There is evidence that biological nitrogen fixation (BNF) is important to supply N for sugarcane. In Brazil, the quantities of N fertilizer applied to this crop are generally equal to or lower than those exported with the harvesting of stem or with burning of straw, without any apparent degradation of soil grown for decades with sugarcane. This has been regarded as indirect evidence of the BNF (URQUIAGA *et al*. 1992; BODDEY *et al*., 2003). The presence of numerous species of N-fixing endophytic bacteria in sugarcane plants also contributes to this thesis (BALDANI *et al*., 1997).

Urquiaga et al. (1992) showed that for some varieties of sugarcane, 60 to 70% of N accumulated came from the BNF. However, in most studies, the contribution of BNF has been much lower, less than 30% of N absorbed and sometimes associated with some varieties of cane sugar (OLIVEIRA *et al*., 2002, 2006). Surveys conducted with the use of δ 15N in several countries showed the BNF contribution ranging from 0 to 70% with an average of around 30% (YONEYAMA *et al*. 1992).

The practical importance of BNF to the nutrition of sugarcane is a controversial issue. It is likely that the contribution of BNF in Brazil has agronomic significance, although it is not constant. Herridge *et al*. (2008) and Urquiaga *et al*. (2011) estimated that the contribution of BNF for the average varieties grown in Brazil is 40 kg N/ha; in other producing countries the BNF would contribute about 20 kg/ha N (HERRIDGE *et al*., 2008). However, studies conducted in Australia, South Africa and Spain suggest that the BNF did not represent a significant source of N for cane sugar in those countries (BIGGS *et al*., 2002, HOEFSLOOT *et al*, 2005)

Inoculants based on diazotrophic microorganisms are being developed and tested extensively in Brazil, but the results are still inconclusive and to date it is not possible to know whether at least part of the nitrogen fertilizer may be replaced by the inoculation of microorganisms. The selection or breeding of sugarcane varieties that allow a better interaction with diazotrophic microorganisms may, in the future, offer other possibilities for the exploitation of BNF and thereby reduce the use of nitrogen fertilizers on this crop.

Legumes in rotation with sugarcane are also an alternative to add N to the system and reduce the input of synthetic fertilizers. For instance, Ambrosano et al. (2011) found that sunn hemp (Crotalaria juncea) green manure grown before sugarcane contained 196 kg of N/ha, 69%of which came from BNF.

References

AMBROSANO, E.J.; TRIVELIN, P.C.O.; CANTARELLA, H.; AMBROSANO, G.M.B.; SCHAMMASS, E.A.; MURAOKA, T.; ROSSI, F. 15N-labeled nitrogen from green manure and ammonium sulfate utilization by the sugarcane ratoon. **Sciencia Agricola**, v. 68, p.361-368, 2011.

BALDANI, J.I.; CARUSO, L.; BALDANI, V.L.D.; GOI, R.S.; DÖBEREINER, J. Recent advances in BNF with non legumes plants. **Soil Biology and Biochemistry**, v. 29, p. 922-928. 1997.

BECARI, G.R.G. **Resposta da cana-planta à aplicação de micronutrientes**. Dissertação (Mestrado). Instituto Agronômico,. Campinas: 79 p. 2010.

BIGGS, I.M.; STEWART, G.R.; WILSON, J.R.; CRITCHLEY, C. N-15 natural abundance studies in Australian commercial sugarcane. Plant and Soil, v. 238, p. 21-30. 2002.

BODDEY, R.M.; URQUIAGA, S.; ALVES, B.J.R.; REIS, V.M. Endophytic nitrogen fixation in sugarcane: present knowledge and future applications. **Plant and Soil**, v. 252, p.139-149. 2003.

CANTARELLA, H. Nitrogênio. In: NOVAIS, R.F.; ALVAREZ V.V.H.; BARROS, N.F.; FONTES, R.L.F.; CANTARUTTI, R.B.; NEVES, J.C.L. (Eds.) **Fertilidade do solo**. Viçosa, Sociedade Brasileira de Ciência do Solo, p. 375-470, 2007.

CANTARELLA, H.; ROSSETTO, R. Fertilizers for sugarcane. In: CORTEZ, L.A.B. (ed). **Sugarcane bioethanol. R&D for productivity and sustainability**. São Paulo: Blucher. p. 405-421. 2010.

CANTARELLA, H.; ROSSETTO, R.; LANDELL, M.G.C.; BIDOIA, M.A.; VASCONCELOS, A.C.M. Misturas em diferentes proporções de fosfato natural reativo e fosfato solúvel em água para a cana-de-açúcar. In: **CONGRESSO NACIONAL DA STAB**, 8. Recife. p. 218-224, 2002.

CANTARELLA, H.; TRIVELIN, P.C.O.; CONTIN, T.L.M.; DIAS, F.L.F.; ROSSETTO, R.; MARCELINO, R.; COIMBRA, R.B.; QUAGGIO, J.A. Ammonia volatilization from urease inhibitor-treated urea applied to sugarcane trash blankets. **Sci. Agric.** v. 65, p. 397-401, 2008.

CANTARELLA, H.; TRIVELIN, P.C.O.; VITTI, A.C. Nitrogênio e enxofre na cultura da cana de açúcar. In: YAMADA, T.; ABDALLA, S.R.S.; VITTI, G.C. (ed.). **Nitrogênio e Enxofre na agricultura brasileira**. Piracicaba: International Plant Nutrition Institute - IPNI, p. 355-412, 2007.

CHIEN, S.H.; PROCHNOW, L.I.; CANTARELLA, H. Recent developments of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts. **Advances in Agronomy**, v. 102, p. 267-322. 2009.

COMPANHIA DE TECNOLOGIA DE SANEAMENTO AMBIENTAL - CETESB. Vinhaça - Critérios e procedimentos para aplicação no solo agrícola. **Norma Técnica**, P4.231. 12p. 2006. Accessed on 11 Oct 2011 at: *http://www.cetesb.sp.gov.br/servicos/normas---cetesb/43-normas-tecnicas---cetesb*

CORDELL, D.; DRANGERT, J.O.; WHITE S. The story of phosphorus: global food security and food for thought. **Global Environmental Change**, v. 19, p. 292-305. 2009.

CRUTZEN, P.J.; MOSIER, A.R.; SMITH, K.A.; WINIWARTER, W. N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. **Atmospheric Chemistry and Physics**, v. 8, p. 389-395, 2008.

Donzelli, J.L. Preservation of agricultural soil. In: MACEDO, I.C. et al. (Ed.) **Sugarcane's energy –twelve studies on Brazilian sugarcane agribusiness and its sustainability**. São Paulo: 2005.

____. Uso de fertilizantes na cana-de-açúcar no Brasil. In: MACEDO, I.C. (Org.) **A energia da cana-de-açúcar**, 2. ed. São Paulo: Única, 246 p. 2007.

ELSER, J.; BENNETT, E. A broken biogeochemical cycle. **Nature**, v. 478, p. 29-31. 2011.

ESPIRONELLO, A.; RAIJ, B. VAN; PENATTI, C.P.; CANTARELLA, H.; MORELLI, J.L.; ORLANDO FILHO, J.; LANDELL, M.G.A.; ROSSETTO, R. Cana-de-Açúcar. In: RAIJ, B. VAN; CANTARELLA, H.; QUAGGIO, J.A.; FURLANI, A.M.C. (coord.) **Recomendações de adubação e calagem para o estado de São Paulo**. 2.ed. Campinas: Instituto Agronômico; Fundação IAC. p.237-239. 1997.(Boletim, 100).

FAO. **Feeding the world, eradicating hunger: executive summary, World Summit on Food Security**, FAO - Food and Agriculture Organization. 2009 Disponível em: *ftp://ftp.fao.org/docrep/fao/Meeting/018k607e.pdf* Accessed on 19 Nov 2011, Rome. p. 18.

FAOSTAT. Disponível em: *http://faostat.fao.org/site/575* Accessed on 6 Nov 2010

FIELD, C.B.; CAMPBELL, J.E.; LOBELL, D.B. Biomass energy: the scale of the potential resource. Trends in Ecology and Evolution v. 23, p. 65-72. 2007.

FIXEN, P. Reservas mundiais de nutrientes dos fertilizantes. International Plant Nutrition Institute (IPNI). Piracicaba: **Informações Agronômicas**, v. 126, p. 8-14. 2009.

GALDOS, M.V.; CERR,I C.C.; CERRI, C.E.P.; PAUSTIAN, K.; VAN ANTWERPEN, R. Simulation of sugarcane residue decomposition and aboveground growth. **Plant and Soil** v. 326, p. 243-259. 2010.

GARCIA, S.S.; ALANIS, L.B.; DIAZ, D.R.; LAGUNA-ESPINOZA, L. del C. **Caña de azucar hacia um manejo sustentable**. México: Colégio de Postgraduados. Campus Tabasco, 395 p. 2003.

GASQUES, J.G.; BASTOS, E.T.; SILVA, L.F. da. Projeções do agronegócio - Brasil 2008/09 a 2018/2019. Brasília, DF: Ministério da Agricultura, Pecuária e Abastecimento - Assessoria de Gestão Estratégica,

2009. Disponível em: *http://www.agricultura.gov.br/pls/portal/docs/PAGE/MAPA/MENU_LATERAL/AGRICULTURA_PECUARIA/PROJECOES_AGRONEGOCIO/PROJECOES%202008-2019%20-%20APRESENTACAO.PDF*. Acesso em: fev 2009.

Gilbert, N. The disappearing nutrient. **Nature** v. 461, p. 716-718, 2009.

HARTEMINK, A.E. Sugarcane for bioethanol: soil and environmental issues. **Advances in Agronomy**, v. 99, p. 125-182. 2008.

HEFFER, P. Assessment of fertilizer use by crop at the global level: 2007/07 – 2007/2008. Paris: International Fertilizer Industry Association (IFA). 12 p. (Ag.Com 09/28, Abril 2009).

HEFFER, P.; PRUD'HOMME. M. Medium-term outlook for global fertilizaer demanda, supply, and trade 2008-2012. Summary Report. Paris: International Fertilizer Industry Association (IFA), 8. 9 p. (Report A/08/87b, Julho 2008).

HERRIDGE, D.F.; PEOPLES M.B.; BODDEY, R.M. Global inputs of biological nitrogen fixation in agricultural systems. **Plant and Soil** v. 311, p. 1-18. 2008.

HOEFSLOOT, G.; TERMORSHUIZEN, A.J.L.; WATT, D.A..; CRAMER, M.D. Biological nitrogen fixation is not a major contributor to the nitrogen demand of a commercially grown South African sugarcane cultivar. **Plant and Soil**, v. 277, p. 85-96. 2005.

LEGENDRE, B.L. **Sugarcane production handbook 2001**. Baton Rouge: Louisiana State University Agricultura Center, Louisiana Cooperative Extension. 54 p. (Pub. 2859). 2001.

LISBOA, C.C.; BUTTERBACH-BAHL, K.; MAUDER, M.; KIESE, R. Bioethanol production from sugarcane and emissions of greenhouse gases - known and unknowns. **Global Change Biology Bioenergy**. 2011. DOI: 10.1111/j.1757-1707.2011.01095.x.

LOPES, A.S.; DAHER, E.; BASTOS, A.R.R. Potencial dos recursos naturais para atender a atual e futura demanda da indústria nacional de fertilizantes e corretivos. 22p. In: FERTBIO 2009. Fortaleza, Universidade Federal do Ceará e Sociedade Brasileira de Ciência do Solo. **CD Rom**. (2009).

MEISINGER, J.J.; CALDERÓN, F.J.; JENKINSON, D.S. Soil nitrogen Budgets. In: Schepers, J. S., Raun, W. R. (Ed.). **Nitrogen in agricultural systems**. Madison: American Society of Agronomy, p. 505–562. 2008. (Agronomy Monograph, 49).

MITCHELL, R.D.J.; THORBURN, P.J.; LARSEN, P. Quantifying the loss of nutrients from the immediate area when sugarcane residues are burnt. **Proc. Aust. Soc. Sugar Cane Technol.**, Bundaberg,-Queensland,-Australia,-2-5-May-2000. p. 206-211.

MINISTÉRIO DAS MINAS E ENERGIA - MME. Marco regulatório da mineração. Disponível em: *http://www.mme.gov.br/mme/menu/marco_regulatorio/marco_regulatorio_da_mineracao.html* Accessed on 10 Dec 2011.

MUTTON, M.A.; ROSSETTO, R.; MUTTON, M.J.R. Agricultural use of stillage, In: CORTEZ, L.A.B. (Ed.) **Sugarcane bioethanol. R&D for productivity and sustainability**. São Paulo: Blucher. v. 1, p.423-440. 2010.

OLIVEIRA, A.L.M.; CANUTO, E.L.; URQUIAGA, S.; REIS, V.M.; BALDANI, J.I. Yield of micropropagated sugarcane varieties in different soil types following inoculation with diazotrophic bacteria. **Plant and Soil**, v. 284, p. 230-32. 2006.

OLIVEIRA, A.L.M., URQUIAGA, S., DOBEREINER, J., BALDANI, J.I. The effect of inoculating endophytic N2-fixing bacteria on micropropagated sugarcane plants. **Plant and Soil**, v. 242, p. 205-215. 2002.

OLIVEIRA, M.W.; TRIVELIN, P.C.O.; GAVA, G.J.D.C.; PENATTI, C.P. Sugarcane trash degradation. **Scientia Agricola** v. 56, p.803-809. 1999a.

OLIVEIRA, M.W., TRIVELIN, P.C.O., PENATTI, C.P., PICCOLO, M.D.C. Field decomposition and release of sugar cane trash nutrients. **Pesquisa Agropecuaria Brasileira** v. 34, p. 2359-2362. 1999b

RAIJ, B. van **Gesso na agricultura**. Campinas: Instituto Agronômico. 233 p. 2008.

RICE, R.W.; GILBER, R.; LENTINI, R.S. **Nutritional requirements for Florida sugarcane**. Gainesville: University of Florida. Institute of Food and Agricultural Sciences Extension. 8 p. 2006. (SS-AGR, 228).

ROBERTSON, F.A.; THORBURN, P.J. Management of sugarcane harvest residues: consequences for soil carbon and nitrogen. **Australian Journal of Soil Research** v. 45, p. 13-23. 2007.

ROSSETTO, R.; DIAS, F.L.F.; LANDELL, M.G.A.; CANTARELLA, H.; TAVARES, S.; VITTI, A.C.; PERECIN, D. N and K fertilization of sugarcane rations harvested without burning. **Proc. Int. Soc. Sugar Cane Trechnol.** v. 27, p. 1-8, 2010b.

ROSSETTO, R.; DIAS, F.L.F.; VITTI, A.C. Fertilidade do solo, nutrição e adubação. p. 221-237. In: DINARDO-MIRANDA, L.L.; VASCONCELOS, A.C.M.; LANDELL, M.G.A. (Ed.) **Cana-de-açúcar**. Campinas: Instituto Agronômico, 882 p. 2008a.

ROSSETTO, R.; DIAS, F.L.F.; VITTI, A.C.; CANTARELLA, H. Fertility maintenance and soil recovery in sugarcane crop. In: CORTEZ, L.A.B. (Ed.). **Sugarcane bioethanol**. R&D for productivity and sustainability, São Paulo: Blucher, v. 1, p. 381-403. 2010a.

ROSSETTO, R.; DIAS, F.L.F.; VITTI, A.C.; PRADO JR., J.P.Q. Fósforo. p. 271-287. In: DINARDO-MIRANDA, L.L., VASCONCELOS, A.C.M., LANDELL, M.G.A. (Ed.) **Cana-de-açúcar**. Campinas: Instituto Agronômico. 882 p. 2008b.

ROSSETTO, R.; DIAS, F.L.F.; VITTI, A.C.; TAVARES, S. Potássio. p. 289 - 312. In: DINARDO-MIRANDA, L.L., VASCONCELOS, A.C.M., LANDELL, M.G.A. (Ed.) **Cana-de-açúcar**. Campinas, Instituto Agronômico. 882 p. 2008c.

SCHARLEMANN, J.P.W., LAURANCE, W.F. How green are biofuels? **Science**, v. 349, p. 43-44. 2008.

SNYDER, C.S.; BRUULSEMA, T.W.; JENSEN, T.L.; FIXEN, P.E. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. **Agriculture, Ecosystems and Environment** v. 133, p. 247–266. 2009.

THORBURN, P.J.; PROBERT, M.E.; LISSON, S.; WOOD A.W.; KEATING, B.A. Impacts of trash retention on soil nitrogen and water: an example from the Australian sugarcane industry., **Proceedings of the South African Sugar Technologists' Association**, Durban, South Africa, v. 73, p. 75-79. 1999.

TRENKEL, M.E. **Slow and controlled-release and stabilized fertilizers: An option for enhancing nutrient use efficiency in agriculture**. 2 ed. IFA - International Fertilizer Industry Association, Paris. 2010.

URQUIAGA, S.; CRUZ, K.H.S.; BODDEY, R.M. Contribution of nitrogen fixation to sugar cane: Nitrogen-15 and nitrogen-balance estimates. **Soil Science Society of America Journal**, v. 56, p. 105-114. 1992.

URQUIAGA, S.; XAVIER, R.P.; MORAIS, R.F.; BATISTA, R.B.; SCHULTZ, N.; LEITE, J.M.; SA, J.M.; BARBOSA, K.P.; RESENDE, A.S.; ALVES, B.J.R.; BODDEY, R.M. Evidence from field nitrogen balance and 15N natural abundance data for the contribution of biological N2 fixation to Brazilian sugarcane varieties. **Plant and Soil online**. 2011.

VITTI, A.C., TRIVELIN ,P.C.O., CANTARELLA, H., FRANCO, H.C.J., FARONI, C.E., OTTO, R., TRIVELIN, M.O., TOVAJAR, J.G. Mineralização da palhada e crescimento de raízes de cana-de-açúcar relacionados com a adubação nitrogenada de plantio. **Revista Brasileira de Ciencia do Solo** v. 32, n. 2757-2762. 2008.

WANG, M. The Greenhouse gases, regulated emissions, and energy use in transportation (GREET) Model. Chicago: Argonne National Laboratory, 2007. Disponível em: *http://www.transportation.anl.gov/software/GREET/index.html* Accessed on: 14 Apr 2008.

YONEYAMA, T.; MURAOKA, T.; KIM, T.H.; DACANAY, E.V.; NAKANISHI, Y. The natural 15N abundance of sugarcane and neighbouring plants in Brazil, the Philippines and Miyako (Japan). **Plant and Soil**, v. 189, p. 239-244. 1997.

Chapter 4

Water usage in bioethanol production in the State of São Paulo

Gilberto de M. Jannuzzi
Rodolfo D. M. Gomes
Mauro F. Chávez-Rodriguez
Klever João Mosqueira-Salazar
Silvia Azucena Nebra

Water

Water availability

The State of São Paulo current environmental regulation demands that changes in the activities of sugar/bioethanol plants must be recorded and submitted to the State Environmental Agency for analysis and approval. Resolution SMA-88 (SMA, 2008a) defines the technical guidelines for licensing bioethanol and sugar plants in the State and takes into account the existing Environmental and agricultural map developed for the State. This map defines regions (Figure 1) where sugarcane can be cultivated and sugar/bioethanol plants can be installed. According to the differing water availability (including the status of local water tables) maximum indices were established for the regions and new installations and crops need to comply with them in order to obtain the required permit for their operation.

There is also a national environmental and agricultural zoning for the sugar/bioethanol industry (MANZATTO ET AL., 2009). However, the one developed for the State of São Paulo presents more details and is the one used for this analysis.

The regulation establishes four types of areas: inappropriate areas, permitted with environmental limitations, permitted with environmental restrictions and permitted areas. Water usage per ton of sugarcane processed in the industrial facilities is one of the parameters used for this classification. Other parameters used to classify these areas include air pollution and impacts on local biodiversity.

The areas classified as permitted and permitted with environmental limitations must comply with a maximum limit of 1 cubic meter of water usage per ton of sugarcane processed in the mills. This applies to new facilities (from 2008 onwards) and any expansion of the existing industrial facilities needed to present a plan to reduce water usage and a timeline to reach the required target index. In those areas classified as Permitted with Environmental Restrictions, the maximum indicator of water usage is 0.7 cubic meters per ton of sugarcane for the new facilities. As in the other case, any expansion of the existing facilities will also require the attainment of this target and a plan with a timeline for the facility to reach this value as well. A proper treatment and disposal of the waste water from the industrial processes is also required.

Inappropriate areas will not permit the installations of new facilities or the expansion of existing ones. The renewal of the Environmental permits of the existing installations is conditioned to a plan to meet the same standards applied to the Permitted areas with Environmental Restrictions.

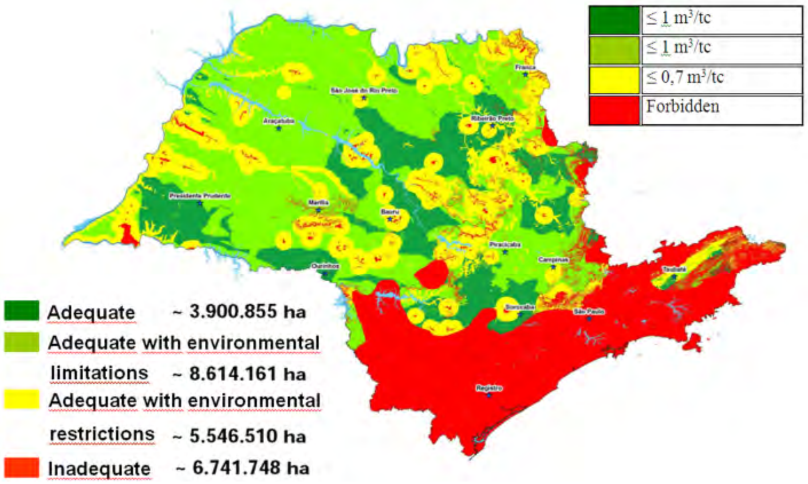


Figure 1. Environmental and agricultural zoning for the sugar and bioethanol industry in São Paulo State

Source: (SMA, 2008b)

According to its environmental and agricultural zoning for the sugarcane sector, Sao Paulo State has 3.9 million ha of adequate areas, 8.9 million ha of adequate areas with environmental limitations, 5.5 million ha of adequate areas with environmental restrictions and 6.7 million ha of inadequate areas.

There are four environmental monitoring programs in the state with direct impacts to the sugarcane sector activities: 1) Monitoring of the surface water and groundwater (contamination by agrochemicals); 2) Monitoring of fauna (verification of the maintenance of preservation areas and buffer zones); 3) Atmospheric emissions (burning) and soil quality at agricultural areas (ferti-irrigation).

The diagnosis of the status of river basins (surface water) and groundwater (Figure 2), as well as their monitoring over time, is part of the environmental and agricultural zoning work.

However, when questioned about the water volume used to irrigate sugarcane crop at the State of Sao Paulo, mainly with its demand increase in the expansion areas, the state-owned Environmental Sanitation Technology Company (Cetesb) stated that this mapping is not up to date and that there were incipient internal discussions concerning the mapping.

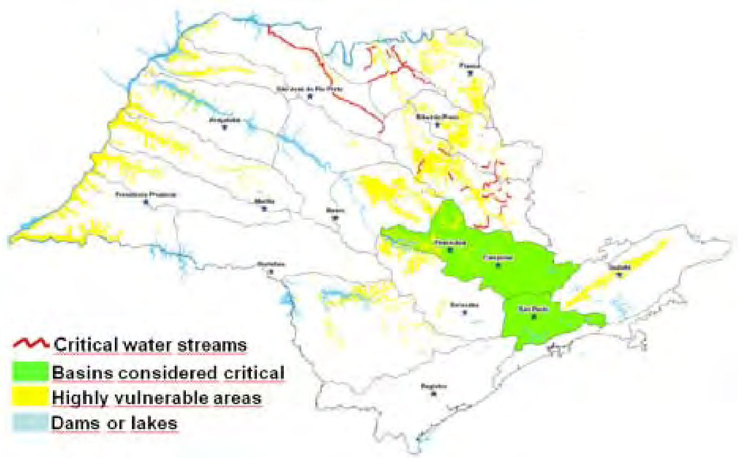


Figure 2. Environmental and Agricultural Zoning: availability of surface water and groundwater vulnerability

Source: (SMA, 2008b)

According to Carmo (2008), the current mills are relatively inefficient water users, an average mill presenting the following water balance: each tonne of sugarcane embodies 700 liters of water which are brought into the mill from the field, 1,830 liters are withdrawn to process this sugarcane tonne and the water is discharged as waste, calculated in 1,919 liters per tonne of sugarcane (by evaporation, in bagasse, washing cane purges and others), and within its products and by-products: sugar (0.03 l/t), bioethanol (0,26 l/t), vinasse (570 l/t), filter cake (40 l/t). According to the same author, even with conventional technologies already available, water consumption can be significantly reduced.

Water use legislation

According to the Brazilian National Water Agency (ANA), charging for the use of water is a mechanism of water resources management, one of its objectives being to motivate the rational use of water and to raise funds to preserve and recover water basins. This mechanism must not be confused with a tax, because it deals with a public price set from a pact among water users, civil society and public power within the water basin commission with the technical support of ANA.

Charging for the use of water sometimes becomes the last resort for water resources management. Nevertheless, this kind of charge was already foreseen in the Brazilian Water Code of 1934 and in the National Environmental Policy of 1981. In the State of Sao Paulo, this management mechanism appears in the State Law n° 7663/91 and in several other enacted state laws, institutionally and legally reinforcing its application (DAEE, 2007).

The National Water Resources Policy created the National System of Water Resources Management in 1997 through the Law n° 9433. This policy charges for the use of these resources, aiming to recognize water as an economic benefit, to give to the consumer an indication of its real value, to promote the rational use of water and to raise funds for finance programs and activities included in the water resources plans. The amount charged takes into consideration the volume of water withdrawn and of effluents discharged. The collected values are primarily invested in the same river basin where they were raised. In 2000, through the Law n° 9984, the National Water Agency (ANA) was created, a federal institution in charge of controlling and managing the National System of Water Resources Management. ANA is responsible for implementing national policy, authorizing water use rights at the federal level and organizing the National System of Water Resources Information (FREITAS, 2008).

According to CRHi (Water Resources Coordination), three elements are measured to assess water use: withdrawal, which represents all water volume withdrawn from rivers or underground before treatment; the volume of water discharged; and the discharge of effluents, which is the volume returned to rivers associated to its pollutant loading. The total charge is calculated by summing up the volume of water withdrawn, the volume of water not returned and the type of pollutant discharged on the watercourses.

The water price is defined by the River Basin Committees according to the requirements of bearing the cost of the approved plans and projects for a 4-year period. Such committees are created to manage the water resources in the river basins. These committees are comprised of representatives of the state government, municipalities and civil society (entrepreneurs, workers, universities and NGOs for environment protection). The availability of water, the number of payer-consumers and their average consumption are also taken into account. Hence, the water price can differ between river basins (DAEE, 2007).

The industrial use of water refers to the uptake of surface water and groundwater. For the former, registration of the authorization granted by the Department of Water and Electric Energy (DAEE) is required and should contain the information of the main industries of the State of Sao Paulo regarding the volume withdrawn and discharged to water bodies (LOPES, 2006).

Water charges and taxes in the State of São Paulo

The charge collected for water resources in the domains of the State of São Paulo was regulated by the government in March 13th, 2006, through the state Decree n° 50.667. The River Basin Committees (there are 22 in the state) are responsible for defining which prices to charge for the use of rivers (with source and mouth within the state boundaries) and groundwater based on the Law n°12183/05 and on its regulatory decree. The mechanism works as an incentive for users to adopt more efficient technologies and consumption habits and reduce wastes, besides adopting a more rational consumption behavior. Those users that do not adapt their patterns of use will have to bear the costs incurred by their actions (Lopes, 2006).

In this sense, estimating a withdrawal of 5.6 m3/t of sugarcane in a facility which mills 2 million tonnes of sugarcane per season and a considering water charge of 0.01 R$/m3, the resources collected would be approximately of R$ 112,000.00.

Legislation regarding water disposal

The São Paulo State Environmental Company (Cetesb) is responsible for monitoring environmental pollution sources within the State. This includes the control of wastewater from industrial processes into rivers, or other places which might have negative impacts on the environment, for human, industrial uses and other activities (LOPES, 2006).

According to the CNRH (National Council of Water Resources), in January 1934 the provisional Brazilian Head of State regulated, through the Decree n° 23777/34, the discharge of the sugarcane industry wastewater (vinasse) into the rivers. It decrees the obligation to discharge the industrial effluents into the main rivers, away from the margins, deep in the river and with sufficient water streams to rapidly disperse the pollutants. If this is not possible, the effluents must be previously treated and then discharged into water bodies. The sedimentation of residues and their transformation into fertilizers were made obligatory. In February 1967, the Law n° 303 forbade the disposal of vinasse in natura in rivers and lakes, seeking to avoid water and environmental pollution. In 1976 the government of Sao Paulo enforced the State Law n° 997 and the Decree n° 8468, creating the System of Environmental Prevention and Control Pollution. In March 1979, the legal act Portaria n° 53 of the Ministry of Home Affairs (Minter) forbade the application of residues in natura for agricultural activities, animal feeding and in water bodies (PIACENTE, 2004).

Industrial management

Potential for reducing water consumption

Biofuels are often criticized for the large amounts of water needed for their production. These criticisms are focused mainly on the agricultural stage. However, water consumption in the industrial stage, although in minor quantities, has particular social and environmental constraints (CHAVEZ AND NEBRA, 2010).

Special efforts must be made for reducing water consumption in the industrial stage for the case of sugarcane bioethanol. As showed in Figure 3, even with a rate of consumption of 1 cubic meter per ton of cane in the conversion process, higher water consumption for sugarcane bioethanol is highlighted (almost four times higher than corn bioethanol).

In order to decrease the water consumption in the industrial stage, strategies for conservation and reuse of water are needed. This option has a particular potential in the case of bioethanol from sugarcane, since sugarcane is composed of 70% water.

The simulation of a sugarcane plant can help to identify the water requirements and water outputs (and eventually, the effluents) in bioethanol industrial production. Furthermore, with this tool the potential of water consumption reduction based on the reuse of water streams can be estimated.

Thus, to accomplish this objective, a standard plant was modeled, which represents the common characteristics of a sugarcane mill producing sugar and bioethanol from sugarcane juice simultaneously. The simulation was developed by Ensinas (2008) using the Engineering Equation Solver® software (EES, 2007) based in data collected in real mills and from literature.

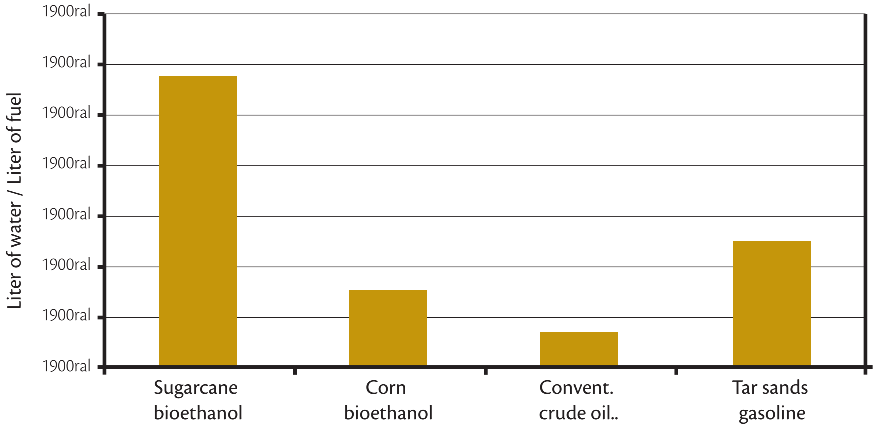


Figure 3. Water consumption in the conversion processes.

Source: Chavez-Rodriguez and Nebra, 2010.

It was assumed that the first stages of the production of sugar and bioethanol are common, including cane handling, cane washing, cane preparation, and juice extraction. The raw juice extracted goes through a treatment step for the production of sugar and bioethanol, being consumed in subsequent stages according to its destination. Sugar production is completed with the juice evaporation, crystallization, centrifugal separation and drying. On the other hand, the production of hydrated alcohol includes a step for preparing the juice for the fermentation stage, in addition to distillation and rectification.

For the distribution of sugars present in cane, it was assumed that 50% of TRS was used for the production of sugar and 50% for bioethanol, the latter being made from the residual molasses of sugar production, including some amount of syrup and treated juice. The general characteristics of the modeled plant, as well as the parameters used in the simulation, are described in Table 1.

Table 1 – Operation Parameters of the modeled sugar-bioethanol mill

Parameter	Value
Mill Capacity (t cane/year)	2,000,000
Crushing Rate (t cane/hr)	500
Season Operation Hours (hr/year)	4,000
Cane Fiber Content (%)	14.0
Cane Pol (%)	14.0
Production: 65 kg sugar and 40 L Bioethanol /t cane	

Demand water streams

Regarding the use of water in the industrial process, the water demands in the mill and the effective withdrawal were compared, the former being a result of the sum of all uses in the process, considering all the water circuits to be opened, and the latter being the effective withdrawal for replacement in existing circuits.

The water use in the industrial process was analyzed, taking into consideration all the water demands. To represent the water requirements, the mill was simulated without any closed circuits of reuse and considering average water rates consumption recorded in literature and in real mills. Table 2 shows the water streams and their parameters under this setting.

Table 2 – Water Use in a sugar-bioethanol mill

Water Uses	m (kg/s)	T (°C)	P (bar)	m (kg/t cane)	%
Cane Washing	416.7	25	1.01	3,000	19.9%
Imbibition	41.7	50	6.00	300	2.0%
Bearings Cooling	6.9	25	1.01	50	0.3%
Lubrication Oil Cooling	55.6	25	1.01	400	2.7%
Sulfitation Cooling	3.1	25	1.00	22	0.1%
Preparing of milk lime	3.2	107	6.00	23	0.2%
Filter Cake Washing	9.7	107	6.00	70	0.5%
Water for centrifugal washing	2.3	107	6.00	17	0.1%
Water for dilution of poor molasses	0.3	107	6.00	2	0.0%
Water for dilution of sugar	1.2	107	6.00	9	0.1%
Water added to pans	0.4	107	6.00	3	0.0%
Barometric Condenser of Evaporation	360.3	30	1.00	2,594	17.2%
Barometric Condensers of Filters	12.5	30	1.00	90	0.6%
Cooling of juice for fermentation	151.3	25	6.00	1,089	7.2%
Water for vacuum in the pans	337.6	30	1.00	2,431	16.1%
Dilution of milk yeast	17.0	25	6.00	122	0.8%

Water Uses	m (kg/s)	T (ºC)	P (bar)	m (kg/t cane)	%
Cooling of fermentation vats	242.7	25	6.00	1,747	11.6%
Condenser of Distillation	7.9	30	1.00	57	0.4%
Condenser of Rectification	105.7	30	1.00	761	5.0%
Cooling of Hydrated Bioethanol	7.0	30	1.00	50	0.3%
Washing Scrubber (boiler)	169.8	25	1.00	1,222	8.1%
Boiler feed water	97.0	128	22.00	701	4.6%
General cleaning	6.9	-	1.01	50	0.3%
Drinkable uses	4.2	25	1.01	30	0.2%
Cooling of Turbogenerators	27.8	30	1.01	200	1.3%
Cooling of Crystallizers	4.2	30	1.01	30	0.2%
			TOTAL	15,071	

The value of 15 m3/ ton of cane crushed is smaller than the 21 m3/ ton of cane reported by Elia Neto (2008). This is probably due to the fact that the studies present some differences in the cane process washing. In the present work we considered a table inclined at an angle of 45º that uses less water (3 m3/t of cane REIN (2007) compared with Elia Neto´s value of 5.33 m3/t). Another difference is that in the simulation, the use of barometric condensers, instead of multi-jet condensers was considered.

As can be seen in Table 2, vacuum for pans and barometric condenser of evaporation represents 33% of the water used in the mill. This consumption, combined with water for sugarcane washing (20%) and for cooling vats (12%), represents 65% of the total, so from this analysis it can be noted that the main action for saving water would be to close off these circuits. With this measure alone, without considering the losses in the closing circuits (evaporation, leaks, etc), it is possible to decrease a consumption of 15.00 m3/t of cane to 5.25 m3/t of cane. Despite being the major current, vinasse was not considered for industrial reuse in this study, following the current practice of fertirrigation destination.

Reusing water streams

The water streams for reuse were identified and quantified. Depending on their quality, these streams have the potential for being reused after treatment. Table 3 shows these currents, their flows, temperatures and pressures.

Table 3 – Water Streams for Reuse

Reuse Water Streams Potential	m (kg/s)	T (ºC)	P (bar)	m (kg/t cane)	%
Condensate of filtration	0.4	70	0.31	3	0.2%
Condensate of 1st effect Vapor (collected in the output of the 2nd effect)	7.9	115	1.69	57	3.8%
Condensate of Bleeding 1st effect Vapor for juice heating treatment	20.2	115	1.69	145	9.8%
Condensate of Bleeding 1st effect Vapor to Pan A heating	11.8	115	1.69	85	5.7%
Condensate of Bleeding 1st effect Vapor to Pan B heating	2.2	115	1.69	16	1.1%
Condensate of 2nd effect Vapor	8.5	107	1.31	61	4.1%
Condensate of 3rd effect Vapor	9.1	98	0.93	65	4.4%
Condensate of 4th effect Vapor	9.7	83	0.54	70	4.7%
Condensate of 5th effect Vapor in Barometric Condenser	10.5	50	1.01	75	5.1%
Condensate of Vapor of Pan A	8.3	50	1.01	60	4.0%
Condensate of Vapor of Pan B	1.5	50	1.01	11	0.7%
Boiler Blowdown	4.9	25	1.01	35	2.3%
Cane washing wastewater *	20.8	25	1.01	150	10.1%
Scrubber washing wastewater *	8.5	25	1.01	61	4.1%
Vinasse*	61.5	76	6	570	38.3%
Cleaning water collected (50%)	3.5	25	1.01	25	1.7%
	TOTAL Without Vinasse and Washing wastewater*			1,489 769	

Table 3 shows the total value of available water and indicates that the mill has a potential reuse volume of around 1.49 m3/ t cane crushed. Without considering the water content in vinasse and the cane washing water losses, this value would be less, resulting in 0.769 m3/ t of cane. Actually, unless the vinasse water content was separated by evaporation or methods such as reverse osmosis was used, a direct reuse of its water content would result in difficulties due to its high load of suspended solids, Biochemical Oxygen Demand (BOD) and low pH. The cane washing water losses, as with the vinasse, are also highly pollutant and a treatment must be performed before their reuse in the mill. From Figure 4 it may be inferred that condensates are the main source of water reuse in the mill. The condensates of the evaporation section represent 43% of the total potential of reduction.

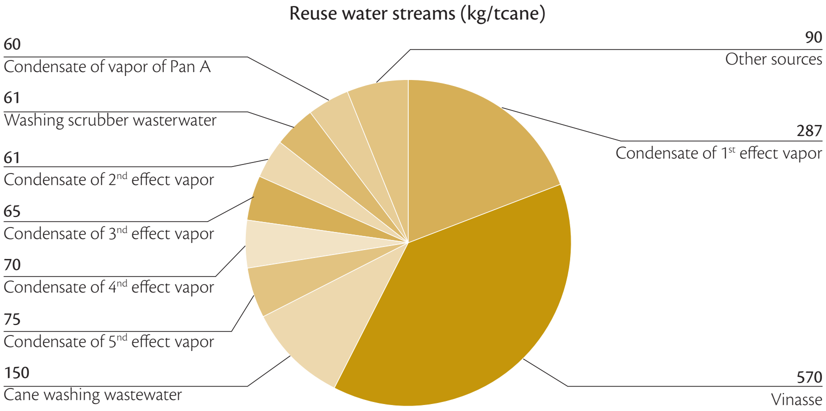


Figure 4. Water streams for potential reuse (L/t cane)

Closing water circuits

To illustrate the potential of effective water collection to attend to the process, a mill was considered where a treatment and/or recirculation in closed circuits are made. Table 4 shows the losses in these circuits.

Table 4 – Water losses of closed circuits (REIN, 2007)

Closed Circuits	Water Losses (%)
Cane Washing Water	5
Bearing Cooling Water	3
Lubrication Oil Cooling Water	3
Sulfitation Cooling Water	3
Spray Ponds Cooling Water	4
Cooling Towers Water	3
Washing Scrubbers Water	5
Recirculation Boiler Feed Water (blowdown)	5

In the simulation, it was assumed that the water currents from the spray ponds attend to the vacuum system of filters, evaporators and pans, condensers of the distillation and rectification columns and the bioethanol cooling. These water currents were assumed to return to spray ponds at 50°C, being cooled down to 30°C and then used again. Wet cooling towers are used to cool the water needed in the juice treatment stage, sulfitation, turbogenerator, bearing and lubrication oil, the water at the inlet being at 30.0°C and at the outlet at 25.0°C (ENSINAS, 2008).

The withdrawal of water occurs for the make-up of the closed circuits and to attend to the demands of yeast dilution, drinking water and general cleaning. Other water consumptions in the process are attended to by condensates, these being:

- Imbibition
- Water for juice clarification
- Filter cake washing
- Dilution of molasses and washing in centrifuges.

Figure 5 shows a process stream diagram to illustrate the plant simulated.

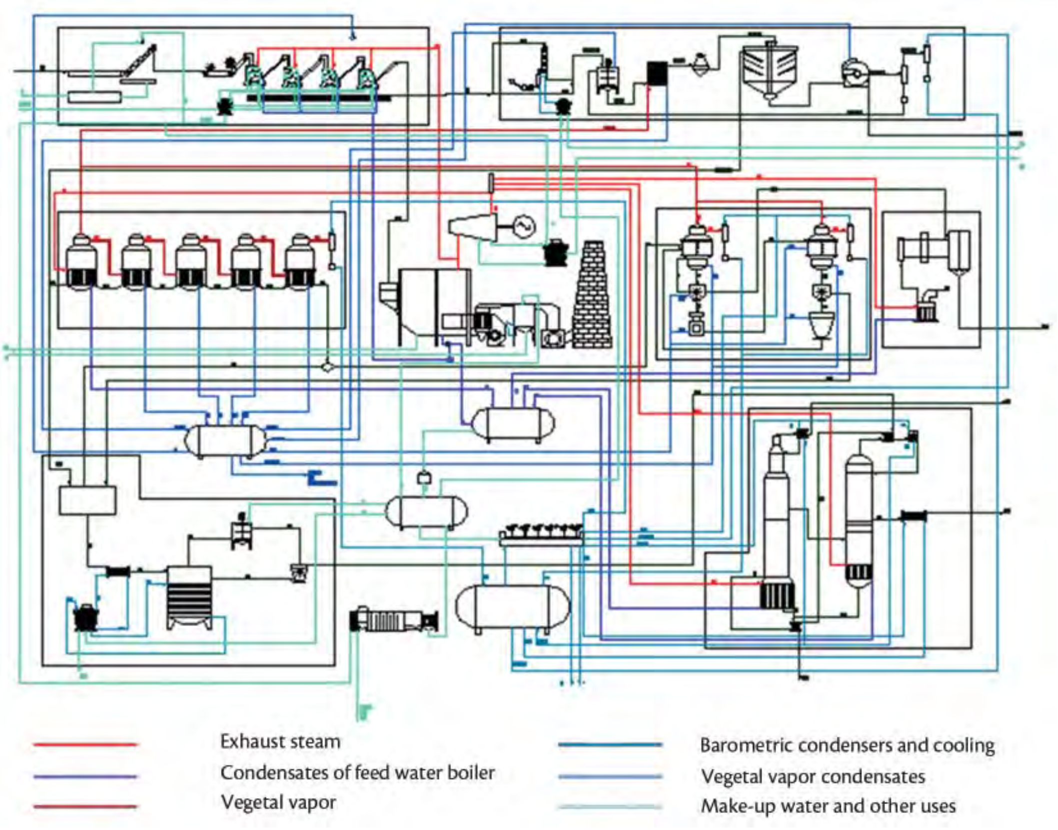


Figure 5. Process diagram of the sugar-bioethanol mill modeled

table 5 shows the effective water flows collected by process. These values represent the demand of water in real time. In theory, the Water Treatment System has to supply these quantities from the water collected in rivers, lakes, underground, etc. Hence, it may be deduced that water stream reuse would result in a lower water plant withdrawal.

Table 5 – Effective water flows demanded by process

Effective water demanded by process	m (kg/s)	T (°C)	P (bar)	m (kg/t cane)	%
Make-up Washing Cane	20.8	25.0	1.01	150	12.2%
Imbibition	41.7	50.0	6.00	300	24.5%
Make-up Bearing Cooling	0.2	25.0	1.01	2	10.0%
Make-up Oil Lubrication Cooling	1.7	25.0	1.01	12	1.0%
Make-up Sulfitation Cooling	0.1	25.0	1.00	1	0.1%
Lime preparing	3.2	107.4	6.00	23	1.9%
Washing filter cake	9.7	107.4	6.00	70	5.7%
Washing centrifugals	2.3	107.4	6.00	17	1.3%
Molasses Dilution	0.3	107.4	6.00	2	0.2%
Sugar B Dilution	1.2	107.4	6.00	9	0.7%
Added to Pan B	0.4	107.4	6.00	3	0.2%
Make-Up Barometric Condensers Evaporation	14.8	30.0	1.00	107	8.7%
Make-Up water for vacuum in the filter	0.5	30.0	1.00	4	0.3%
Make-Up water for juice bioethanol cooling	4.5	25.0	6.00	33	2.7%
Make-Up Vacuum Pans Circuit	13.9	30.0	1.00	100	8.1%
Yeast dilution	17	25.0	6.00	122	10.0%
Make-Up Fermentation Vats Cooling	7.3	25.0	6.00	52	4.3%
Make-Up Distillation Condensers	0.3	30.0	1.00	2	0.2%
Make-Up Rectification Condensers	4.2	30.0	1.00	30	2.5%
Hydrated Bioethanol Cooling	0.3	30.0	1.00	2	0.2%
Make-Up Washing Scrubber	8.5	25.0	1.00	61	5.0%
Make-Up Feed Water Boiler	4.9	25.0	1.00	35	2.8%

Effective water demanded by process	m (kg/s)	T (°C)	P (bar)	m (kg/t cane)	%
General Cleaning	6.9	-	1.01	50	4.1%
Drinkable Water	4.2	25.0	1.01	30	2.4%
Make-Up Turbogenerators cooling	1.4	30.0	1.01	10	0.8%
Make-Up Crystallizers Cooling	0.2	30.0	1.01	2	10.0%
			TOTAL	1,228	

If we subtract the value of 0.769 m3/t of cane of potential water for reuse without considering the vinasse and the washing cane water (Table 3) from the 1.228 m3/t of cane, a net effective water collection of 0.459 m^3/t cane is obtained. This value takes into consideration that the water flow from internal recycling has a previous treatment to be re-used.

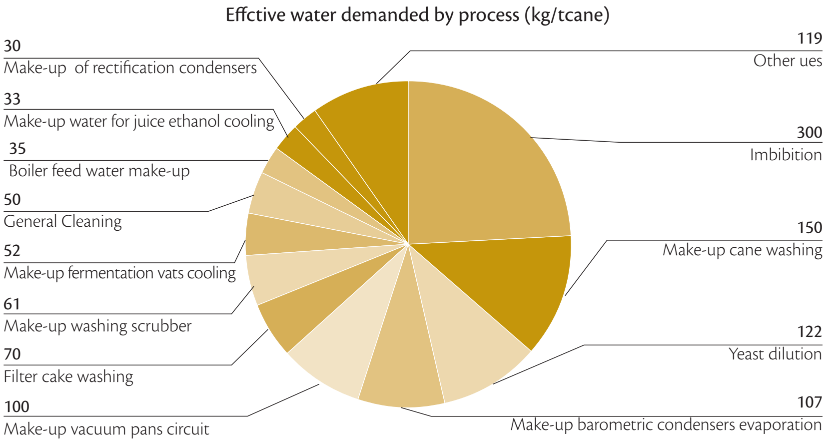


Figure 6. Effective water demand by process (L/t cane)

As we can see from Figure 6, the main consumer of water in the modeled sugar-bioethanol mill is the imbibition; however, a great part of this water can be recuperated from evaporation condensate currents. Losses from evaporation in the Barometric Condensers and Vacuum Pans Circuits represent together 16%. These losses could be avoided if dry cooling towers are used, but in practical terms, it would be very difficult, taking into account that these are much more expensive and require larger heat transfer areas than humid cooling towers. Another important consumer of water is that used for yeast dilution. This water current finishes in the water content of vinasse. If a dry cane cleaning system is used, instead of a wet system, it would result in an effective water collection demand of

1.078 m3/t of cane. Subtracting the quantity of 0.769 m3/t of cane of water for re-use, it would result in a rate of 0.309 m3/t of cane to external collection, very close to the goal of zero withdrawal.

Several authors such as Vignes (1980), Birkett and Stein (2004) and Eijsberg (2006) report losses of sucrose in the cane washing operation. According to Procknor (2002), the washing cane circuits tend to be reduced to sporadic use during rainy days, as a consequence of intensifying mechanical harvesting.

Except for dry cleaning, at this stage, "easy" measures have been tested in the industry to avoid water losses, such as the closing of circuits and re-use of available water streams, as condensates.

Besides that, streams at high temperatures have an energy content which may be recovered as a heating source inside the process. This capacity can be used in a second stage of measures to decrease the water losses, using the thermal integration methodology to reduce cooling water requirements.

Table 6 – Summary of the results

Concepts	m3 of water/t sugarcane processed
Use of water in the sugarcane plant	15.07
Measures	
Closing Circuits	1.23
Reuse of water streams (without vinasse and sugarcane washing losses)	0.46
Reuse of water content in vinasse and washing cane losses	-0.26

*the negative sign means a surplus of water.

Based on the results of Tables 1 and 6, it can be seen that from 1 tonne of sugarcane processed in a sugarcane plant, a total of 65 kg of sugar, 40 liters of bioethanol and 260 liters of water could be produced. This reveals another potential for environmental competitiveness for the sugarcane industry that has to be explored.

It must be stated that the values of effective water collection presented in this work are the results of a mass balance which considers that water currents for reuse have undergone a previous treatment (if it was necessary) to be reused without mass losses in those treatments. In actual fact, this would not be the case, as it is very difficult to recover the water loss in washing operations because it exists in moisture sludge form. However, this work is useful to estimate limits in the recovering and reuse of water in sugar and bioethanol plants.

References

NATIONAL WATER AGENCY – ANA. The implementation of the tariff by the water resources uses and the waters agency of the rivers Piracicaba, Capivari and Jundiai. 2007.

BIRKETT H.S; STEIN J.M. Cane washing losses. Sugar Journal. v. 67, n. 4,p. 17-21; n. 5, p. 25-28; n. 6, p. 16-21. 2004.

CARMO, V.B. Uso da água na produção de etanol de cana de açúcar – fase industrial. Apresentação em 24/Nov/2008. Faculdade de Engenharia Mecânica, UNICAMP. 2008.

____. Water use in the production of etanol from sugar cane- industrial stage. Dedini S/A Indústrias de Base. In: WORKSHOP: Project of Research Program in Public Policies. University of Campinas. 2008.

CHAVEZ-RODRIGUEZ, M.; NEBRA, S.A. Assessing GHG emissions, ecological footprint, and water linkage for different fuels. Environ. Sci. Technol., v. 44, n. 24, p. 9252-9257. 2010.

SÃO PAULO. DEPARTAMENTO DE ÁGUAS E ENERGIA ELÉTRICA - DAEE. Projeto FEHIDRO. Plano Estadual de Recursos Hídricos 2004/07 e Regulamentação da Cobrança pelo Uso dos Recursos Hídricos. Disponível em <http://www.daee.sp.gov.br/cgi-bin/Carrega.exe?arq=/cobranca/index.htm>.

EES, Engineering Equation Solver. Disponível em: <http://www.mhhe.com>. 2007.

EIJSBERG, R. Ethanol production: the current situation – technical design and economic evaluation of modern ethanol factory located in Brazil. Mestrado (Tese) Master Thesis of Technical University of Delft (TUD), Holland. Campinas: Oct. 2006.

ELIA NETO, A. Uso e reuso de água na indústria canavieira. In: WORKSHOP on the Impact of New Technologies on the Sustainability of the Sugarcane/Bioethanol Production Cycle. Campinas: CTBE (Centro de Ciência e Tecnologia do Bioetanol), 14 a 15 de maio de 2009. Disponível em: http://www.bioetanol.org.br/workshop32009.

____. Water in the Sugar Cane Industry. In: WORKSHOP: Project of Research Program in Public Policies, Enviroment Aspects of the Ethanol from Sugar Cane Chain. São Paulo. 2008.

ENSINAS, A.V. Thermal integration and thermoeconomic optimization applied to the industrial process of sugar and ethanol production from the sugar cane. Doctoral (Thesis). University of Campinas. 2008.

FREITAS, V.P. Águas – aspectos jurídicos e ambientais. Curitiba: Juruá, 2008.

LOPES, C.L.V. Gerenciamento de recursos hídricos e o processo de internalização da variável água nas indústrias. Tese (Mestrado). Campinas: Instituto de Geociências, Universidade Estadual de Campinas, 2006.

MANZATTO, C.V.; ASSAD, E.D.; BACCA, J.F.M.; ZARONI, M.J.; PEREIRA, S.E.M. Zoneamento agroecológico da cana-de-açúcar. Rio de Janeiro, RJ: Embrapa, 2009.

PIACENTE F.J.; PIACENTE E.A. Desenvolvimento sustentável na agroindústria canavieira: uma discussão sobre os resíduos. Campinas: Instituto de Economia e Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, 2004. (Apresentação de trabalho/seminário).

PROCKNOR, C. Rational use of water. Engineering, Factory Solutions, Abril, 2002.

REIN, P. Cane sugar engineering, Verlag Dr. Albert Bartens KG, Berlin, 768 p. 2007.

SÃO PAULO. Secretaria do Meio Ambiente do Estado de São Paulo – SMA. Resolução SMA - 88 (19-12-2008). Resolução SMA - 88 ().2008a.

_____. Zoneamento agroambiental para o setor sucroalcooleiro do Estado de São Paulo. São Paulo: SMA. Disponível em: <http://www.ambiente.sp.gov.br/etanolverde/zoneamentoAgroambiental.pph> 2008b.

VIGNES E.C. The implications of cane washing. Proc. Int.Soc. Sugar Cane Echnol. v. 17, p. 2221-2230. 1980.

Chapter 5

Sugarcane bioethanol and bioelectricity

Luiz Augusto Horta Nogueira
Manoel Regis Lima Verde Leal

Introduction

From the point of view of sustainability of the bioethanol production chain, the agricultural area has a considerably higher impact than the industry. Around 90% of the external energy demand, 95% of greenhouse gas (GHG) emissions, more than 60% of the bioethanol production costs and most of the labor requirements come from the sugarcane cropping and transportation to the mill (MACEDO *et al*., 2008). Besides, industrial technology has evolved rapidly since the launching of the Proalcool in 1975, reaching a plateau of performance in the early 1990s, especially in the fermentation, juice extraction (the two areas with highest sugar losses in the factory) and automation areas (Table 1); nevertheless, there are some areas that could be improved with incremental gains in efficiency and yields, and especially in cost reduction. In the 1990s significant cost reductions were achieved through improvements in factory management based on the Benchmark Program introduced by Copersucar Technology Center – CTC (since 2004, Sugarcane Technology Center) and the extensive use of information technology and reliable laboratory routines, combined with the capacity building of key staff in factory management.

The potential gains possible in the key sectors will be discussed in detail later on in this chapter.

Some areas have a clear potential for improvement in performance, but energy and co-products are notably the ones that could have the highest impacts, in the short and medium term, on the sustainability of sugarcane bioethanol in Brazil.

Table 1 – Distillery sector performance improvements

Parameter	1975	2005
Milling capacity – 6x78" tandem (tc/day)[1]	5,500	14,000
Juice extraction efficiency (%)	93	97
Fermentation time (h)	16	8
Fermentation efficiency (%)[2]	82	91
Distillation efficiency (%)	98	99.5
Overall distillery efficiency (%)[2]	66	86
Boiler efficiency in LHV (%)	66	88

Source: Olivério, 2007 and Finguerut, 2005

Notes: [1] Milling tandem with six units of 78 inches roll width;
[2] Stoichiometric efficiency (100% corresponds to 0.511 kg of pure bioethanol/kg of sucrose)

In the energy sector, the concept of maximum feedstock primary energy recovery shows large room for improvement since today, under average conditions, less than 30% of the total primary sugarcane energy (around 7,400 MJ/tonne of cane stalks) is converted into useful forms of energy (bioethanol, surplus electricity and surplus bagasse); even in the cases where top technology is used to generate surplus electricity in cogeneration systems using high pressure boilers and turbine generators, the useful energy production reaches only a little bit above the 30% of the feedstock primary energy. The reason for this low performance in recovering the primary energy contained in the sugarcane in the form of sugars and fibers (in the stalk and in the leaves and tops) is the inefficient use of bagasse and total waste of the leaves and tops (LEAL, 2007).

The concept of biorefinery is slowly starting to be integrated in the operating model of the Brazilian sugarcane industry where sugar, bioethanol and electricity are becoming the standard products. However, this trend has to advance much further before our mills can be called biorefineries, where several value added products are produced making efficient use of the feedstock components and intermediate process streams, like a petroleum refinery.

This chapter will discuss the evolution of the sugarcane processing in Brazil leading to the present production model of sugar, bioethanol and electricity, indicating the present status and tendencies in size and technology. The main sugarcane processing steps, normally referred to as mill sectors, will be briefly presented and the sector efficiency evolution for the medium and long term will be discussed, including the improvements in recovery of the sugarcane primary energy (contained in the sugars, stalk fibers and leaf fibers in the cane in the field) in the form of useful energy (bioethanol and electricity), considering different alternatives of use of cane biomass. Bioelectricity potential to reduce GHG emission will be briefly discussed and, finally, the improvements leading to GHG mitigation in the total bioethanol production chain is treated, based on possible alternatives.

This chapter will discuss the Brazilian production model in its present state, including the types of mills, sizes, sugarcane processing sectors, present and future performance indices, full use of the feedstock and the impacts on the energy and GHG balances and land use.

The brazilian sugarcane production and processing model

Brazil has a long tradition in producing bioethanol in the sugar mills. Since the 1920s bioethanol production using final molasses from the sugar factory, known as residual bioethanol, became a common practice in many sugar mills and in 1931 a federal law mandated the addition of 5% bioethanol in all imported gasoline consumed in the country, creating a stable market for a considerable amount of fuel bioethanol. When the National Alcohol Program (Proalcool) was launched in 1975, Brazil already had a significant experience in sugarcane cropping (being the world's second largest producer) and bioethanol production (close to 600 million liters were already being produced), and the system of joint production of bioethanol and sugar was the basis for the initial phase of the Proalcool. After the second oil shock in 1979 the government decided to speed up the bioethanol production and stimulated the installation of autonomous distilleries that produced only bioethanol from sugarcane juice; during the stagnation phase of Proalcool the increase in sugar exports in the early 1990s induced the autonomous distilleries to add a sugar factory to each of them, thus consolidating the so called Brazilian sugar/bioethanol production model. So, the expansion of sugarcane production and processing after 1975 had three distinct periods until 2004: annexing bioethanol distilleries to the existing sugar mills, installing autonomous distilleries and annexing sugar factories to the existing autonomous distilleries. Since the mid 1980s, after the cold oil shock caused the rapid drop in oil prices that made it very difficult for bioethanol to compete with gasoline without heavy subsidies, practically no green field projects were developed; on the contrary, the crisis brought about the incorporation of less efficient mills by the more modern groups, decreasing the number of mills, but significantly increasing the average size. Between 1994 and 2002, 92% of the production increase came from the expansion of the existing mills and favored the joint production of bioethanol and sugar. Table 2 shows three distinct points in the sugar and bioethanol sector evolution.

Table 2 – Sugar and bioethanol sector evolution in the last 20 years

Type of mill	19901	20021	20092
Sugar mill	27	15	16
Autonomous distillery	180	104	168
Annexed distillery	168	199	253
Total units	375	318	370
Sugarcane milling (million tonnes/year)	220	318	600

Sources: 1UNICA, 2005 and 2EPE, 2010

Up to 1990, the sugar exports were very small, compared with the total production, rarely exceeding one million tonnes, and the bioethanol production had stagnated at around 11 billion liters/year; the autonomous distilleries prevailed as the type of producing units, reflecting the big push to increase bioethanol production in the second phase of the Proalcool. From 1990 to 2002, the sugarcane production growth was motivated by the increase in sugar exports and the size of the mills increased at the expense of the number of units, as a consequence of the consolidation of the sector after the crisis at the end of the 1980s due to the bioethanol program stagnation. Finally, in 2003 the bioethanol production started to increase again, motivated by the escalating oil prices and the introduction of the Flex Fuel Vehicles (FFV), and by 2005 the new greenfield units started to be built at a fast pace, changing the profile of the production growth that used to be based on the expansion of existing units. The average size of the mills continued to increase to take advantage of the economies of scale and the desire to implement a very fast growth in bioethanol production.

Today, the sugar and bioethanol sector profile as assessed by Conab – Companhia Brasileira de Abastecimento (Brazilian Company for Food Supply)(CONAB, 2008) reflects the sector situation right before the 2008 crisis (Table 3), and after the fast expansion period between 2004 and 2008, including the installation of 84 greenfield projects (FIGLIOLINO, 2010).

Table 3 – Sugar and bioethanol sector profile in 2008

Region	Annexed distillery	Autonomous distillery	Sugar mill	Total
Number of units				
Center-South	176	81	7	264
N-NE	49	23	7	79
Brazil	225	104	14	343
Milled sugarcane (Mtc/year)*				
Center-South	367.5	51.7	6.5	425.7
N-NE	49.6	8.2	4.7	62.5
Brazil	417.1	59.6	11.2	488.2

Source: CONAB, 2008

* Million tonnes of sugarcane/year

From the table above it can be seen that more than 85% of the cane was milled in sugar mills with annexed distilleries, justifying referring to this system as the "Brazilian Model"; the sugar only mill has almost disappeared since it represented only a little over 2% of the total processed sugarcane. Although the autonomous distilleries constituted 30% of the total number of operating units, they account for only 12% of the milled cane, an indication that, on average, the sugar mills with annexed distilleries are much larger units since they are a combination of the sugar mills with an autonomous distilleries, taking advantage of the economies of scale in the juice extraction and energy systems.

The sugarcane production growth up to 2003, based on the increase in milling capacity of the existing units, has caused a continuous increase in the mill average capacity. The new greenfield units being installed are of milling capacity averaging around 2.5 million tonnes of cane per season (BNDES, 2008). Table 4 shows the mill size distribution of the mills in 2008 (CONAB, 2008), categorizing the sizes in small (< 1.5 Mtc/year), average (between 1.5 and 3.0 Mtc/year and large (> 3.0 Mtc/year).

Table 4 – Mill size distribution in number of units

Region	Small	Medium	Large	Total
Center-South	154	77	33	264
N-NE	72	7	0	79
Brazil	226	84	33	343

Source: CONAB, 2008

In spite of the predominance of milling units of the small size (66%), they represent only around 30% of the milled cane. Several of the new greenfield plants are in 4 Mtc range, with plans to expand to twice that capacity.

Another characteristic of the Brazilian model is the increasing implementation of surplus power generation to sell electricity as a third party product, after sugar and bioethanol; according to UNICA (2008), the average share of electricity in the total mill revenues is expect to increase from 1% in the 2006/2007 season to 16% in the 2015/2016 season. The evolution of the sector in this area took place slowly. At the beginning of the Proalcool the mills already produced electro-mechanical and thermal energy used in the plant operation, using bagasse as fuel. However, the high process steam consumption, low efficiency of energy equipment and low steam pressure (in the 10 to 20 bar range, saturated) required the use of wood fuel to supplement the bagasse available and electricity was purchased from the grid to make up for the plant´s needs. The increasing difficulty to find wood to burn in the boiler and the growing price of electricity stimulated the mills to improve the energy sector, by mainly reducing the process steam consumption and increasing the boiler pressure, temperature and efficiency (LEAL AND MACEDO, 2004). By the mid 1990s, self sufficiency in energy was reached in nearly all mills, but surplus power generation was present in very few mills; this changed only after the proper legal framework started to motivate the mills (the greenfield ones and those old mills that had reached the end of the lifespan of some of their boilers) to install high pressure units to generate significant amounts of surplus electricity. Today the trend is to have 67 bar/520 0C for the units operating in pure cogeneration and 100 bar/530 0C for the larger units using extraction/condensing turbine generators.

Sugarcane processing

This section is based on the works of Procknor (1999, 2002 and 2004), Finguerut (2005 and 2007), Rein (2007), CTC (2006, 2008 and 2009) and on the authors' experience working within the sugarcane sector.

The typical Brazilian sugar and bioethanol mill is shown in a simplified way in the flow diagram in Figure 1.

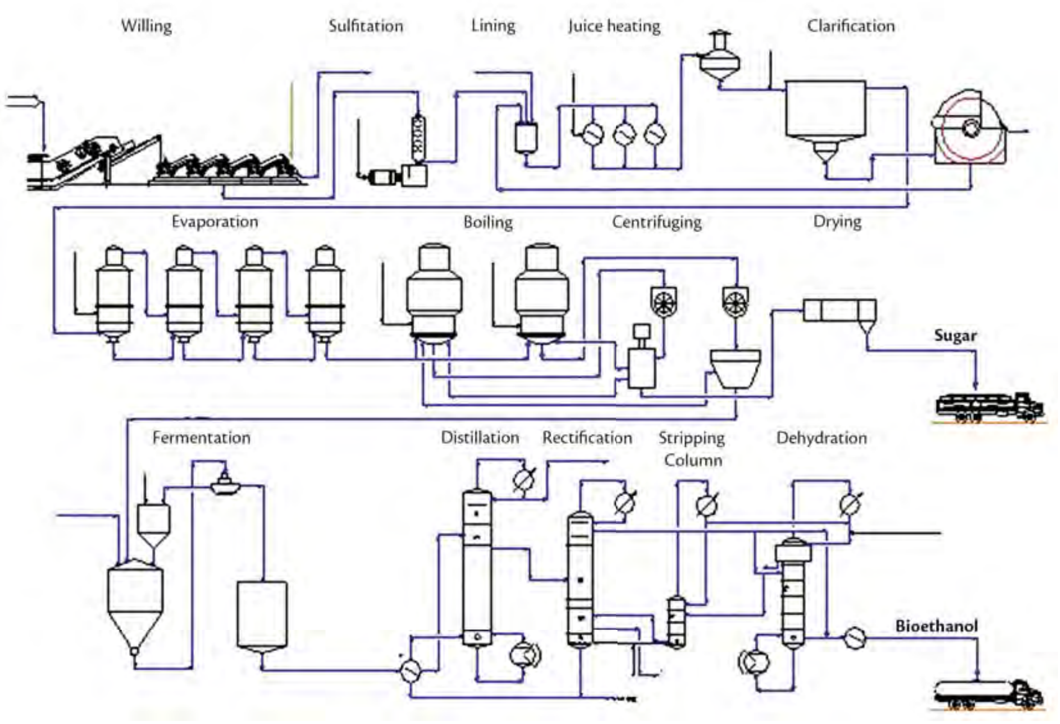


Figure 1. Simplified process flow diagram of the joint production of sugar and bioethanol

Source: Finguerut, 2007

In this section the process depicted in Figure 1 will be described briefly taking each plant sector at a time.

Sugarcane reception

In the past few years a clear reduction in the storage time of sugarcane in the mills has been observed, having reached conditions closely resembling a "just in time" cane delivery system. In the past, to avoid having to stop milling due to lack of cane, a significant amount of cane used to be stored in a yard for several hours or even days, which caused further deterioration of the cane quality. Long lines of cane transportation trucks were also common and even with these precautions it was not uncommon to have cane shortages for certain periods. Today, the system of cane delivery to the mill is planned using operational research optimization software and online communication between the harvesting fronts, the truck drivers and the mill operation. The storage of sugarcane at the mill is reduced to a minimum and cane shortage has become a rare event. The tradition of washing the incoming cane with water sprayed at the top of the feeder tables to remove extraneous matter, mineral and vegetal, to reduce the equipment wear and the negative impact of the extra fiber in the juice extraction system, remained for hand harvested cane . The environmental concerns over water use with a high organic matter load and high sugar losses in the case of mechanically harvested cane are leading to the phasing out of the traditional cane washing systems, fomenting an interest in cane dry cleaning systems that use air blowing instead of water washing in the cane cleaning operation. In the case of mechanically harvested cane, only devices to remove the mineral impurities are still used (perforated plates or steel bars at the bottom of the feeding tables, high slope tables with two stages and others). Several types of dry cleaning systems are being offered commercially but further improvements may be needed before full acceptance of this technology is reached. Also, in some situations a reduced capacity water cleaning system may be required for rainy periods even in the case of mechanically harvested (billeted) sugarcane.

From the point of view of sustainability, the past evolution of the sugarcane reception system in the mills has moved in the direction of a more sustainable bioethanol production, since the closing of the cane cleaning water circuit, treatment of the cane wash water and, ultimately, the phasing out of the cane washing operation due to the introduction of mechanically harvested cane, have decreased water consumption and the environmental impact of discharging high BOD/COD water in rivers and lakes. Also, the operating cost reduction resulting from this fact and from the optimization of the cane delivery to the mill has contributed to the improved competitiveness of Brazilian bioethanol. The only significant additional technology improvement foreseen for the medium term in this area is the advances in the dry cleaning system that will have a positive impact on the whole plant operation due to the partial elimination of the extraneous matter in the cane that causes reduction in the milling capacity, difficulties in the juice cleaning and increased equipment wear. An additional benefit from this system is expected when it can be successfully used as part of the sugarcane straw recovery system. It is worth mentioning that, even without the implementation of straw recovery systems, the current mechanical harvesting of unburned cane has remarkably increased the total fibrous material carried to the mills with the cane, due to the relatively low efficiency of the harvester cleaning system.

Sugarcane preparation and juice extraction

Prior to being subjected to the juice extraction process, the sugar containing cells of the sugarcane need to be opened to facilitate this process. This operation is called cane preparation and is normally executed by two sets of equipment called knifes and shredders operating in series; the most common set up is to have two sets of knifes, one cutting the whole cane in billets and the second acting as a leveler of the cane mat, and a heavy duty shredder that pulverizes the cane to open the sugar containing cells. To have an efficient juice extraction, the minimum percentage of open cells in the shredded cane, called Preparation Index, needs to be at least 82% and 92% in the cases of mills and diffusers, respectively.

Traditionally, the juice extraction process in Brazil has been dominated by milling tandem, using from 4 to 7 mill units, that works by squeezing the cane between two steel rolls with grooves. Upstream from the second mill, the cane mat is soaked with the juice exiting this unit, in a successive process up to the next from the last mill ; upstream of the last mill the cane mat is then soaked with warm water; this cane soaking process is called mixed imbibition and it is a crucial operation to achieve high efficiency in the extraction of sugars from the cane. In the past 10 years, another technology has been challenging the dominance of the mill as the favorite juice extraction process: diffusion, where the juice extraction from the prepared cane is achieved by leaching the sugars with hot water, in a combination of washing and diffusion of the sugars, added at the end of the diffuser and going counterflow with the cane mat. There are normally between 12 and 18 stages of diffusion (REIN, 2007) and in each one the juice is pumped forward, crossing the cane mat from the top to the bottom, and at the bottom it is pumped again to the top of the upstream stage. At the outlet of the diffuser the bagasse is passed through one or two dewatering mills to bring the moisture content to 50% or less. Approximately one third of the new sugar/bioethanol mills have opted for diffusers, especially those that have priority in the bioethanol production. Around the world mills are the preferred option for juice extraction but in South Africa the diffusers dominate entirely and present very high performance in terms of extraction efficiency. The defenders of diffusers state that their main disadvantages compared to mills, such as higher ash in bagasse and higher sucrose inversion, are more than compensated by the cleaner juice, higher extraction efficiency, lower maintenance costs and higher surplus power generation. On the other hand, those in favor of the mills claim a higher flexibility to operate at partial load, as low as one third of nominal value, and to process sugarcane with variable quality as their main advantages.

In the case of larger size mills it seems that the larger unit capacity has favored the use of milling tandem. In this case it is advantageous to use more advanced milling technology such as automatic control of the cane feeding system, individual roll driver speed control and use of electric or hydraulic mill drivers. In the case of an electric driver, electronic inverters/tri phase motors with an independent electric motor for the pressure roll is the recommended set up. This set up significantly increases the amount of surplus power generation since the high pressure steam is more efficiently used in the turbine-generators than in the traditional turbine drivers of the mills.

Since the cane preparation and juice extraction systems are the highest electric/mechanical energy consumers in the mill/distillery (16 to 20 kWh/tonne of cane out of the 28 to 30 kWh/tonne of cane for the whole plant), advances in technology leading to higher energy and sugar recovery efficiencies, and associated lower operating and maintenance costs, are very important. The best mills are already operating with extraction efficiency at around 97.5% with commercially available technology and well known mill preparation and operating procedures, and this know-how could be spread to a significant portion of the larger mills in the sector, increasing the sustainability of Brazilian bioethanol.

Juice treatment

In the recent past, several technology trends have been consolidated in the juice treatment sector, normally adding automation and control systems at the same time; this sector has a simpler configuration for the juice treatment for the distillery than in the case of juice for the sugar factory. A good example of this development is the trayless clarifiers (SRI – Sugar Research Institute design), with a much shorter residence time, but requiring an efficient control system to handle the variations in the juice properties and flow, that would otherwise impair the equipment performance due to its fast process.

For the juice heating prior to feeding it to the clarifier, heat recovery is used to a great extent using either direct contact heaters, that do not require cleaning, or plate heat exchangers, that provide a better energy efficiency at the cost of frequent stops for cleaning; the latter type of equipment is the preferred option in the more modern mills. In the juice concentration step both tubular evaporators, easier to clean, and plate type evaporators are used; in spite of having a much better energy performance the plate evaporators are not the most popular alternative due to the difficulties in the cleaning process, but they will be necessary in the future to significantly reduce the process steam consumption in the mills and distilleries.

For the process of recovering most of the sugar contained in the clarifier mud, the most common alternatives are the traditional vacuum filters and the more modern dewatering press, where the mud is progressively compressed and dried between two screens. The dewatering press is preferred due to its lower investment cost, more clear filtrated juice and filter mud with lower moisture content; the large volume of screen washing water required to operate the dewatering press can be supplied by the waste water streams existing in the mill, thus reducing the impact on the mill water withdrawal.

Fermentation

This key process in the distilleries has presented significant progress in performance, especially in the first two decades after the launching of the Proalcool, as shown in Table 6.1. In this period there was an extensive discussion about the batch and continuous processes, trying to determine which one is better, considering the broth of pure juice or the blend of juice and molasses in different proportions. It became clear only recently that the batch fermentation has predominated, even in the case of pure juice broth, with a good automation system to bring the operating costs to acceptable levels, due to high flexibility to operate with variable broth characteristics (very common in Brazil) and an efficiency slightly higher than the continuous process.

The main factors that have favored the batch fermentation compared to the continuous fermentation are related to the difficulties of the latter to solve infection problems, due to the limitation to execute frequent asepsis of the equipment and piping and to treat in a specific way the yeast of the several fermenters that operate under different conditions. The failure of the continuous fermentation to perform well in other countries also favored the choice of batch process in Brazil, that lastly has the important advantage of allowing the operation with a higher bioethanol concentration in the wine, thus reducing the vinasse volume and promoting the increase in useful equipment capacity. It is expected that in the future, when the present difficulties of handling infections and broth variations are properly resolved, the continuous fermentation will come back with greater strength (CGEE, 2009).

To improve the fermentation process even further, the main objectives are to reduce the fermentation time and to produce a wine with a higher bioethanol concentration (7.5% in 1975, 8-9% in 2005, with some distilleries reaching 10%) (OLIVÉRIO, 2008), maintaining a high efficiency in sugars conversion and competitive costs. Along those lines, Finguerut (2006) suggest some possible courses of action:

a) reduce the fermentation temperature or develop an yeast population highly adapted to elevated temperature and aggressive to other thermo-tolerant populations;
b) reduce the vinasse volume by having a higher bioethanol concentration in the wine or by recycling the effluent or its water fraction;
c) reduce the consumption or replace the sulfuric acid;
d) find alternatives to the use of antibiotics;
e) find alternatives to the use of nitrogen and potassium;
f) a reduction in the centrifugation cost in the cell recycle step, keeping under control the yeast losses and the elimination of bacteria and solids;
g) standardize the methods of fermentation analysis.

Distillation

The separation of bioethanol from the wine requires two steps: the production of hydrous bioethanol, by conventional distillation, almost reaching the azeotropic point (95.6% bioethanol and 4.4% water, by weight) and the subsequent dehydration to anhydrous bioethanol; this latter step normally uses cyclohexane to form a ternary mixture of bioethanol/water/cyclohexane that is distilled to produce anhydrous bioethanol. The pressure to replace cyclohexane and to reduce process steam consumption has led to another very popular alternative that is the use of monoethyleneglycol to extract the water from the hydrous bioethanol.

Besides the cost, energy efficiency has been a factor of growing importance in the selection of the most adequate distillation process. In this sense, distillation columns operating under vacuum started to be adopted recently. However, considering the typical capacity of the distillation columns installed in the Brazilian distilleries, the operation under vacuum brings relevant technical difficulties that result in high investment costs.

Molecular sieves have become the main alternative to the traditional dehydration process, due to significantly lower steam consumption and its wide adoption in other countries in the bioethanol production. Nevertheless, bioethanol dehydration using membranes is becoming increasingly competitive and has the potential to present steam consumption 15% lower than the molecular sieves. Of course, the alternative that will prevail will depend on the future situation of the cost and benefit of each one.

In the distillation process a significant amount of vinasse is also produced, or stillage, a liquid residue which should be properly disposed of to avoid environmental problems due to its very high organic material content. Today, it is largely used as a fertilizer in Brazilian sugar/bioethanol mills, with good results, reducing the chemical fertilizer demand and improving the energy balance of bioethanol production. Recently, vinasse concentration started to be considered again as an alternative to reduce the operating costs of its distribution to the fields and to meet eventual environmental restriction to raw water withdrawal. Also, in this line of motivation, the interest in the production of methane from the vinasse is increasing, and the Up-flow Anaerobic Sludge Blanket (UASB), operating in the thermophilic range of 56ºC and with application rates in the range of 8 to 10 kg COD/m3/day, is the preferred alternative. It is an interesting option to reduce the effluent COD, and broadens the application in the field as a fertilizer, although the economic advantages remain to be demonstrated.

Sector efficiencies and future improvements: 2007, 2015 and 2025

From the sustainability point of view, and in the context of the interactions between agroindustrial production systems and the environment, the most important parameters are those associated to mass and energy losses that can occur during the transformation of the feedstock into final products. In the case of sugarcane, the flows that deserve to be followed are the ones consisting of sugars (sucrose and reducing sugars), fibers and water; considering the conventional technologies, the sugars are directed to the bioethanol production, while the fibers are used as a source of energy for the process, with eventual surpluses.

In order to develop the mass balances related to sugars in the case of the Brazilian sugarcane agroindustry, where the sucrose and reducing sugars are used in the sugar and bioethanol production, having direct juice and final molasses as the factory streams, CTC (Sugarcane Technology Center) established a model that is very useful for the separation and evaluation of the losses and the performance of the different sector processes, summarized in Figure 2.

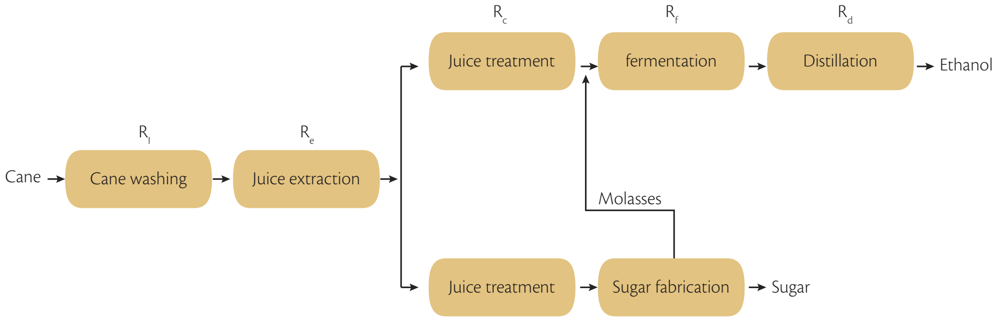


Figure 2. Model to evaluate the sugar flows in the different sectors of Brazilian mills

Source: Finguerut, 2006

As shown in Figure 2, the sugar losses that take place in the cane washing, juice extraction, juice treatment, fermentation and distillation, and the corresponding mass flows are presented below, where the sugar flows (including sucrose and others sugars in the cane) and bioethanol must be presented as hexoses equivalents (Total Reducing Sugars, TRS):

Cane washing efficiency (with respect to sugar losses)

$$R_l = \frac{\textit{sugar in the washed cane}}{\textit{sugar in the raw cane}} = 1 - \frac{\textit{sugar losses income}}{\textit{sugar in the raw cane}}$$

Juice extraction efficiency

$$R_e = \frac{\textit{sugar in raw juice}}{\textit{sugar in washed cane}} = 1 - \frac{\textit{sugar losses in bagasse}}{\textit{sugar in washed cane}}$$

Juice treatment efficiency

$$R_c = \frac{\textit{sugar in treated juice}}{\textit{sugar in raw juice}} = 1 - \frac{\textit{sugar losses in filter mud}}{\textit{sugar in raw juice}}$$

Fermentation efficiency

$$R_f = \frac{\textit{bioethanol in wine}}{\textit{sugar in the broth}}$$

Distillation efficiency

$$R_d = \frac{\textit{produced bioethanol}}{\textit{bioethanol in wine}} = 1 - \frac{\textit{bioethanol losses in vinasse}}{\textit{bioethanol in wine}}$$

These parameters can be used to evaluate how the flows of sugars are processed in sequence and converted to bioethanol, eventually including the inputs of residual sugars from the molasses from the sugar factory. Compared with the agricultural activities, naturally dependent of the soil/climate conditions of each mill, and therefore less adequate for generalization, sector efficiencies in the mills are less dependent on the local conditions of the production units, thus allowing for the comparison of values among the different mills.

Present Situation (considering the 2007/2008 harvesting season)

Recognizing the importance of the efficiency indicators and of other parameters associated with the agroindustrial process, CTC has implemented since 1991 a benchmarking program, the Mutual Control Program of the Sugar and Bioethanol Production, based on the strengthening of monitoring of the process efficiencies and standardization of the testing procedures. This systematic assessment has allowed the follow up of the production process evolution in the agricultural and industrial areas, making available to the producers involved in the program a very important and consistent information data base related to the performance of the agroindustrial activities in the sugarcane agroindustry.

Specifically in the industrial context, this program follows on a monthly and annual basis 39 important processes in the sugarcane processing to sugar, bioethanol and electricity. They are grouped into the following mill sectors: Juice Extraction, Juice Treatment, Sugar Production, Bioethanol Production, Energy, Automation and Laboratories, in a very representative number of mills in the Center-South Region, where 88% of the sugarcane is produced. To select the indicators to be used as references in this chapter, the data referring to the crushing seasons of 2004/2005 and 2007/2008 were chosen and are presented in Table 5, which also includes the values of 1975 shown in Table 1. These data were collected from 160 mills, possibly with a performance slightly above the average mills in the Center-South Region.The data shown in the table above are an indication of the advances in the control of the process and the reduction of the feedstock losses, and confirm the saturation of the evolution as mentioned before. However, these parameters are not the only ones of interest in the follow up of the bioethanol industrial production process. Other indicators, particularly those associated with steam consumption and electric energy generation, are of great interest, and they show a similar improvement, as indicated in Table 6, for the state of the art mills.

Table 5 – Mill sector efficiencies in the bioethanol production

Parameters	1975	2004/05	2007/08	
	Average	Average	Average	Maximum
Cane washing efficiency (%)	-	99.3	99.52	99.99
Juice extraction efficiency (%)	93	96.1	95.83	97.22
Juice treatment efficiency (%)	98	99.5	99.48	99.96
Fermentation efficiency (%)	80	91.1	90.09	91.36
Distillation efficiency (%)	-	98.0	99.74	99.95
Undetermined losses (%)	-	3.5	3.36	3.47

Source: CTC, 2006 and CTC, 2008

In this case, performance is determined by the combined efficiency of steam generation (a function of bagasse conditions, boiler efficiencies, condensate recovery, etc.) and steam use (a function of the performance of the steam turbines, heat exchangers, evaporators, vacuum equipment, use of vapors, management and maintenance of piping and equipment insulation, etc.). When surplus power is to be generated, these indicators become of the highest importance to a successful installation.

Table 6 – Energy performance data for the state of the art mills

Parameters	1975	2005
Process steam consumption (kg/tc)	600	380
Distillation steam consumption-hydrous bioethanol (kg/l)	3.4	2.0
Distillation steam consumption-anhydrous bioethanol (kg/l)	4.5	2.7
Surplus power generation (kWh/tc)	-	Up to 146

Source: Olivério, 2008 and Seabra, 2008

It is important to point out that besides reducing the sugar and bioethanol losses, as well as increasing energy efficiencies, the technology improvement efforts are also directed to reduce the process residence times, investment costs, operation and maintenance costs, and to increase flexibility, reliability and automation, and they should also be considered in the assessment of the current state of the sugarcane agroindustry in Brazil, along with the diversification of technology configurations existing today.

On the other hand, the adoption of state of the art equipment and systems is within reach of the new plants being installed, and of the old plants in operation that want to modernize their facilities as well, because all equipment and designs are available in the Brazilian industrial sector, which has the capacity to provide these top performing systems and even large turnkey type projects. The decision to adopt the best technologies available depends, among other things, on the capacity and production profile (sugar/bioethanol/electricity) of each plant, product market prices, age of the existing equipment (in the case of plants in operation) and, naturally, the tendency to seek innovation of each enterprise. The competing options for the available resources for investment, such as modernization versus capacity expansion, is another point that affects the final decision to modernize. Some considerations will be made as follows with respect to potential improvements for the medium term (2015) and long term (2025)

Prospective values for 2015

Even while taking into account the intense and diversified technology dynamics discussed above, it is not so difficult to establish medium term scenarios for efficiency improvements of the present technology, since it is in the full maturity stage and the incremental gains are potentially small. Also, it is reasonable to assume that the new plants that will start to operate from this date are likely to be using the best technologies available today. In other words, the changes in the medium term scenario will tend to be affected mostly by the new mills starting operations with performance indicators corresponding to the best values now available. Under these assumptions, the values shown in Table 6.5 for the best mills in the 2007/2008 season and in the target values suggested by CGEE (2007) for 2015 were used to produce the values shown in Table 7.

Table 7 – Mill sector efficiencies expected for bioethanol production by 2015

Parameter	Average	Maximum
Cane washing efficiency (%)	99.7	99.99
Juice extraction efficiency (%)	96.4	97.50
Juice treatment efficiency (%)	99.6	99.96
Fermentation efficiency (%)	90.5	91.5
Distillation efficiency (%)	99.8	99.95

Source: The authors based on CTC, 2008 and CGEE, 2007

The average values at the end of this period were estimated assuming that half of the present installed capacity and the new units that will be installed will have efficiencies between the best and average values of the 2007/2008 season. The existing installed capacity was calculated based on the bioethanol production in this reference season of 22.5 billion liters (MAPA, 2009) and the new capacity was calculated according to the National Energy Plan (EPE, 2007), estimating an bioethanol production of 36.0 billion liters in 2015. Of course, these are arbitrary assumptions, but the basic point is that differences between the best and average units are expected.

As expected, the possible changes are small, but could represent significant gains due to the large volumes of cane to be processed. With proper design and operation, the new distilleries could be producing 91 liters of anhydrous bioethanol per tonne of cane, with process steam consumption of 353 kg per tonne of cane, surplus electricity of 28 kWh per tonne of cane and vinasse concentrated to 60% solids (FREIRE AND CORTEZ, 2000). With improvements in cane quality, especially in sucrose content, higher bioethanol yields could be obtained. It is important to point out that distilleries with process steam consumption of around 300 kg per tonne of cane are already being offered in the Brazilian market (OLIVÉRIO, 2008b); if vinasse concentration is not used, the surplus power generation could be around 80 kWh per tonne of cane. The sugarcane dry cleaning station is assumed to be the technology of choice to permit the extra low sugar losses in the cleaning process. Possibly, the technology improvement most relevant in this period will be the introduction of optimized cogeneration systems that will permit the full and efficient use of bagasse to increase the amount of surplus power generation.

Prospective values for 2025

When the horizons of the performance projections get further , the forecasts become more and more difficult due to the increase in the number of technical alternatives (many of them still in the laboratory stage) and in the uncertainties (in the context of this agroindustry) of important areas such as price of the energy vector (fuels and electricity) in Brazil and abroad, evolution of competing technologies, and mechanisms to mitigate greenhouse gas (GHG) emissions, among others outside factors.

To establish a probable future configuration of the bioethanol agroindustry in 2025, the incremental gains of conventional technology, with smaller uncertainties, and the perspective introduction of innovative and revolutionary technologies, particularly those making use of the lignocellulosic materials and industry effluents (for either bioethanol and/or electricity production), will each be considered separately.

This section is based essentially on the work developed by the Interdisciplinary Nucleus of Energy Planning of the University of Campinas (Nipe/Unicamp), with the support of the Center for Management and Strategic Studies (CGEE, 2007), where the evolution and impacts of the new industrial technologies up to 2025 were evaluated together with the incremental improvements of conventional technology.

The bioethanol distillery that will be installed by 2025 will have a cane dry cleaning station, electric drives for all cane preparation and juice extraction equipment and optimized mills or diffusers. The juice treatment system will have a six-effect evaporation tandem for the juice concentration and broth sterilization system, feeding continuous fermentation vats with a cooling system to keep the fermentation temperature below 28 0C, without the use of sulfuric acid and antibiotics, and operating with a final wine bioethanol concentration of 12%. Finally, the distillation will be of the multistage type with three effects, using thermal compression and vacuum distillation, and the dehydration will be done by molecular sieves or by more advanced alternatives such as pervaporation with membranes. Rossell (2008) summarizes the results that could be obtained in such a distillery, where all technologies used are basically available today: bioethanol yield of 92.5 liter/tonne of cane (for sucrose content in cane of 14.5%, wet basis), process steam and electric energy consumption of 372 kg/tonne of cane and 28 kWh/tonne of cane, respectively, a vinasse production of 3 liter/liter of bioethanol; the surplus power generation will be 160 kWh/tonne of cane, making partial use of the agricultural residues and all bagasse in a 90 bar/520 0C steam conditions system. Assuming the sugarcane sucrose content increases to 15.5%, wet basis, the bioethanol yield will reach 100 liter/tonne of cane.

For this conventional technology distillery the expected sector efficiencies are summarized in Table 8.

Table 8 – Mill sector efficiencies expected for bioethanol production by 2025

Parameter	Efficiencies (%)
Cane washing efficiency (%)	99.99
Juice extraction efficiency (%)	98.00
Juice treatment efficiency (%)	99.75
Fermentation efficiency (%)	92.00
Distillation efficiency (%)	99.75

Source: Rossell, 2008

Aside from the juice extraction and fermentation processes, the other distillery sectors present efficiencies close to the maximum ones estimated for 2015. These values refer to a new distillery and the estimation of the average and maximum values, as was done for 2015, is a very difficult task.

With respect to the innovative technologies, still with many uncertainties, within the scope of this chapter, only the most important trends will be analyzed. In fact, there are many possibilities to change the industrial processes, not only to increase the electric power, but also to produce different intermediate chemical products, biodegradable plastics, animal feed, and other products. A 2005 diagnostic of the sugarcane industry in Brazil indicated more than 60 technologies using sugarcane as feedstock in different industrial sectors (IEL/SEBRAE, 2005), and the spectrum tends to increase, adding value to the production and transforming the existing mills into "biorefineries", being very flexible and complex producing units, integrating processes and streams that have very low values today (BNDES, 2008).

The technologies that could bring the largest impact to the total yields of this agroindustry are related to the partial use of the agricultural (sugarcane tops and leaves) and industrial (bagasse) residues through hydrolysis or gasification to produce liquid fuels or electricity in advanced combined cycle (gas and steam cycles). Some of these alternatives will be discussed in more detail later on in this chapter.

It is also worth mentioning some new technologies that have been proposed in the recent past and have drawn great interest, in spite of low process performances and high costs, indicating that their potential and economic viability is still to be demonstrated. One of these is the biofuel similar to diesel by means of biosynthetic processes with microorganisms especially developed for this purpose, using sugars from cane juice or from hydrolysis processes as feedstock; an example of this process was developed by the American company Amyris Biotechnologies (using genetically modified yeast), which is operating a 5,000 liters per day demonstration unit, since July of 2009 (AMYRIS, 2009), with plans to reach the market in 2012. Another case is the production of butanol, produced today in petrochemical plants and widely used as an industrial solvent, also via a biologic process, using lignocellulosic materials as feedstock (DUPONT, 2008). A third option, still currently in the laboratory stage, is the route to producing bioethanol by means of residues gasification and biosynthesis, circulating the syngas containing carbon monoxide and hydrogen in a water phase with special microorganisms (COTTER ET AL., 2009 AND DATAR ET AL., 2004).

Bioelectricity generation

The sugarcane processing mills that produce sugar and/or bioethanol are traditionally also producing energy in the forms determined by the plant: thermal (process steam), mechanical (drives of heavy equipment) and electrical (drives of other equipment, lighting and other uses). Since the mid 1990s nearly all mills have reached energy self-sufficiency using bagasse produced at the mill as the only fuel. The equilibrium condition, where nearly all bagasse was consumed to generate all the energy needed by the mill, was achieved with live steam conditions at 20 bar/300 0C (LEAL AND MACEDO, 2004) and operating in a pure cogeneration condition where the electro-mechanical energy demanded is generated by the expansion of the live steam from 20 bar to 2.5 bar in steam turbines, and the turbine exhaust steam at 2.5 bar is used as a process stream, in an amount of around 500 kg of steam per tonne of cane processed. Under these conditions, the surplus bagasse is of the order of 5 to 10% of the total bagasse produced.

Since the focus of the mills was to produce sugar and bioethanol, and the electricity market offered very low prices for this product, there was no incentive to generate surplus power for sale or to improve the plant energy efficiency to save more bagasse, which had very limited market opportunities. However, this situation started to change at the end of the last century when the new regulatory framework for the electric power sector created the proper environment to develop the production and sale of electricity by the sugarcane mills. The more open minded mills started to see surplus electricity as a third party product to improve the stability and economic conditions of the business; these mills, when the time arrived to change obsolete boilers, chose to install high pressure units, initially in the 42 bar range and later on going beyond the 60 bar pressure level. Today, the 67 bar/520 0C seems to have become the new standard. The new groups of investors that have entered the sugarcane sector since the beginning of the great expansion of the production and use of bioethanol, have, naturally, presented the focus on the energy products of the cane: bioethanol and electricity. Even under this new priority bagasse continues to be the only fuel, but the expansion of mechanical harvesting of unburned cane made available an increasing amount of straw (cane tops and leaves) in the cane fields, a potential biofuel to supplement bagasse; so far, this potential has not been used in significant amounts. The Environmental Protocols signed by the main sector stakeholders (cane producers, millers, environmental agencies and government authorities) in São Paulo and Minas Gerais states, which cultivate nearly two thirds of the Brazilian cane, will speed up the phasing out of burnt cane harvesting in these two states, reaching around 80% of the cane to be harvested in 2014, and practically 100% in 2017. Other cane producing states will follow this trend, with some exceptions in the hilly fields of the Northeast states, pushed by the federal law that establishes the end of cane burning in all mechanizable areas in the country (slopes below 12%) by

2018. In summary, in the next five to ten years there will be a considerable increase in the availability of sugarcane straw in the fields that could be partially recovered and used as a supplement to bagasse as a fuel for additional power generation for the production of second generation biofuels.

A few questions remain to be answered about the future of the energy use of the sugarcane biomass (bagasse and straw):

- How much straw can or should be recovered from the fields, considering the agronomic impacts (that are dependent on the local conditions) such as soil protection, nutrient recycling, weed control, cane yields, pest populations and others, and the value of the straw as a feedstock for fuel and electricity production?
- What is the potential for increase in sugarcane primary energy recovery by the smart use of sugarcane residues?
- What are the best final products: biofuels or electricity?
- What are the impacts on the GHG emission abatement potential?

These questions will be discussed as follows:

Straw recovery

There are five main carbon reservoirs on the planet: the oceans, the geological (mainly in the form of fossil fuel reserves), the soil, the atmosphere and living beings. The amount of carbon stored in soil is approximately twice as much as that stored in the atmosphere (Lal, 2008), which is responsible for the global warming phenomenon. Therefore, it is extremely important that the soil carbon stock dynamics be carefully evaluated every time that there are changes in soil use or crop management practices, since the five carbon reservoirs are closely interlinked and are dynamic by nature.

With the increase of green cane harvesting (unburned cane), the amount of agriculture residues (the tops and the leaves of the cane) is increasing very rapidly and there is a growing interest in using these residues for extending power generation in the mills or, in the future when the second generation technologies are commercially available, to increase the bioethanol production per tonne of cane harvested.

The amount of straw that should be left in the fields, in terms of tonnes of residue per hectare (dry basis) is highly variable depending on the local climate (moisture and temperature), type of soil (especially if it is sandy or of a clay type), the soil C/N ratio, culture management, ground slope and other factors. The potential of losing soil carbon due to inadequate agricultural practices is very high and can take place in relatively short periods of time, especially in the first five to ten years in the tropical areas. Conservationist practices, such as no tillage, green cane harvesting and adequate fertilizer and lime applications can slow down or even invert the soil carbon losses once the new equilibrium condition is reached. The use of nitrogen fixing cultures in the rotation of crops is an important practice since the organic matter is stable when the C/N ratio is in the order of 10 to 13; in other words, the increase of organic carbon in the soil must be accompanied by an increase of nitrogen, a limiting nutrient in many ecosystems. Cantarella et al. (2007) have made a revision in the international literature concerning the effects of the straw blanket on the soil properties and carbon content. The oldest experiment comparing the effects of green cane with burnt cane harvesting practices has been conducted since 1939 in South Africa (GRAHAM *et al.*, 2000). Measurements made after 59 years have shown that significant changes in the carbon and nitrogen content in the soil occur essentially in the top surface layer at between 0 and 10 cm depth. Although the differences in carbon and nitrogen content below the 10 cm depth, between the two harvesting practices, are very small, there were improvements in the green cane harvesting area in terms of increase in the microbial mass. Unfortunately the type of soil where the experiments were conducted is not very representative of the soils used for sugarcane cropping, even in South Africa. Another study by Robertson and Thorburn (2000), after three to six years of straw blanket on the ground, observed that a large fraction of the carbon was metabolized by the microorganisms and released into the atmosphere as CO2. The authors estimated the possible gains in carbon and nitrogen contents in soil, after 20 to 30 years of straw on the ground, as 8 to 15% for organic carbon and 9 to 24% for total nitrogen. Field tests in Australia carried out over 17 years (THORBURN ET AL., 2000; ROBERTSON ET AL., 2000) have shown that the accumulation of carbon and nitrogen is concentrated in the top 5 cm layer of the soil. The accumulation of nitrogen is higher than carbon due to the high carbon/nitrogen ratio in the straw (GRAHAM *et al.*, 2002b).

Results of field experiments in the state of São Paulo indicate an increase of soil carbon content in areas of green cane harvesting in the range of 0.32 to 0.8 tonne/ha/year. The lower value seems to be more representative because it refers to a 12 year experiment. Besides, the cane culture is renewed every six or seven years, normally with a great soil movement for the next cane planting operation, which is likely to promote the oxidation of part of the accumulated carbon (CERRI ET AL., 2009). Under São Paulo state conditions, Faroni et al. (2003) observed that 40 to 50% of the straw dry matter still remained on the ground after one year; however, the carbon/nitrogen ratio decreased from 85 to 34 in the straw blanket. Oliveira et al. (1999) indicated similar results with the straw decomposition after one year on the ground staying in the range of 20 to 70%.

Knowledge of the agronomic impacts of the straw in the soil is still very poor and a lot remains to be done in that area. In the few existing studies the main focuses are the soil carbon stock, nutrient recycling and the ratoon conditions, but the protection against erosion, weed control and water balance have also been receiving some attention. In the USA, the corn stover recovery is a similar problem and the maximum amount to be taken from the fields was established as 50% in the case of no tillage practice, or 35% when other conservationist practices are used (EPA, 2010). Recently, Tarkalson et al. (2009) have estimated that, for the case of wheat in temperate climates, the minimum amount of straw to be left on the ground was equivalent to 1.5 tonnes/hectare of carbon, corresponding to an average of 3.1 tonnes/ha of grains. These authors also considered that for high yield irrigated areas, the carbon in the roots was sufficient to maintain the adequate amount of organic matter in the soils, since 25 to 50% of the total carbon in the biomass of some cereals is in the roots. For sugarcane, it is estimated that on average around 0.8 to 2 tonnes/ha of dry matter in the roots is added to the soil each year.

In tropical regions the annual demand for carbon to maintain the necessary amount of soil organic matter is larger, especially in hotter and more humid areas, where it is difficult to produce residues in the winter. According to Sá (2010) some preliminary data have indicated that in the center-north regions of Brazil the soil carbon equilibrium may require up to 4 tonnes/ha per year. Nevertheless, the research results discussed above indicate that, in spite of the large quantities of sugarcane straw left on the ground, the variations in the amount of soil organic matter are relatively small and slow, in other words, the straw is decomposed with the return of the carbon to the atmosphere due to oxidation.

It is important to point out that the capacity of the soil to retain organic carbon is dependent on some of its characteristics, the climate and the agricultural practices. This means that there is a maximum potential to increase soil organic matter and that, once the point of equilibrium is reached, additional amounts of organic matter on the ground will not result in more benefits. Therefore, it is reasonable to assume that some of the straw resulting from green cane harvesting can be removed while still achieving the agronomic benefits. However, the few data available on this subject are not sufficient to point to the optimum amount to be left on the ground. The work of Sugarcane Technology Center (CTC, formerly Copersucar Technology Center), partially presented by Hassuani et al. (2005), presents some preliminary results concerning the impacts of the straw mat on weed growth inhibition, nutrient recycling, cane yields and insect population, among others. Some preliminary results indicated that 7.5 tonne/ha (dry basis) was sufficient to inhibit weed growth and it represented about 60% of the total straw produced during the green cane harvest; of course, this result could be different under other climate and soil conditions and other agronomic impacts of the straw blanket must be better understood and quantified.

Bagasse availability

The amount of surplus bagasse, on the other hand, will depend mainly on the sugarcane fiber content, the process steam consumption, the efficiency of the boilers and the profile of the mill startups, shutdowns and hot standbys in terms of frequency and duration. Favorable to increasing bagasse availability, technology to allow for 300 kg of process steam per tonne of sugarcane is commercially available in Brazil and modern high pressure boilers are offered with efficiencies in the order of 89% in the lower heating value of bagasse. Going in the opposite wrong direction is the sugarcane fiber content that is consistently being reduced due to the breeding program policy in this respect, since high fiber in the cane reduces the milling tandem capacity, increases the sugar losses due to carryover by the bagasse and increases the energy consumption in the cane preparation and juice extraction systems.

Energy balance

Before evaluating the alternatives to improve the energy efficiency of the mill, it is important to know the average situation today. For that, reference cane quality parameters and yield will be assumed:

- Cane yield (clean stalks): 70 tonnes/ha/year of planted area or 85 tonnes/ha of harvested area.
- Fiber: 13%, wet basis.
- Sucrose content: 14%, wet basis.
- Reducing sugars: 0.6%, wet basis.
- Straw: 140 kg/tonne of clean stalks, dry basis.

Under these conditions, the primary energy content of the sugarcane is the one summarized in Table 9.

Table 9 – Primary Energy of Sugarcane per Tonne of Clean Stalks (Higher Heating Value)

Component	Energy (MJ)
146 kg of sugars	2,400
130 kg of stalk fibers	2,300
140 kg of straw fibers	2,500
Total	7,200 (1.2 boe)*

Source: The authors

* boe: barrel of oil equivalent

The sugarcane harvested in one hectare has 610 GJ of primary energy. On average one tonne of cane produces 82 liters of bioethanol (1,920 MJ), 5 kWh/tonne of cane (18 MJ) and 5% of surplus bagasse (124 MJ) in the new mills, totaling 2,062 MJ of useful energy, or less than 30% of primary energy recovery. This low efficiency value indicates that there is plenty of room for improvement, and some alternatives will be presented based on Seabra (2008) that considered that 40% of the available straw in the field will be recovered and used at the mill (56 kg/tonne of cane, dry basis).

Present situation

As mentioned before, almost all mills in Brazil have reached the energy self-sufficiency stage with steam conditions at 22 bar/300 0C, process steam consumption of 500 kg/tonne of cane, mechanical energy consumption of 16 kWh/tonne of cane and electricity consumption of 12 kWh/tonne of cane. Under these conditions some mills are able to produce a little bit of surplus electricity in the range of 0 to 10 kWh/tonne of cane. Recently Conab (2011) produced the first comprehensive and national scale assessment of the power generation in the Brazilian mills (2009/2010 crushing season) indicating that around 28% of the mills (111 of 393 units surveyed) are interconnected with the grid and sell surplus electricity, but the ones that sell electricity process 47% of the cane in Brazil due to the fact that the larger units are the ones with surplus power generation; 90% of the mills in São Paulo processing above 4 million tonnes of cane per year are selling electricity, but there is no mill processing less than one million tonnes of cane per season generating surplus power. The total installed capacity in the 393 mills is 5,615 MW with 3,844 MW in the mills that sell electricity, generating a total electric energy of 20 TWh, where 12.5 TWh is used by the mills and 7.3 TWh is sold to the grid, corresponding to 33 and 12 kWh/tonne of cane of total generation and energy sold to the grid, respectively. According to the ONS (National System Operator) in 2009 the country produced a total of 446 TWh and the 20 TWh produced by the mills is equivalent to almost 5% of this total. Considering that the size of the new mills is becoming larger and larger and that they are normally being built with state of the art technologies, it is fair to assume that the situation tends to improve, in spite of the serious problems pointed out by the sugarcane sector: difficulties with elevated capital costs of the interconnection between the mill and the national grid and low tariffs being offered at the energy auctions.

Considering the fast increase in green cane harvesting and the availability of straw as a supplemental fuel to bagasse, the potential of surplus power tends to increase. To make an assessment of this future potential, the following alternative technologies will be used in the comparison of the possible different uses of sugarcane biomass:

Present technology: surplus power generation with a pure cogeneration system with a backpressure (BP) steam turbine generator and steam conditions at 22 bar/300 0C, using only bagasse as fuel.

Advanced technology I: surplus power generation with a condensing/extraction steam turbine generator (CEST), steam conditions at 90 bar/520 0C, using only bagasse as fuel.

Advanced technology II: surplus power generation with a condensing/extraction steam turbine generator (CEST), steam conditions at 90 bar/520 0C, using all bagasse and 40% of the straw.

Advanced technology III: surplus power generation using Biomass Integrated Gasification/ Combined Cycle (BIG/CC), using all bagasse and 40% of the straw.

Advanced technology IV: additional bioethanol production by hydrolysis of the available biomass and generation of surplus power in a cogeneration system supplying the power required by both the conventional and hydrolysis bioethanol plants, with steam conditions at 65 bar/480 0C, using all bagasse and 40% of the straw.

The process steam consumption for the conventional bioethanol plant was assumed to be 500 kg/ tonne of cane for the Present Technology and 340 kg/tonne of cane for all Advanced Technology cases. The output of useful forms of energy (bioethanol and electricity) for the five cases above is summarized in Table 10 (SEABRA, 2008).

It is important to point out that the hydrolysis technology to produce bioethanol from lignocellulosic material and the biomass gasification for power generation (both considered second generation technologies) are not yet at the commercial stage, and therefore the performance data used in the simulations are expected values for these technologies at their mature stage, probably around 2020. In the same way, the routes to collect and process the straw for final use at the mill are still being tested in some mills and further developments are required before they can be put in commercial use. Even the use of straw in bagasse boilers needs extensive testing and adaptations to avoid problems in the fuel feed system and deposit formation and corrosion in the boilers tubes due to the higher alkali and chlorine levels compared to bagasse.

Table 10 – Useful energy production for the different alternatives

	Present	Adv I	Adv II	Adv III	Adv IV
Steam conditions					
Pressure (bar)	22	90	90	90	65
Temperature (0C)	300	520	520	520	480
Process steam (kg/tc)	500	340	340	340	340
Power generation technology	BP	CEST	CEST	BIG/CC	BP/Hydrol.
Bagasse (% total)	95	100	100	100	100
Straw (% total)	0	0	40	40	40
Bioethanol yield (l/tc)	82	82	82	82	119
Surplus electricity (kWh/tc)	5	81	145	194	44

Source: Seabra, 2008

Note: tc = tonnes of cane processed

From Table 10 it can be seen that the recovery and use of 40% of the straw available after the green cane harvest will considerably increase the surplus power generation with a technology that is fully commercial today (CEST), making it possible also to generate surplus power all year round. The use of sugarcane biomass in a hydrolysis process, when fully developed, will increase the bioethanol yield per tonne of cane around by 45% (additional 37 liters/tc), but will reduce the surplus power generation. The use of second generation technologies is likely to be possible only if a significant part of the sugarcane straw is recovered and used.

The impacts of state of the art technologies (CEST) and second generation technologies (BIG/CC and hydrolysis), with a better use of sugarcane biomass (bagasse and 40% of straw) on the energy and GHG balances, under the assumptions made above, are summarized in Table 11. Here it is important to point out that this energy recovery efficiency was calculated using concepts from the First Law of Thermodynamics by adding different forms of energy (work - electricity, and heat - bioethanol) without due consideration of the unavoidable conversion losses of heat to work determined by the Second Law of Thermodynamics. The national energy balances also uses this procedure, which is unable to recognize that there are physical limits of around 60% in primary energy recovery in these systems.

Table 11 – Energy and GHG emission balances for the alternative uses of sugarcane biomass

	Present	Adv I	Adv II	Adv III	Adv IV
Bioethanol yields (l/tc)	82	82	82	82	119
Surplus power (kWh/tc)	5	81	145	194	44
Final products energy (HHV)					
Bioethanol (MJ/tc)	1919	1919	1919	1919	2785
Surplus electricity (MJ/tc)	18	292	522	698	158
Surplus bagasse (MJ/tc)	124	0	0	0	0
Total (MJ/tc)	2061	2211	2441	2617	2943
Primary energy recovery (%)	28.6	30.7	33.9	36.3	40.9
Avoided GHG (kgCO$_2$e/tc)					
Bioethanol	173	173	173	173	251
Electricity (Brazil average)	1	22	38	52	12
Bagasse	12	0	0	0	0
Total	186	195	211	225	263

Source: Seabra, 2008

Note: tc = tonnes of cane processed

Some important observations can be made from Table 11:

- Even with the use of 40% of the straw to supplement the bagasse using conventional technology, the gains in efficiency of conversion of the sugarcane primary energy into useful forms of energy (bioethanol and electricity) are modest (from 29% to 34%).
- The more advanced technologies, especially hydrolysis, will allow significant gains in this efficiency of recovery (from 29% to 41%).
- Without the use of straw the result achieved with the best technology today, in terms of energy balance, is quite insignificant (from 29% to 31%).
- The same conclusions are also valid for the GHG emission reductions.
- The technologies used in the conversion of sugarcane residues into useful products, both in terms of energy balance and GHG emission reduction, show a clear advantage over the hydrolysis alternative. This is due to the fact that the energy balance presented used the First Law of Thermodynamics, which penalizes electricity generation (Second Law of Thermodynamics), and low emission of the Brazilian power sector (80% hydro power).

Nevertheless, the final decision on the technology of choice will be heavily dependent on the economic results of each option. Due to the inherent difficulties in performing a detailed economic analysis of technologies that are still a decade away from the commercial stage, a very simplified vision of this aspect is presented in Table 12 including only the gross income of the distillery per tonne of processed cane; the average prices before 2008 are used as references, consisting of R$ 0.80/liter bioethanol and R$ 140.00/MWh of electricity, both without taxes. The Certified Emission Reduction (CER) was assumed to be R$ 27.00/t CO2e

Table 12 – Impacts of the technologies in the distillery gross income

	Present	Adv I	Adv II	Adv III	Adv IV
Bioethanol yields (l/tc)	82	82	82	82	119
Surplus electricity (kWh/tc)	5	81	145	194	44
GHG emission reduction (kg CO_2e/tc)	186	195	211	225	263
Bioethanol income (R$/tc)	65.60	65.60	65.60	65.60	95.2
Electricity income (R$/tc)	0.70	11.34	20.3	27.16	6.16
CER income (R$/tc)	5.02	5.26	5.70	6.08	7.10
Gross income w/o CER (R$/tc)	66.30	76.94	85.90	92.76	101.36
Gross income with CER (R$/tc)	71.32	88.22	91.60	98.84	108.46

Source: The authors, based on Seabra (2008)

Note: tc = tonnes of cane processed

There is a significant improvement of the distillery gross income per tonne of processed cane (not necessarily in the net economic results, nor evaluated here) with the use of advanced technologies, especially when some of the straw is made available. Bioethanol from hydrolysis exhibits the best result, but the final choice of the best technology will be done in the future, when the technologies will be consolidated based on detailed economic analysis, evaluation of the sustainability aspects and also the perception of risk due to the use of new technologies.

State of the art technologies are already being used (CEST), but straw recovery and use need further study and development to become a commercial practice.

Perspectives for improvements in the GHG mitigation potential

In the section above, several alternatives have been explored with a view to see the potential improvements in energy balance and GHG mitigation, but only the wide use of the sugarcane biomass (bagasse and straw) was considered. There are other alternatives in the production and usage value chain that could be evaluated to assess the impacts on the national GHG emission reduction from bioethanol, such as in the bioethanol production process (agriculture and industry), in surplus electricity generation and bioethanol transport and distribution. The aspect of end use is also very important but it is analyzed in Chapter VII, including the impacts on tail pipe emissions.

Bioethanol production chain: from field to tank

The medium term GHG emission reduction potential, using the period between 2005 and 2020, has been deeply analyzed by Macedo et al. (2008) and Seabra (2008). The Life Cycle Analysis emission reduction in this period, using a broad data base covering around 25% of the sugarcane produced in Brazil, indicated that total process emissions (agricultural and industry phases, but not including the emissions resulting from Land Use Change) will be reduced from 417 to 330 gCO_2e/m_3 of hydrous bioethanol and from 436 gCO_2e/m_3 of anhydrous bioethanol (a little bit above 25% in both cases). The authors worked with average values of the parameters to develop the energy and GHG balances, and performed a sensitivity analysis for a varying range of these parameters.

The emissions derived from Land Use Change (LUC), both directly and indirectly, can have a significant impact on GHG balances, and they are discussed in Chapter XII.

In a recent study prepared for the World Bank (GOUVELLO, 2010), where mitigation measures were evaluated, the authors used Macedo et al. (2008) as the most important reference, while adding some of the results from Seabra (2008), particularly for the bioethanol transportation by trucks from the producing units to the filling stations. In this case, the variation of LCA GHG emissions from 2005 to 2020 changed from 490 to 403 gCO_2e/m_3 of hydrous bioethanol and from 514 to 422 gCO_2e/m_3 of anhydrous bioethanol, assuming no improvement in the transportation systems (such as the use of pipelines, railroad or barge modals). The projections up to 2020 were extended to 2030 using similar assumptions that Macedo et al. (2008) used for the World Bank study, arriving at values of 345 and 415 gCO_2e per cubic meter of hydrous and anhydrous bioethanol in 2030, respectively.

The main observations made in these evaluations were the end of cane burning in the pre-harvest, which was responsible for most of the emission reductions, and the increase in diesel use in the agricultural phase due to growth in mechanization, causing most of the increase in emissions during the period. The latter case could be mitigated by the use of biofuels (bioethanol or biodiesel) in some of the agricultural operations or by the simplification of the these operations by the use of conservational practices such as no tillage; however, none of these alternatives have been explored here, and some years of research will be required before practical use of these technologies can be implemented.

Surplus electricity generation

In this case, the basic assumption is that all LCA GHG emissions in the sugarcane production and processing to bioethanol are contributed to bioethanol and not to bagasse and straw used for surplus power generation. Of course, other allocation methods could be used but they will not be included here.

In this way, the possible GHG emission reductions are associated to the evolution of the electric power generation and the emission factors estimated for the power sector. For emission balances, it is understood that the emission factors to be used are those calculated taking into account all power plants that generate electricity within a certain period. It is well known that in Brazil the values are very low, when compared to other countries, due to the profile of the power generation national system. Data made available by the Ministry of Science and Technology (MCT, 2010) indicate average values for the emission factor from 2006 to 2009 varying between 24.6 and 48.4 kg CO_2e/MWh. The maximum value observed in more than 50 months was 66.8 kg CO_2e/MWh in February 2008.

The National Energy Plan 2030 (EPE, 2007), used as a reference for the power sector expansion, considers emission factors for 2010 with values that were never observed before (94 kg CO_2e/MWh); in this study there is a trend of reduction of this value to 79 kg CO_2e/MWh in 2030 due to the sector expansion focused on large size hydro power plants.

Therefore, from the point of view of GHG emissions, the positive effect of electricity generation from the sugarcane residues would come exclusively from the significant increase in power generation. In the alternative scenario, electric power generation from bagasse and straw could be up to four times greater compared with the two scenarios considered (200.8 TWh in 2030 in a lower emission scenario, against 49 TWh in the same year in the reference scenario) (GOUVELLO, 2010). Although advanced technology (BIG/CC) was assumed to be used in the low emission scenario, even while still being far from reaching the commercial stage, the potential power generation would not be significantly affected in the case of this assumption not materializing or not becoming economic (only 15% of the total power generation was assumed to come from BIG/CC systems in 2030). Most of this potential would be realized using technologies that are already commercially available. The difficulty with generating the 200 TWh forecast for 2030 using the sugarcane residues would come from the high costs of interconnection between the plants and the national grid, and the low economic attractiveness of the business.

A second aspect to consider is that this potential strongly depends on the availability of sugarcane straw to supplement bagasse in power generation. In this way, the recovery, transport and final use of the straw are challenges that need to be faced over the next few years. Even the use of straw in the existing bagasse fired boilers could become a serious problem due to the higher ash, alkali and chlorine content in the straw compared to that of bagasse.

The third point of concern is the eventual need to increase water withdrawal due to the use of steam condensers in the large scale CEST systems. This aspect is also considered in the EPE study (2007).

Even with low GHG emission factors in the Brazilian electric power sector, the avoided emissions due to the increase in sugarcane biomass power generation, accumulated between 2010 and 2030 (GOUVELLO, 2010) would reach 157.9 $MtCO_2e$. In the hypothesis of an emission factor of 360 kg CO_2e/MWh, typical of high efficiency natural gas fired thermal power plants, the avoided emissions in the 2010-2030 period would be 763.4 $MtCO_2e$, which is 4.8 times larger than the total estimated in the World Bank study (GOUVELLO, 2010).

Final comments

It is clear that the conventional industrial technology of bioethanol production from sugarcane does present opportunities for gains in yield and efficiencies in the agricultural area, but nevertheless, they are no less important. Besides the value of the increase in the amount of final products, the value of costs and possible effects associated with the diversification of possible production are also relevant; as are the aspects associated with the strategy of improving the sustainability of Brazilian bioethanol. As an example, the use of diffusers in the juice extraction process may not have a large improvement in extraction efficiency compared with a milling tandem, but the better energy balance could favor the increase in surplus electricity production.

The scenarios established, based on the industrial efficiency values, confirm the initial expectations: bioethanol production, as it is done today and considering the potential evolution in the next few years, does not present relevant environmental problems and has a significant level of byproducts recycling, while sugar losses are maintained at a very low level. The great uncertainties in the direction of future improvements are related to the introduction of innovative technologies, where the speed of advancement was expected to be faster than it really is today, in both of the most prominent cases of hydrolysis and gasification of the lignocellulosic residues of sugarcane for the production of biofuels and electricity. It is fair to recognize the inherent difficulties in the transition from the scale of research and development, where the control of the process variables and cleanliness are a lot easier, to the scales necessary to meet the demands of the agroindustry of energy which represents a considerable challenge. The important effort of the international scientific community in this direction, both in basic and applied science, has shown significant advances in the understanding and modeling of these processes and, in due time, will achieve the practical deployment stage. Besides, and possibly more importantly, the boundary conditions, determined by the prices of conventional energies and the will to invest in new technologies, were not the most favorable ones, mainly due to the instabilities and volatilities of past years. In this sense, it is important to point out the role of the Government as an agent to mitigate the economic uncertainties, aiming at promoting the investments necessary without which a reasonable expectation of economic returns will not happen in a healthy way.

Nevertheless, the main factors that have promoted biofuels in general (positive energy balance, low demand for natural resources, social acceptability and economic gains), and the sugarcane bioethanol in particular, as the most promising renewable energy alternatives to reduce GHG emissions and the dependence on imported fossil fuels, are becoming more and more important, pushing the expansion of production and use, either under the incremental gains of conventional technologies or the large steps expected from the revolutionary technologies.

References

AMYRIS. Disponível em: http://www.amyrisbiotech.com/. Acesso em: ago 2009.

BNDES, Bioetanol de cana-de-açúcar: energia para o desenvolvimento sustentável. Rio de Janeiro: Banco Nacional de Desenvolvimento Econômico e Social, 2008.

CANTARELLA, H.; TRIVELIN, P.C.O.; VITTI, A.C. Nitrogênio e enxofre na cultura da cana-de-açúcar. In: YAMADA, T.; ABDALLA, S.R.S.; VITTI, A.C. (Eds) Nitrogênio e enxofre na agricultura brasileira, Piracicaba: International Plant Nutrition Institute, p. 355-412, 2007.

CARVALHO, J.L.N.;, AVANZI, J.C.; SILVA, M.L.N.; MELLO, C.R.; CERRI, C.E.P. Potencial de seqüestro de carbono em diferentes biomas do Brasil, RBCJ v. 34, p. 277-289. 2010.

CERRI, C.E.P.; CERRI, C.C.; MAIA, S.M.F.; GALDOS, M.V.; FEIGEL, B.J.; BERNOUX, M. Brazilian greenhouse gas emissions: the importance of agriculture and livestock, Sci.Agric. v. 66, p. 831-843. 2009.

GRAHAM, M.H.; HAYNES, R.J.; MEYER, J.H. Changes in soil fertility induced by trash retention and fertilizer applications on the long-term trash management trial at Mount Edgecombe. In: SOUTH AFRICA SUGAR TECHNOLOGISTS ASSOCIATION CONGRESS, v. 74, p.109-113. 2000, Proceedings... 2000.

CENTRO DE GESTÃO DE ESTUDOS ESTRATÉGICOS – CGEE. Estudo sobre as possibilidades e impactos da produção de grandes quantidades de etanol visando à substituição parcial de gasolina no mundo – Fase 2. Campinas: Nipe/Unicamp e Centro de Gestão de Estudos Estratégicos, 2007.

____. Bioetanol combustível: uma oportunidade para o Brasil. Brasília, DF: CGEE, 536 p. 2009.

COMPANHIA NACIONAL DE ABASTECIMENTO – CONAB. Perfil do setor do açúcar e do álcool no Brasil. Brasília: CONAB, MAPA, 76 p. 2008.

____. A geração termoelétrica com a queima do bagaço de cana-de-açúcar no brasil – análise de desempenho da safra 2009-2010. Brasília: CONAB, MAPA, 160 p. 2011.

COTTER, J.L.; CHINN, M.S.; GRUNDEN, A.M. Ethanol and acetate production by clostridium ljungdahlii and clostridium autoethanogenum using resting cells. Bioprocess and Biosystems Engineering, v. 32, 2009.

CENTRO DE TECNOLOGIA CANAVIEIRA – CTC. Centro de Tecnologia Canavieira- 2009. Disponível em: <www.ctc.com.br>.

____, Programa de controle mútuo agrícola e industrial. Piracicaba: Centro de Tecnologia Canavieira, 2006.

____. Programa de controle mútuo industrial. Piracicaba: Centro de Tecnologia Canavieira, 2008.

DATAR, R.P.; SHENKMAN, R.M.; CATENI, B.G.; HUHNKE, R.L.; LEWIS, R.S., Fermentation of biomass-generated producer gas to ethanol. Biotechnology and Bioengineering, v. 86, n. 5. 2004.

DUPONT. BioButanol, 2008, Disponível em: <http://www2.dupont.com/Biofuels/en_US/index.html>. Acesso em: mai 2009.

ENVIRONMENTAL PROTECTION AGENCY – EPA. Renewable fuel standard Program (RFS2), S.l.: U.S. Environmental Protection Agency Report, 2010, 1120 p.

EMPRESA DE PESQUISA ENERGÉTICA – EPE. Plano nacional de energia 2030. Rio de Janeiro: EPE / Ministério de Minas e Energia, 2007.

____. Plano decenal de energia 2019. Rio de janeiro, RJ: Empresa de Pesquisa Energética, Ministério das Minas e Energia, 2010.

FARONI, C.E.; VITTI, A.C.; GAVA, G.J.C.; MANZONI, C.S.; PENATTI, C.P.; TRIVELIN, P.C.O. Degradação da palha(15N) de cana de açúcar em dois anos consecutivos, In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 29, 2003, Ribeirão Preto, SP, UNESP/SBCS. Proceedings... Ribeirão Preto, SP: UNESP/SBCS, 2003.

FIGLIOLINO, A. Visão e tendências do setor de Açúcar e Álcool no Brasil, Reunião Anula Canaplan – 2010. Ribeirão Preto, SP: 2010.

FINGUERUT, J. Simultaneous production of sugar and alcohol from sugarcane. In: INTERNATIONAL SOCIETY OF SUGAR CANE TECHNOLOGISTS (ISSCT) CONGRESS, 25., Guatemala City, Guatemala, 2005. Proceedings... Guatemala City, Guatemala: 2005.

____. Processo fermentativo, Position Paper para o I Workshop Tecnológico sobre obtenção de etanol", Projeto PPPP Etanol, Lorena, SP. 2006,

FREIRE, W.J.; CORTEZ, L.A.B. Vinhaça de cana de açúcar. Guaíba, RS: Livraria e Editora Agropecuária, 203 p. 2000.

GOUVELLO, C. Low carbon study for Brazil, Washington: World Bank, 2010.

HASSUANI, S.J.; LEAL, M.R.L.V.; MACEDO, I.C. Biomass power generation: Sugar cane bagasse and trash. Project BRA/96/G31 Report to UNDP, 217 p., 2005.

INSTITUTO EUVALDO LODI/SERVIÇO BRASILEIRO DE APOIO ÀS MICRO E PEQUENAS EMPRESAS - IEL/SEBRAE. O novo ciclo da cana: estudo sobre a competitividade do sistema agroindustrial da cana-de-açúcar e prospecção de novos empreendimentos, Brasília: 2005.

LAL, R. Carbon sequestration, Philosophical Transactions of the Royal Society, v. 363, p. 815-830, 2008.

LEAL, M.R.L.V., The potential of sugarcane as an energy source, In: International Society of Sugar Cane Technologists Congress, 26., v. 26, p. 23-34. 2007. Proceedings… 2007.

LEAL, M.R.L.V.; MACEDO, I.C. Evolução tecnológica dos sistemas de geração de energia nas usinas de açúcar e álcool. Biomassa & Energia, v. 1, n. 3, p. 245-253. 2004.

MACEDO, I.C. Tecnologia para a produção e uso do etanol: desenvolvimento, situação atual e perspectivas. Estudos Avançados, v. 21, n. 59, São Paulo, Jan-Abril 2007.

MACEDO, I.C.; SEABRA, J.E.A.; SILVA, J.E.A.R. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and the prediction for 2020. Biomass and Bioenergy, v. 32, n. 7, p. 582-595. 2008.

BRASIL. MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO - MAPA. Anuário estatístico da agroenergia. Brasília: Mapa/ACS, 160 p. 2009.

BRASIL. MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO – MCTI. Fatores de Emissões de CO2 pela geração de energia elétrica no Sistema Nacional Integrado, 2010. Acesso em: <www.mct.gov.br/index.php/content/view/74694.html>

OLIVEIRA, O.C.; URQUIAGA, S.; BODDEY, R.M. Burning canethe long term effects. International Sugar Journal, v. 94, n. 1147E. p. 272-275, 1994.

OLIVÉRIO, J.L. (DEDINI). As usinas de açúcar e álcool: O estado da arte da tecnologia. In: INTERNATIONAL CONGRESS OF AGROENERGY AND BIOFUELS, Teresina, PI, 13 de junho de 2007.

____. Cogeração: Uma nova fonte de renda para usinas de açúcar e álcool, SIMTEC 2008, Piracicaba, SP, 04 de julho de 2008b.

____. Novas tecnologias para biocombustíveis, In: ENCONTRO DE NEGÓCIOS DE ENERGIA, 9., São Paulo: FIESP/CIESP, 2008a.

PROCKNOR, C. Algumas tendências da tecnologia açucareira, seção soluções de fábrica. Revista STAB, Piracicaba. maio de 1999.

____. Dilemas, Seção Soluções de Fábrica. Revista STAB, Piracicaba, maio/junho de 2004.

____. Rational use of water. Engineering, Factory Solutions, Abril, 2002

REIN, P. Cane sugar engineering, Verlag Dr. Albert Bartens KG, Berlin, 768 p. 2007.

ROBERTSON, F.A.; THORBURN, P.J. Trash management – consequences for soil carbon and nitrogen, Proceedings of the Australian Society of Sugar Cane Technologists, v. 22, p. 225-229, 2000.

ROSSELL, C.E.V. Evolução tecnológica da produção de etanol. expectativas futuras: destilarias otimizadas, etanol da hidrólise de bagaço. In: REUNIÃO ANUAL DA SBPC, Campinas. 2008. Trabalho Apresentado... Campinas, 2008.

SÁ, J.C. Personnal communication. 2010.

SEABRA, J.E.A. Avaliação técnico-econômica de opções para o aproveitamento integral da biomassa de cana no Brasil. Tese (doutorado). Faculdade de Engenharia Mecânica - UNICAMP. Campinas, 274 p. 2008.

TARKALSON, D.D.; BROWN, B.; KOK, H.; BJORNE BERG, D.L. Impact of removing straw fro wheat and barley fields: A literature review. Better Crops, v. 93, n. 3, p. 17-19, 2009.

THORBURN, P.J.; KEATING, B.A.; ROBERTSON, F.A.; WOOD, A.W. Long-term changes in soil carbon and nitrogen under trash blanketing, Proceedings of the Australian Society of Sugar Cane Technologists Conference, p. 217-224. 2000.

UNICA. Outlook for Brazilian biofuels, In: VELASCO, J. Canadian Renewable Fuels Summit, December 1-3, 2008. Power Point presentation… 2008.

Chapter 6

Bioethanol use in light vehicles

Luiz Augusto Horta Nogueira
Manoel Regis Lima Verde Leal

Introduction

Although light vehicles are an icon of freedom and power and represent an essential commodity in modern society, they are also one of most concerning sources of gaseous pollutants and thus an enormous problem to deal with when designing sustainable scenarios for cities. In this context, biofuels and in particular bioethanol produced by efficient routes can play a relevant role. This biofuel is able to significantly mitigate global impact engine emissions (GHG), as already clearly recognized by EPA, which classified sugarcane bioethanol as an advanced biofuel, and also reduces harmful local emissions and helps to improve air quality in cities.

In this chapter the emissions related to local impact are discussed with regards to the use of bioethanol in light vehicles. Initially the relationship between vehicle emissions and air quality and the evolution of legislation are briefly reviewed, opening the discussion of engine technologies developed or put forward, aiming to control emissions and the effect of bioethanol on engine emissions. In conclusion, the impact of bioethanol use on vehicle fuel consumption is evaluated under different conditions, according to studies by Walter (2010).

Vehicles emissions and air quality

Knowledge of the effects of vehicular emissions on air quality in cities has influenced the actions of United States policy makers and environmental offices since the late 1960s. The large volume of cars in this country explains its leadership in actions to control vehicular emission. California is well renowned to have the most radical policies.

The First Clean Air act was declared in 1963 but it did not concern itself with specific emission levels . It was only in 1970, with the Clean Air Act Amendment, that the first measures were made concrete and effective in controlling vehicular emissions.

The Environmental Protection Agency (EPA) was created in 1970 with the objective to develop and monitor the regulations and standards of emissions and fuels. Two areas were targeted as priorities: reduction of the emissions of CO and of the precursors of tropospheric ozone (NOx and hydrocarbons). Both SO2 and NOx are a concern and deserve close attention due to their significant role in acid rain formation and emission of fine particulates (smaller than 10micra).

Global warming at the time was still a small scale concern. CO emissions were caused by the ignition and the operation of engines while still cold, principally in cities situated at high altitudes, such as Denver. When inhaled, CO causes a reduction in the bloods capacity to transport oxygen. In addition it can lead to the loss of reflexes and distorted vision. Also, Ozone and particulate (soot), combined with condensed humidity are the prime causes of smog, which reduces drivers' visibility. Besides, ozone can also irritate the airways, promoting asthma, while the particulates, (smaller than 2,5micra) are capable of reaching the deepest region of the lungs causing permanent damage.

The Clean Air Act Amendment of 1990 brought additional requirements for the control of vehicular emissions, including the determination of the use of oxygenated gasoline in areas with CO levels above the limit and reformulated gasoline in areas with ozone levels above the limit. Oxygenation of gasoline allowed the use of bioethanol, MTBE and ETBE as the preferred oxygenating agents. Reformulated gasoline has its composition controlled in some components, such as olefins and aromatics. MTBE has been banned as an oxygenating agent, which considerably increased the bioethanol consumption in the U.S. due to groundwater contamination problems.

Brazil was next to follow (albeit with some delay) the emissions-control legislation for light vehicles (Otto cycle) that had been adopted in the U.S. in addition to the European experience for the emissions of heavy vehicles (diesel cycle). Conama (National Environment Council, established in 1981) launched in 1986 the Program for the Control of Pollution from Motor Vehicles (Proconve), aiming at the elaboration and monitoring of emission standards and fuel quality. Cetesb (Environmental Company of São Paulo) has a significant role in this context, as the Metropolitan Region of São Paulo is noted to have a serious urban pollution problem. In 1995, the number of vehicles accounted for 98% of CO emissions, 97% of HC's, 97% of NOx, 85% of SOx and 40% of the MP (MONTEIRO, 1998). Over the years both the auto industry and fuel suppliers have had to adjust to the regulations as the emissions limits have been gradually tightened. Limits and deadlines for implementation were agreed between the several stakeholders involved.

Regarding light vehicles, the method of certification of emissions adopted in Brazil and the U.S. uses the 'load cycle' of the Federal Test Procedure FTP-75. This is an American standard that simulates an average daily trip in the U.S., reproduced in tests performed on a chassis dynamometer. Therefore, it takes into account the whole vehicle, not just the engine. The test is performed under conditions that reproduce a driver's actions (starts, stops, accelerations) and the behavior of the set engine-vehicle (weight, inertia, the engine characteristics, etc.). In this test, three distinct phases are observed as indicated in Figure 1, with a total duration of 1,874 seconds for a distance of 17.77 km (11.04 mi) and an average speed of 34.1 km/h (21.2 miles/h):

1. **Cold start:** this is the most critical phase, especially for bioethanol as the engine is still cold. This makes it harder for the fuel to combust, while increasing the emission of CO and hydrocarbons (HC) in larger scales. The duration of this phase is 505 seconds.
2. **Transient phase:** several stops and starts are simulated with few intervals of near constant speeds. It lasts for 864 seconds.
3. **Hot start:** this phase simulates the vehicle departing while still hot, corresponding to the path of return. It lasts approximately 505 seconds.

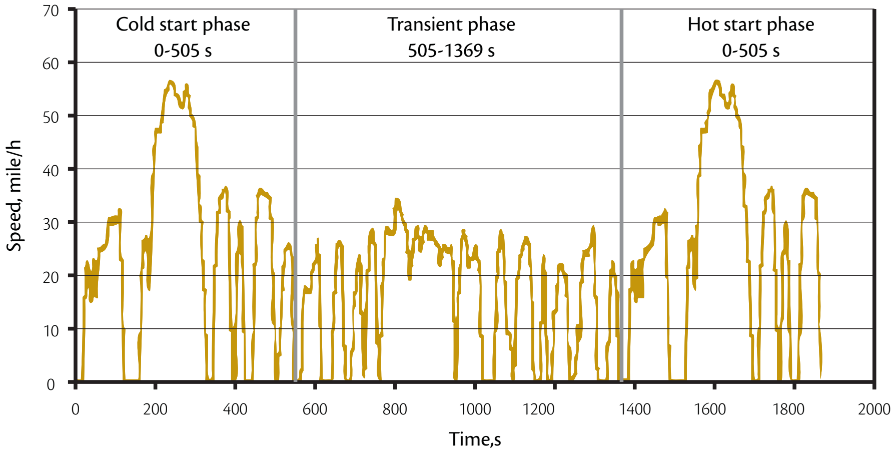


Figure 1. Test cycle for vehicle emissions according to the FTP-75 standard

In Europe a similar procedure is adopted, although a cycle of different charge is considered, intending to simulate the traffic conditions in European countries more accurately.

Emissions are independently collected and analyzed at each stage and the results are presented as mass of pollutant per distance traveled (g/mile or g/km). The final results of the weighting of different phases give the following values: 0.43 for the cold start, 1.0 for the transient phase and 0.57 for the hot start.

United States context

In the U.S., the emission limits set by the EPA were gradually tightened until they reached Tier 2 Regulations in late 1999, which had an implementation period from 2004 to 2009. Important innovations of this regulation are:

- The limits are independent of fuel (diesel or gasoline).
- They must be met by vehicles with up to 120,000 miles (193,000 km) of use.
- Vehicles weighing up to 8,000 lb (3,600 kg) are classified as light vehicles.

The emission limits that define eight classes of light vehicles which will comprise the fleet of new vehicles are shown in Table 1. Vehicle manufacturers are free to choose the composition of the fleet of new vehicles that will be offered on the market to meet the limits of Tier 2.

Table 1 – Emission limits for light vehicles according to Tier 2

Certification level	NMHC (g/mile)	CO (g/mile)	NOx (g/mile)
Bin 1	0,0	0,0	0,0
Bin 2	0,010	2,1	0,02
Bin 3	0,055	2,1	0,03
Bin 4	0,070	2,1	0,04
Bin 5	0,090	4,2	0,07
Bin 6	0,090	4,2	0,10
Bin 7	0,090	4,2	0,15
Bin 8	0,125	4,2	0,20

Source: EPA, 2010

EPA also includes a limit to gasoline sulfur content of 30 ppm, to be implemented from 2005.

Brazilian context

With the creation of Proconve, the control of vehicular emissions now has a national dimension. The establishment of limits for different years, given in Table 2, has promoted significant reductions in emission limits. It considers the limits defined in 1988 and forecasts to 2013 (covering classes L-1 to L-6). There is a reduction of 95% in CO emissions, 98% in HC, 96% in NOx and 87% in total aldehydes.

Highly polluted regions, such as the Metropolitan Region of São Paulo (MRSP) benefited highly from Proconve. Barros (2006) estimates that despite the considerable increase of the fleet, the total load of the main vehicular pollutants was 50-65% lower in 2010 due to Proconve .

Table 2 – Evolution of light vehicles emissions in Proconve

Class	Year	CO (g/km)	HC (g/km)	NOx (g/km)	aldehydes (g/km)4
L-1	1988	24,0	2,10	2,00	-
L-2	1992	12,0	1,20	1,40	0,15
L-3	1997	2,0	0,30	0,60	0,03
L-4	20051	2,0	0,162	0,25	0,03
L-5	2009	2,0	0,05	0,12	0,02
L-6	20133	1,3	0,05	0,08	0,02

Source: Joseph Jr, 2009

Notes: 1) Progressive introduction: 2005: 40% in 2006: 70% and 2007: 100%. 2) From 2005, the methane was removed from the hydrocarbons (HC's) and is now rated as NMHC. 3) Progressive introduction: 2013: Diesel light cycle in 2014: new Otto cycle, in 2015: 100% of the Otto cycle and 4) total aldehydes.

Bioethanol and engine technologies for emission control

The tightening of vehicle emission limits led to significant improvements in the technology of light and heavy vehicles, which in turn brought other benefits such as improved drivability, fuel consumption and engine reliability. So far the significant technological improvements forced by environmental regulations were electronic injection and ignition, the canister and the three-way catalytic converter with lambda probe. The electronics were also improved by gradually being incorporated into systems of injection and ignition control, thus allowing the gains achieved.

In Brazil, these technologies (single point injection and/or catalytic converter) have been introduced and improved since 1992 and were consolidated in 1997 through multipoint fuel injection and a three-way catalytic converter. Since 1992 to the present day, systems of fuel injection and ignition control have been rethought and optimized, seeking trade-offs between performance, fuel consumption and emissions. The three-way catalyst must perform the hard task of oxidizing HC's, CO and aldehydes, while reducing the NOx. It requires the engine to operate close to the stoichiometric conditions of the air/fuel mixture, allowing the variation of this ratio to benefit from the power gains with the rich mix, as well as savings from the leaner mixture. Engines working with very lean mixtures, compatible with bioethanol, were being developed with great potential for fuel economy but they were abandoned due to difficulties in achieving the NOx limits required by law.

Bioethanol impact on engine emissions

The following presents an analysis of the impact of bioethanol (pure or mixed) on Otto cycle vehicle emissions. It is necessary to remember that, considering the technology and emission limits of today, electronic fuel injection combined with a catalyst allows for the compliance of emissions legislation, such as gasoline and bioethanol .

- *Carbon Monoxide (CO)*

One of the first incentives to use an bioethanol-gasoline mix was the potential to reduce CO emissions, particularly in regions of high altitude where carbureted engines operate on a rich mixture of air/fuel due to lower air density. Oxygen represents 35% of the weight of bioethanol, which favors the complete combustion. In addition, the preferable conditions of the burning behavior of bioethanol allow for the use of lean mixtures, which in turn further reduces CO production.

Whitten and Cohen (1996) conducted a statistical analysis of the CO levels in the atmosphere. In areas where oxygenated fuels are used it indicated a possible 14% reduction in the concentration of site CO (as related to the national average). Since the effect of the CO reduction promoted by bioethanol is more pronounced on vehicles emitting more, the result will be more evident in regions where there is a reasonable number of older vehicles. Whitten (2006) demonstrated that the reduction of CO by the use of E10 also results in reduced levels of VOC (HC), attempting to show that the net effect between the reduction of the exhaust emissions of VOC from Otto cycle motor vehicles and the increase of evaporative emissions caused by the increase of vapor pressure of gasoline by bioethanol addition is a VOC reduction. The message was intended for the Air Resources Board (ARB) of California, which assumed a position contrary to the definition of reformulated gasoline for California (only 5.7% bioethanol). The weather in the winter implies a greater impact of CO vehicular emissions (in the level of concentration of this pollutant in the atmosphere) due to reduced dispersal of pollutants.

- *Nitrogen Oxides (NOx)*

The nitrogen in the air and the nitrogen that may exist in the fuel form nitrogen oxides in the combustion process. In the case of bioethanol, the presence of nitrogen is negligible. Bioethanol also helps to reduce NOx emissions as it reduces the combustion temperature. On the other hand, oxygenated fuels tend to produce more NOx than pure gasoline but this represents a small effect and may be explained by the ability of leaning the mixtures by the presence of oxygen in the molecule.

- *Ozone*

The formation of ozone in urban areas results from photochemical reactions between complex volatile carbon compounds, including CO, in the presence of NOx. Therefore, the fact that bioethanol reduces CO emissions of HC's, when used in blends with gasoline, tends to offset the increase in evaporative emissions due to the increased vapor pressure of the oxygenated fuel. In addition to the concentrations of HC's and NOx, ozone formation depends on the weather and sunshine, explaining its higher atmospheric concentrations in spring and summer.

- *Particulate matter (PM)*

U.S. legislation has focused on particulate matter with apparent diameter smaller than 2.5 microns, which can reach the deeper regions of the lungs and cause serious damage to health. In Brazil, Proconve chose to evaluate the suspended particles with apparent diameters below 10 microns. In gasoline vehicles, part of the PM is formed from unburned heavy compounds (boiling point above 100 °C), non-existent in pure bioethanol. Another part of the PM suspended in the atmosphere is formed by secondary reactions of NOx and SOx with moisture in the air, resulting in nitrates and sulfates in the form of powdered solids. The vehicle tires are another significant source of PM.

- *Sulfur oxides (SOx)*

Important for its role in the formation of acid rain and particulate matter, SOx does not appear much in evidence in U.S. law of the control of emissions given the U.S's success in dramatically reducing the sulfur level in diesel fuel (in some cases up to 1 ppm) and gasoline (30 ppm). The evolution of specifications is still ongoing in Brazil. Diesel, for instance, contains high levels of sulfur, 500-1800 ppm, which will be significantly reduced in Proconve's P-7 Phase. Diesel is limited to 10 ppm for the metropolitan areas. Currently, Brazilian gasoline contains 1000 ppm of sulfur, to be reduced to 50 ppm in Proconve's Phase L-6, from 2013. Petrobras, the main source responsible for supplying the Brazilian fuel market, has introduced enhancements to its refineries to meet those specifications. As bioethanol does not have sulfur in its composition, its use helps to reduce emissions of SOx.

- *Toxic Substances*

Some substances present in exhaust gases from motor vehicles are highly toxic, carcinogenic or mutagenic. These products, although dangerous to human health are somehow monitored and controlled. The main pollutants in this category are benzene, 1,3-butadiene, acrolein, polycyclic organic matter, naphthalene, formaldehyde and acetaldehyde (EPA, 2009).

Benzene is probably the most important of these pollutants due to its toxicity, carcinogenic and mutagenic power, as well as the volume of emissions compared to other toxic compounds. It appears in the gasoline composition in varying amounts but usually above 5%. The addition of bioethanol to gasoline reduces emissions of benzene in two ways: by dilution and by enabling the use of base gasoline with lower quantities of benzene, which is a main elevator of the octane of gasoline together with xylene and toluene, other aromatic with toxicity similar to benzene (Whitten, 2001). Pure bioethanol vehicles do not emit benzene.

The 1,3-butadiene is also a carcinogenic compound that causes damage through inhalation. Data from clinical trials are still insufficient to conclude the entire number of negative impacts of this product on human health; although the known effects are sufficient to categorize it as a carcinogen. Classification of acrolein as carcinogenic is not entirely proven, despite strong indications already observed. However, it is extremely irritating to the respiratory tract and to the mucosa of eyes when inhaled, even for short periods of exposure and at very low concentrations. The polycyclic organic matter is a large class of pollutants that stand out as polycyclic aromatic hydrocarbons (PAHs), which are carcinogenic and teratogenic. Naphthalene, another potentially carcinogenic substance, is present in gasoline in small quantities, but levels in exhaust emissions indicate that it is also formed as a product of combustion of gasoline. More studies are needed to confidently determine the negative impacts of these compounds on human health; however, it is important to note that adding bioethanol to gasoline reduces the emission by the dilution effect and reduces hydrocarbons in general. The vehicles using pure bioethanol do not emit these pollutants at significant levels.

The aldehydes are products of incomplete combustion of hydrocarbons and alcohols, the main ones being formaldehyde and acetaldehyde. The emissions of aldehydes from alcohol engines (mixed with gasoline or pure) are larger than those produced in gasoline engines, however, it is worth highlighting three important points:

a) emissions of aldehydes are much smaller than those of other pollutants (see Table 2),

b) emissions of other toxic substances are more harmful to human health than aldehydes. As stated in the previous paragraphs, these substances are significantly higher in gasoline engines than in alcohol,

c) most of the emissions of aldehydes of bioethanol engines are in the form of acetaldehyde, which is less reactive and aggressive in the atmosphere to human health than the formaldehyde produced in gasoline engines, even in minor amounts as indicated in Table 3.

Table 3 – Characteristics of toxicity and reactivity of aldehydes

Parameter	Formaldehyde	Acetaldehyde
Maximum Incremental Photochemistry reactivity	6,2 gO3/g	3,8 gO3/g
Limit of occupational exposure	2,0 ppm	100,0 ppm

As shown in Table 3, the formaldehyde concentration considered an occupational hazard is 50 times smaller than the value corresponding to acetaldehyde. The actual emissions of 2006 flex fuel vehicles average aldehyde emissions of 0.014 g/km for bioethanol and 0.003 g/km for gasoline. Although the gasoline emission is less than five times the bioethanol emission, due to the aldehydes composition it cannot be said that the emissions of such a compound by bioethanol vehicles are more harmful to human health when compared to gasoline. Szwarc (2010) also provides evidence that aldehyde emissions from other fuels such as natural gas and Diesel are equal or more important than the emissions from bioethanol.

Flex-fuel vehicles (FFV's)

As already noted, the technological development of engines and emission control equipment for biofuels receives less attention than the conventional gasoline system. Even in Brazil, where biofuels are indispensable components to the energy matrix, flex-fuel engines capable of using bioethanol and gasoline in any blend level were launched in 2003, mainly based on gasoline engines adapted to run on bioethanol. Up to date flex-fuel engines do not fully benefit from the advantages of bioethanol compared to gasoline in the Otto cycle, such as a high octane number, high heat of vaporization, no sulfur and better defined physicochemical properties.

Table 4 shows the evolution of flex fuel technology in Brazil, indicating the progress towards the optimization of engines for bioethanol fuel used in approximately 70% of the flex fuel fleet. Flex fuel engines are being developed to achieve better performance, designed for bioethanol, and with significant advantages over gasoline engines.

Table 4 – Evolution of flex fuel technology in Brazil

Generation	Launch year	Engine compression ratio	Bioethanol effect			Use of gasoline in cold start
			Power	Torque	Consumption	
1st	2003	10,1-10,8	+ 2,1%	+ 2,1%	+ 25 a 35%	Yes
2nd	2006	10,8-13,0	+ 4,4%	+ 3,2%	+ 25 a 35%	Yes
3rd	2008	11,0-13,0	+ 5,6%	+ 9,3%	+ 25 a 30%	Yes
4th	2009	11,0-13,0	+ 5,6%	+ 9,3%	+ 25 a 30%	No

Source: Joseph Jr, H., Bioethanol Summit 2009, in Nigro, F.E.B., 2009

In Table 4, it is possible to observe the evolution of the flex-fuel engine in Brazil. From a design optimized for gasoline in a direction more suited for bioethanol, with higher compression ratios and sensitive gains in horsepower and torque. In the process, the reduction in bioethanol consumption is also noted, albeit more slowly. The improvement of cold start without the use of gasoline, an objective in the fourth generation, extends the benefits of bioethanol in flex-fuel vehicles to its most difficult operating conditions, the cold phase of its operation.

Impact of bioethanol use in light vehicles

Although bioethanol's calorific value is lower than that of gasoline, bioethanol characteristics allow greater efficiency for engines using pure bioethanol or bioethanol blends than pure gasoline engines. Figure 2 presents a diagram that estimates the amount of additional fuel required when using mixtures E5 and E10, depending on the relative efficiency of the engines using these mixtures (compared to engines using gasoline) In actual engines the comparatively low additional consumption when using bioethanol gasoline/bioethanol blends indicates that vehicles operating on these blends have greater efficiency in the use of pure gasoline. In other words, the use of bioethanol effectively increases engine efficiency.

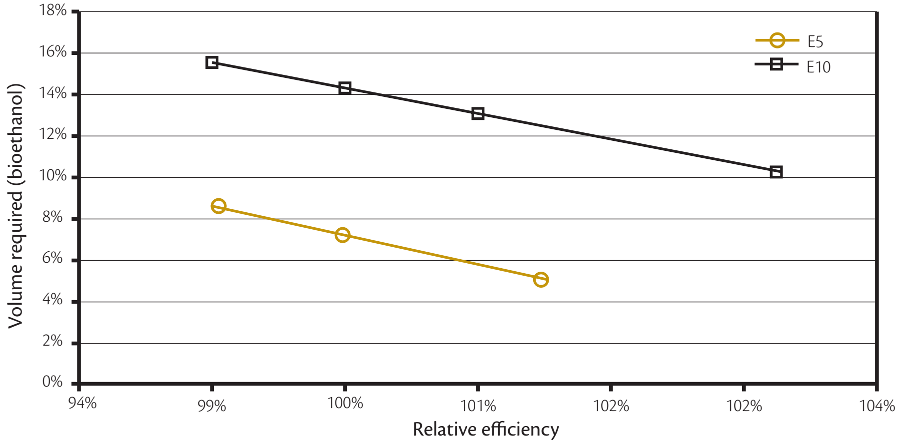


Figure 2. Increase of consumption of E5 and E10, as a function of relative efficiency of engines operation on E5 or E10 and pure gasoline (WALTER ET AL., 2008).

Until the advent of flex-fuel vehicles the specific fuel consumption (by volume) of a vehicle operating with Brazilian E22 was 5.5% higher than with pure gasoline In the case of using E100, typical consumption was 29.4% higher (JOSEPH JR., 2005). Taking into account the ratio of heat of combustion values of hydrated bioethanol and pure gasoline, these results indicate significant gains in efficiency when using bioethanol, as the increase in consumption with E100 should be 54% if there were no such gains in efficiency.

With the advent of flex-fuel vehicles and advances in electronics this situation has been significantly modified. The flex-fuel vehicles in Brazil have a higher compression ratio than older gasoline vehicles but lower than that of hydrated bioethanol vehicles. In this case, to use gasoline without knocking problems associated with the flex-fuel engines, modern combustion control techniques are applied, using knocking sensors and electronic systems made available just a few years ago. Moreover, most of flex-fuel models available in Brazil were not developed specifically for bioethanol use. .

Based on data reported by four manufacturers (Fiat, GM, Honda and VW) in 2009, 24 flex-fuel cars models were analyzed regarding kilometers traveled per liter of bioethanol (km/l), a relationship established on the basis of specific energy consumption (MJ/100 km), as shown in Figure 3, considering the use of these models with E100 (hydrated) or E25 (Brazilian gasoline) in urban traffic and roads. The average relative efficiency of vehicles in urban traffic, when using E100 (in relation to the use of E22) is 96% (i.e., 4% loss of efficiency), while in road traffic the average relative efficiency is 96.2%. There are cases where the relative efficiency in urban traffic is as low as 93.2 %, and even worse situations in road traffic, resulting in relative efficiencies as low as 91.9 %. In other words, the rapid adoption of flex-fuel technology resulted in loss of efficiency in engines, in a general evaluation.

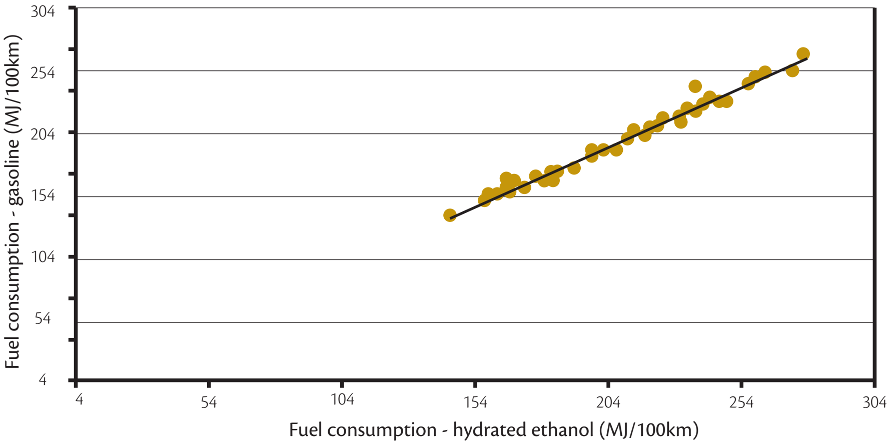


Figure 3. Relation of specific consumption, in urban and road traffic, of flex-fuel vehicles using E22 and E100,

Confirming the perceived reduction in fuel efficiency of cars with flex-fuel engines in relation to those consuming only gasoline, Figure 4 shows test results of the consumption of vehicles by means of a consumption indicator that takes into account the mass of the vehicle and engine power. For flex-fuel vehicles, the results are for operation with E22 or E100. It is evident that the advantage that the bioethanol vehicle had (in the 1970s and 1980s) has been lost over the last two decades, since the flex-fuel engines running on hydrated bioethanol have a higher energy consumption in comparison when using gasoline and bioethanol.

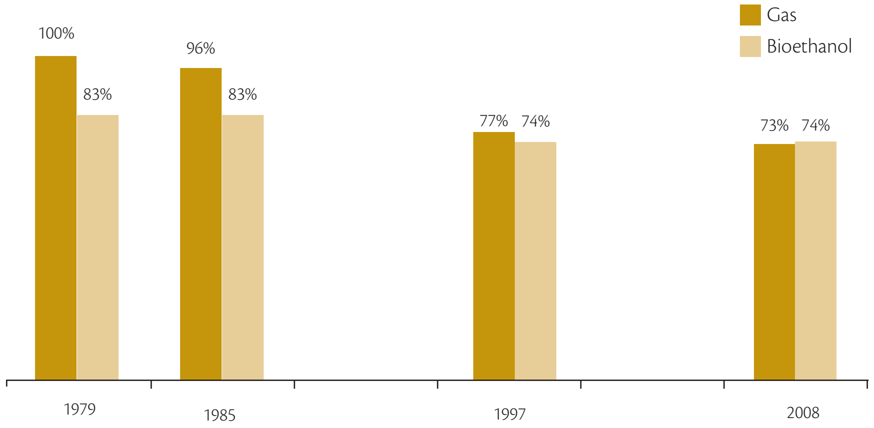


Figure 4. Evolution of the fuel consumption of light vehicles operating on gasoline and bioethanol (average results, by means of a consumption indicator which measures the mass of the vehicle and engine power) (NIGRO, 2009)

As a relevant outcome it can be stated that bioethanol has characteristics that, when compared to gasoline, improves engine efficiency. However, most of current flex-fuel engines still do not take advantage of the differential benefits of bioethanol. Thus, one challenge for the modern auto industry is to improve the flex-fuel engines to use bioethanol even more efficiently.

Evolution perspectives for light vehicles: energy issues

Observing the consumers and market demand, vehicle technology has improved significantly in recent years, mainly looking to increase performance (power, handling, acceleration, etc...), safety and comfort of vehicles. In a complementary condition and essentially determined by governments, the automobile industry, especially in developed countries, has been asked to also produce efficient and less polluting vehicles. These energy efficiency requirements are increasingly evident in Brazil, where, beyond the control program of vehicle emissions already mentioned, an increasingly large and well designed Vehicle Labeling Program is in implementation, through cooperation between Inmetro and Conpet, evaluating and presenting classes in vehicle consumption, considering urban and road use cycles.

In order to improve the energy efficiency of vehicles, there are several car engine technologies under development. Some present incremental gains and others have more radical changes. This section will only consider the technologies relevant to light vehicles, of immediate relevance to conventional bioethanol engines, although there are also some interesting perspectives that bioethanol will undergo a significant demand for heavy-duty (diesel cycle) engines. Recent advances in hydrated bioethanol engines with high compression ratios and superior performance have been achieved by Scania, this indicates new frontiers for bioethanol but they are still in the definition phase.

It is vital to recognize that there are several work fronts to reduce energy losses and increase fuel use efficiency in vehicles. This involves broad aspects such as the road network and systems management of mobility, moreover aspects directly related to vehicles such as aerodynamics of the truck, design and tire pressure and, of course, the performance of powertrain.

The EPA (2009) developed detailed studies on the introduction of numerous technologies to reduce GHG emissions and fuel consumption in various types and models of vehicles. The key technologies were subdivided into four groups: engine technologies, transmission technologies, accessories technologies and vehicle technologies, as briefly listed below:

Engine technologies

The main developments made to increase the efficiency of drive systems were:

a. Intake and exhaust valves, improvements in mechanical actuation of valves, electronic valves allowing variation in time and aperture area.
b. Friction losses in the engine, reducing friction in the engine component by decreasing the size of the engine, use of specific low friction lubricants, and cylinder deactivation at low loads.
c. New engine designs: direct injection in cylinder in gasoline engines, and Homogenous Charge Compression Ignition (HCCI) using gasoline.
d. New concepts of power systems, hybrid vehicles and electric vehicles.

Transmission technologies:

Using the hydraulic transmission with four speeds forward as reference, the options of five and six speeds forward, continuously variable transmission, optimized torque converter for low speeds and dual clutch were analyzed in comparison with the reference.

Accessories technologies

The use of 42 V electrical system, integrated starter-generator, replacement of hydraulic steering by electric power steering, electrification of accessories (pumps of water and oil, fans, high efficiency alternator) were the alternatives evaluated.

Vehicle technologies:

Two aspects were analyzed in this area; one related to improvements in vehicle aerodynamics and the reduction of friction between the ground and tires (rolling resistance).

Various combinations of alternatives were used in the final analysis with the aim of reducing fuel consumption and GHG emissions plus the investment required for each. It is essential to note that the sum of the benefits of each advanced technology adopted is not equal to the total benefit of the technological package by positive and negative impacts of technology on the others. The analysis was extremely extensive and highly detailed in the technical aspects and it may point to some important results considering only those on the Otto cycle light vehicles were grouped as low, medium and high investment.

The investment cost for some incremental improvements in the technologies has a remarkably low value (in many cases under US$ 100/unit). This is the case of more efficient transmissions, low friction tires, low aerodynamic resistance and a 42V high efficiency electrical system. Other modifications present intermediate costs (between US$ 100 and US$ 1000) such as intake and exhaust valves variable drive (time and aperture area), use of supercharging and size reduction of the engine, gasoline direct injection cylinder and homogeneous charge compression ignition (HCCI gasoline). Lastly, technologies that require a high investment (over US$ 1000) relative to what is in use today include hybrid vehicles (HEV, Hybrid Electrical Vehicle), hybrid battery charge on the network (Plug -in Hybrid Electric Vehicle, PHEV) and fully electric vehicles (Electric Vehicle, EV). An important point to note is that electric vehicles (EV) present much higher investments than the reference case (around US$ 27,000), under the current conditions and in the short term, while additional hybrids have lower values (in the range of US$ 4000 to US$ 7000), which somewhat explains the growing interest in this vehicle in recent years.

In relation to the anticipated benefits, reducing fuel consumption and GHG emissions, the results are different for the various technological alternatives. Incremental technologies such as the engine friction reduction, variable action valves, cylinder deactivation and others reduce GHG emissions by 1-5%. Meanwhile, change of concept technologies such as gasoline direct injection with lean mixture and HCCI have a potential to reduce GHG emissions by 5-15%. Hybrid cars are expected to reduce emissions by 30 to 40% while electric vehicles would reduce GHG emissions by 100%. These cases do not consider GHG emissions in the production of electricity used by vehicles (EV and PHEV) as it depends on the region where it is produced.

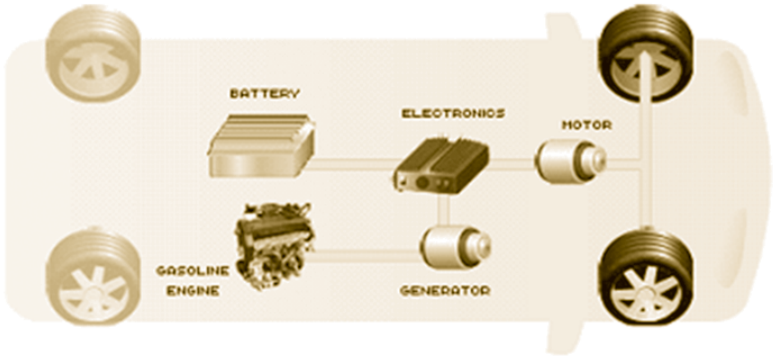
Hybrid vehicles

This technology could be considered as a gradual transition from current technology (internal combustion engines) to fully electric vehicles. However, the high cost presented by EV technology indicates room for alternative technologies for a reasonably long period. This also explains the growing interest of major auto manufacturers in hybrid vehicles.

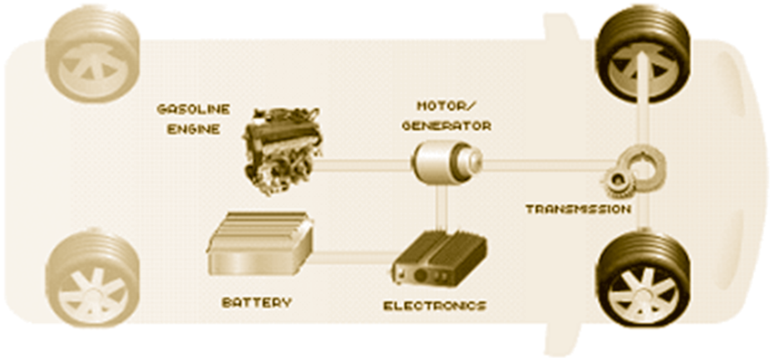
This concept is not absolutely new since Ferdinand Porsche introduced it in 1901. Nevertheless, various attempts to make it commercial failed several times throughout the twentieth century. Since the launch of the Toyota Prius in 1997 and the Honda Insight in 1999, hybrid technology has become a real option for users of motor vehicles. After a slow start the supply of hybrid models has accelerated in recent years From 2005 to the present, 24 new models were launched, many of which are SUVs (Sport Utility Vehicle) and light trucks. Japanese manufacturers dominated the early releases but nearly all major auto manufacturers now offer this technology as an option, including Mercedes and BMW. By August 2009, only Toyota had reached the mark of two million hybrid vehicles manufactured, whereas 1.43 million were from Prius.

Hybrid cars are a combination of a propulsion system with an internal combustion engine (IC) and an electric propulsion system. In a simplified form and in terms of drive wheels of the vehicle, the hybrid can be grouped into three technologies: series, parallel or series/parallel, as shown in Figure 5 (HYBRID CENTER, 2010).

(5a) Series



(5b) Parallel



(5c) Series/Parallel

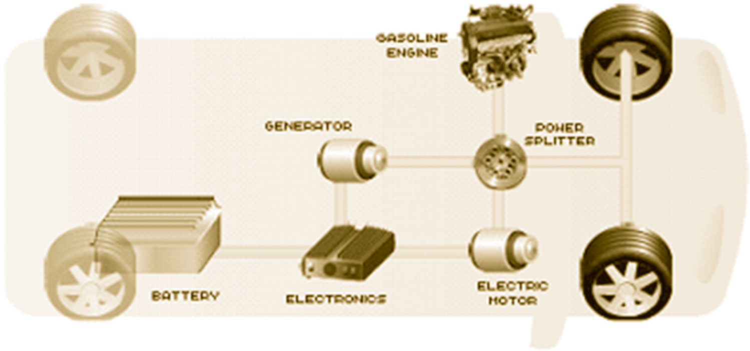


Figure 5. Types of hybrid vehicle in terms of the drive wheel (HYBRID CENTER, 2010)

In the series configuration (Figure 5a), the drive wheel is always operated by the electric(s) engine(s); the function of the internal combustion engine (IC) is to drive the electric generator that sends the energy generated to the engine or storage batteries in a process controlled by an oscillator. The IC engine is much smaller and less powerful than the conventional vehicles of the same size as it provides only the average power consumption; peak demand is provided by the battery/electric motor. This requires a larger set of batteries besides using separate engine and generator and a larger electric motor, which makes this option expensive when compared to the other two. On the other hand, the IC engine works always close to its condition of maximum efficiency and without transient, greatly reducing the fuel consumption and pollutant emissions. Typically, the regenerative braking system that uses the power absorbed in speed reduction is transformed into electrical energy that is stored in the batteries, further increasing the efficiency of the vehicle.

In the parallel hybrid version (Figure 5b), the drive wheel is made by both motors (IC and electric), with the help of the electronic module and the power transmission system (there are methods in which the motor drives a set of IC electric wheels and the other set). The battery charge, which is smaller than in the case of series hybrid, is made mainly with regenerative braking but also by the IC engine when the vehicle power demand is low. The fact that the IC engine directly drives the wheels eliminates efficiency losses in the conversion of mechanical energy into electrical and back to mechanical, which in turn helps fuel economy on the road; nevertheless, the frequent changes in demand by stops and starts in urban routes is not totally met by the electric motor, causing greater fuel consumption under these conditions. In this technology the generator and electric motor are combined into a single device.

The alternative series/parallel (Figure 5c) was designed to be a more sophisticated and complex system that takes advantage of both technologies. The IC engine can power both the wheels and the electric motor directly. In conditions of low power demand the IC engine is disconnected from the wheels and leaves the drive solely dependent on the electric motor. Hence, the system operates as a parallel at higher speeds and like a series in lower speeds, allowing the IC engine to operate more and more closely to its conditions of maximum efficiency. The need for a separated electric motor and generator, a larger IC engine and a more sophisticated control system, makes parallel hybrid a more expensive option over the other two, however, the benefits usually compensate for this additional cost.

Another type of hybrid vehicle is the plug-in hybrid electric vehicle (PHEV). This is a hybrid that can have their batteries charged from the electrical network, significantly reducing the use of the IC in a normal vehicle operation. An important parameter in these models is the all-electric range, which is the driving range of a vehicle without the need to use the IC engine. The larger the range the more expensive the vehicle (due the need for larger batteries), and the closer the vehicle is to a pure electric vehicle (EV). The first commercial model of a PHEV (BYD F3DM) was launched in late 2008 in China to be used by government and corporate fleets and it reached the general public in the first half of 2010. However, there are several models scheduled for launch in the near future by several manufacturers in several countries.

As might be expected, the potential to reduce GHG emissions through the use of PHEV, is strongly dependent on the type of route. Also, the fuel used and the emissions profile of the power generation systems in which the vehicles are connected to charge the batteries. A study considering three regions of the USA (California, New York and Illinois) – published by Argonne National Laboratory in 2009 - found a wide variation in the energy balances and GHG emissions between the different fuel production technologies and the mix of production of electrical networks. A summary of the results of this study is shown in Table 5 by comparing the energy use and GHG emissions of well to wheels of PHEV (with an all-electric range 16 to 64 km) using different fuels compared with an IC engine vehicle using pure gasoline. These simulations refer to the year 2020 with a 2015 PHEV model. As sugarcane bioethanol has recognized lower GHG emissions than those observed for corn bioethanol, it is correct to infer that the values in this table for sugarcane bioethanol should be significantly lower. It should also be noted that emissions due to LUC and ILUC were not considered.

Table 5 – Emissions performance comparison according to the fuel type

Analysis	Reformulated gasoline or low sulfur diesel	E85 from corn or switch grass (2G)	Hydrogen fuel cell
Energy use reduction	40-60%	70-90%	> 90%
GHG emissions reduction	30-60%	48-80%	10-100%

Source: Argonne National Laboratory, 2009

In the previous table, we can see that despite the wide variation in results, due to variations of electric energy sources and technologies for the PHEV fuel, reductions in energy consumption and GHG emissions by the use of PHEV are significant, even when using fossil fuel. This explains the interest from governments and auto manufacturers to develop and enhance these hybrid technologies as a way of reducing GHG and toxic pollutants emissions required by new laws, especially in the USA and Europe, as well as reducing dependence on imported oil.

In the medium term it is not possible to predict when pure electric vehicles will have a significant market share. This is due to its high cost when compared to existing alternatives. Depending on the power production profile of the country or region where it would be used, the result of using EV may be negative, i.e., they may contribute to increased overall emissions of greenhouse gases. The most critical part in the process of economic viability of EVs is the battery technology, as it represents a significant proportion of the total cost of the whole vehicle. According to the mentioned study the additional cost of a PHEV vehicle with all-electric range of 64 km, compared to the cost of an equivalent conventional vehicle would be around US$ 18,100 of which US$14,000 corresponds to the batteries.

References

ARGONNE NATIONAL LABORATORY. Well-to-wheels energy use and greenhouse gas emissions analysis of plug-in hybrid electric vehicles, by Elgowainy, A.; Burnham, A.; Wang, M.; Molburg, J.; Rousseau, A. Energy Systems Division Paper ANL/ESD/09-2, 2009

ENVIRONMENTAL PROTECTION AGENCY – EPA. Final rulemaking to establish light-duty vehicle greenhouse gas emission standards and corporate average fuel economy standards, Washington: EPA, 2010.

HYBRID CENTER. Hybrids under the hood. Available at: <http://www.hybridcenter.org/hybrid-center-how-hybrid-cars-work-under-the-hood.html>, Accessed on: Sept 2010.

JOSEPH Jr, H. Proconve: as fases passadas e futuras. In: SEMINÁRIO SOBRE EMISSÕES DE VEÍCULOS DIESEL, São Paulo, October, 2009

MONTEIRO, A.G. Estratégia de redução de emissões de poluentes no setor de transportes por meio de substituição modal na RMSP. Mestrado (Dissertação), COPPE/UFRJ, Rio de Janeiro, 1998.

NIGRO, F.E.B. Etanol como combustível veicular: perspectivas tecnológicas e propostas de políticas públicas, São Paulo, 2009.

SZWARC. A. O Impacto do uso do etanol na qualidade do ar das grandes cidades. In: CORTEZ, L.A.B. (Editor). Bioetanol de cana-de-açúcar, Ed. Blucher, São Paulo, 2010.

WALTER, A.C.S. Emissões e desempenho de motores flexíveis, documento preliminar. Campinas: Centro de Tecnologia do Bioetanol, 2010.

WALTER, A.C.S.; ROSILLO-CALLE, F.; DOLZAN, P.; PIACENTE, E.; CUNHA, K.B. Perspectives on fuel ethanol consumption and trade, Biomass and Bioenergy, v. 32, 2008.

WHITTEN, G.Z.; COHEN, J.P. Regression modeling of oxyfuel effects on ambient co concentrations. Systems Applications Report n. 96/78, 1996.

Part III

Integrated production systems and land use

Chapter 7

Sugarcane cropping and cattle husbandry integration

Miguel Taube-Netto
Luis Franco de Campos Pinto
Juan Castañeda-Ayarza
Luís Augusto B. Cortez

Introduction

Nowadays sugarcane bioethanol is well known as a more efficient conventional biofuel. In Brazil the use of bioethanol as fuel began over a hundred years. However, it was not until the creation of the National Alcohol Program, Proálcool, in 1975, that the use of bioethanol fuel became an institutional infrastructure and a progressive evolution of agroindustrial technology, transforming it into the global benchmark in sugarcane bioethanol production [1, 2].

For Brazil, bioethanol fuel plays a strategic role in the economy, which over the years has reduced gasoline imports and boosted the sugar industry. Currently, Brazil is the world's largest sugar and bioethanol producer from sugarcane (producing around 28 billion liters of bioethanol in 2010 and 40 million tons of sugar in 2010, which represents around 30% and 40% of the world market, respectively) and can significantly increase its production without any negative impacts [3, 4, 5].

Several auspicious convergent factors exist in an expansion scenario of bioethanol fuel market in the world, such as high oil prices and global warming, just to name a few. In particular, the Brazilian scenario is even more attractive, because it has vast agricultural areas available, low cost production, technological domain of the production chain, and is the best option for bioenergy production from biomass for the sugarcane feedstock [4, 6].

Concomitantly to the expansion of the bioethanol fuel market, the issue of food security brings about an important guideline which should be considered. Accordingly, the Brazilian government, specifically the Brazilian Ministry of Agriculture, Cattle and Supplies (Mapa), have developed the

Sugarcane Agroecological Zoning, aimed at giving orientation to the future of biofuels production in the country, allowing a balanced and sustainable growth of sugarcane production.

The Agroecological Zoning is a thorough study of the Brazilian regions' weather and soil that has innovated by taking into account environmental, economic and social aspects to guide the sustainable expansion of sugarcane production and investments in the sugar and bioethanol sectors [7].

To perform the mapping (Figure 1) of national territory, the following guidelines have been set: exclusion of areas with native vegetation; exclusion of areas for cultivation in the Amazon and Pantanal biomes, and in the Upper Paraguay River Basin; identification of areas with agricultural potential without need for full irrigation; identification of areas with slopes below 12%; prioritization of degraded areas or pasture[7].

Figure 1. Sugarcane Agroecological Zoning [7]

The Brazilian proposal to replace 5% of gasoline worldwide

In 2005, researchers at the Interdisciplinary Center for Energy Planning (Nipe) at (Unicamp) started a project to determine if sugarcane bioethanol could meet 5% of the projected world gasoline demand for 2025.

World motor gasoline consumption in the transport sector was estimated to be 1.2 trillion liters in 2009 [8]. Based on the Annual Energy Outlook from the EIA [9], gasoline consumption would rise by 46% by 2025, resulting in a projected gasoline use of 1.7 trillion liters. The study assumed that Brazil would provide 5% of the expected world demand. To achieve this level of production, Brazil would have to produce 102 billion liters, accounting for energy density differences and increased engine efficiencies [6].

Such was the case for the Sugarcane Agroecological Zoning. This study surveyed potential areas capable of economically producing sugarcane, eliminating all environmentally sensitive areas. Finally, all land occupied with other crops (permanent and temporary ones) such as soybean, corn, wheat, banana, cassava, etc. were not considered for sugarcane expansion. This made certain that bioethanol production did not directly compete with food production [6]. The remaining lands available (without irrigation) for possible sugarcane production are shown in Figure 2. A more complete quantitative view of potential sugarcane areas in Brazil are given in Table 1.

Table 1 – Potential areas for sugarcane in Brazil considering different productivities and two scenarios (with and without irrigation) [11]

Potential	Expected Productivity (t/ha)	Potential Area				Potential Production – 2005			
		Without Irrigation		With Irrigation		Without Irrigation		With Irrigation	
		(1,000 ha)	(%)	(1,000 ha)	(%)	(1,000 t)	(%)	(1,000 t)	(%)
High	81.4	7,897	2.2	37,920	10.5	642,494	3.4	3,085,076	14.6
Good	73.1	113,895	31.5	98,019	27.1	8,324,183	44.7	7,163,832	33.9
Average	64.8	149,217	41.3	167,645	46.4	9,671,027	51.9	10,865,412	51.5
Inadequate	n.a.	90,579	25.1	58,005	16.0	n.a.	0.0	n.a.	0.0
Total		361,588	100.0	361,588	100.0	18,637,704	100.0	21,114,319	100.0

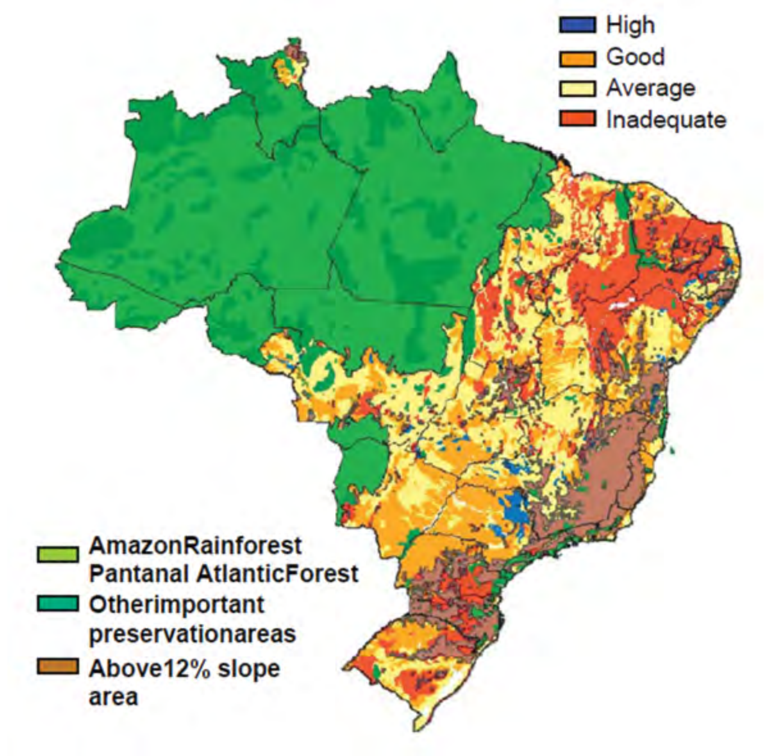


Figure 2. Potential for sugarcane production without irrigation [10]

With average yields of 71 tonne/ha of sugarcane and 85 litters of bioethanol per tonne of sugarcane, it would take 17 million hectares of sugarcane to provide enough feedstock to meet the projected demand of 102 billion liters of bioethanol. Brazilian law requires that the producer sets aside 20% of farm land for permanent environmental preservation [12]. Thus, to meet this requirement, 21 million hectares are required, where 17 million hectares are in production (80%) and 4 million hectares are in preservation (20%).

In 2010, Brazil had 196 million hectares in pasture and 68 million hectares in arable land and permanent crops. Of the cropland, 23 million hectares are used for soybean production, 13 for corn and 9 for sugarcane. The remaining 23 million hectares are used for other minor crops [3].

This rough calculation does not take into account many factors, such as land adjacency, climate and soil suitability, and, importantly, infrastructure. Based on potential productivity, location and logistics, 12 areas were selected as sites for potential expansion of fuel bioethanol production. These areas are shown in Figure 3. These areas are mostly located in the Brazilian Cerrado, found between the states of Mato Grosso do Sul (MS) and South Maranhão (MA).

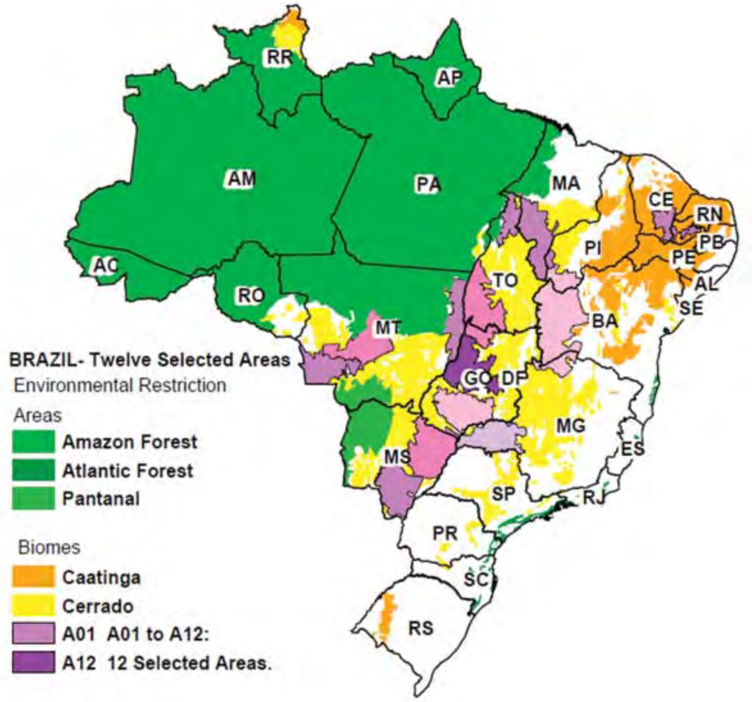


Figure 3. Twelve selected areas for bioethanol production (A = area)

Because sugarcane expansion causes the reduction of pasture lands, allowing for a slight intensification of cattle grazing [13], a case study was developed on the integration of sugarcane plants and meat production, based on mathematical programming techniques.

Mathematical programming and simulation of sugarcane-bioethanol and beef production in Brazil

Mathematical programming, simulation and, in general, operations research methodology, have been in use in Brazilian sugarcane mills for more than 30 years, in particular for sugarcane harvesting and its related logistic problems. More recently, [14] used the algebraic language GAMS (General Algebraic Modeling System) to develop an optimized planning model for sugarcane farming using linear programming. A more integrated planning system involving harvesting and production at the mill has been investigated by [15] at the University of Sao Paulo, Sao Carlos, Brazil. The authors have developed a system for integrated planning of field, industrial and commercial operations of a complex of sugarcane mills using the algebraic language AIMMS (Advanced Integrated Multidimensional Modeling Software). This initiative has been partially supported by Fapesp (Fundação de Amparo à Pesquisa do Estado de São Paulo, Brazil). This system is currently undergoing preliminary validation based on data available on a sugarcane mill complex. On the animal production side, Brazilian companies, due to their highly integrated supply chain activities involving field, plant, logistics and sales operations, have applied operation research modeling for planning and control, as reported by [16]. This application, in particular, refers to a poultry production chain for which placement and slaughtering dates of flocks are optimized, taking into consideration statistical analysis for better representation of growth, feed consumption and mortality. Each flock is individually represented, in particular, in terms of breed performance and feeding alternatives. This representation is necessary for other animal production chains, such as the one considered in this work, for which growing patterns of cattle, influenced by breed and feed regime, must be appropriately quantified, providing the necessary data for optimal integration of the ingredients obtained from the mill and from pasture. Pires [17], editor of Bovinocultura de Corte, indicates a large spectrum of technological initiatives of the beef industry in Brazil, including modeling of growth under pasture and complementary nutritional alternatives.

Mathematical modeling of crop rotation constitutes an important planning alternative for sugarcane reforms and grain production, in a planning horizon of more than 12 years, in order to capture the effects of different rotation patterns. Shorter planning horizons are considered for vegetable rotations as studied by [18] in her doctoral thesis. She takes advantage of the sparse structure of the decision-constraint matrix to develop appropriate heuristics in order to speed up optimization algorithms.

Optimal planning of complex decision chains, as shown [19], involves integrated initiatives of Decision Technology, Information Technology and Management. Agribusiness, and because of strong interdependencies of field, industry, logistics and commercial activities, has shown increasing interest in optimal modeling of its planning and control decision structure. In the context of this work, it is important to realize that decision structures are shared by different business agents (mills, farmers, beef producers etc), which require a better quantification of their interests.

Modeling scenario of sugarcane-bioethanol and beef production in Brazil

In this research, a sugarcane bioethanol distillery with a total annual milling of two million tones of sugarcane is considered as a reference. A given percentage of bagasse is used as the ingredient for cattle feeding, partly hydrolyzed using steam produced in the distillery, and partly raw. Also, soybean and corn are used as ration ingredients. These are produced in the land used for sugarcane plantations during reform periods. It is important to note that corn is not a typical choice for rotations for some sugarcane farmers, but according to [20], this is technically advantageous. The interaction between the distillery and cattle farmers is shown in Figure 4.

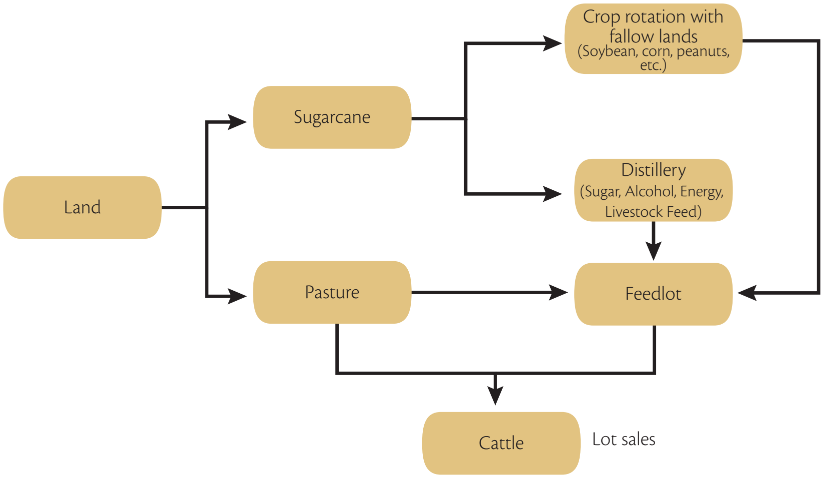


Figure 4. Interaction between distillery and cattle farmers

it is assumed that the distillery owner faces an investment horizon in confinement and pasture improvement of his sugarcane suppliers in order to optimize the dynamics of animal purchase, growth and selling, in a planning horizon of a few years. The dynamic aspect consists of the combination of decisions of purchasing and feeding cattle in pasture under extensive and/or intensive technology, with the possibility of the termination phase occurring in confined feedlots three months before selling. These decisions occur in a planning horizon of 10 years in order to capture the best way of managing the integration, starting from empty pasture, and allowing for investments payback. Forecasts of cattle purchase and sales prices, as well as other economic and performance parameters, are given for each month of the entire planning horizon. For example, for every month of the planning horizon and for each feeding option, rates of growth are predicted, which can vary annually depending on investments in technologies available to the decision maker (planner) at given prices. Feed formulations for supplementing cattle on pasture under intensive technology and for feedlots are based on ingredients available in the plant (regular and hydrolyzed bagasse, yeast and molasses) and also grain obtained from corn and soybean planted in yearly available areas resulting from sugarcane plantation reforms (about 15% of the whole plantation every year, from which 60% is assumed to be used for soybean and corn). The cost of the feed formulation takes into consideration the alternatives of selling the ingredients. Costs of supplementary ingredients are also considered.

The standard bio bioethanol plant was considered to be installed in an area of extensive pasture in the southern region of the State of Goiás, from which parameter values were taken, such as the rent price of land. The idea is to find the potential for improving meat production, considering only feed ingredients available in the plant (except micro ingredients), as illustrated in figure 5.

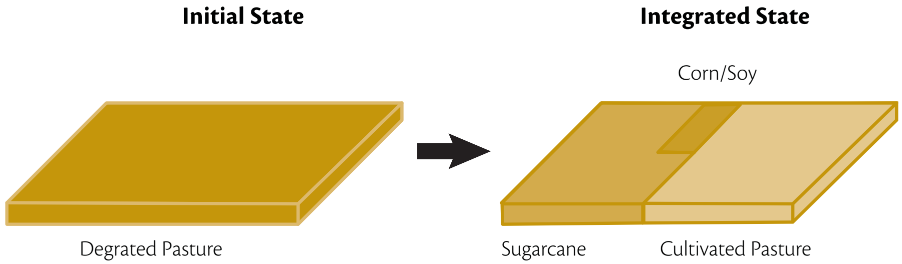


Figure 5. Before and after integration

Notice that the land required by the standard bio bioethanol plant and the resulting amount of available bagasse for selling electricity and/or for feeding can be calculated easily, taking into account the plant production capacity and the average sugarcane yield during the harvest period. Once the area required by the sugarcane plantations is obtained (28,000 ha), the amount of available bagasse that can be used for selling electricity and/or for feeding can also be calculated taking into consideration the plant parameters and the average sugarcane yield. Assuming that all corn, soybean and a given percentage of bagasse can be used for feeding, the cultivated pasture area and cattle activities can be calculated (optimized), which requires a more complex methodology.

Mathematical modeling of sugarcane-bioethanol and beef production in Brazil

For the mathematical modeling that will be applied in this case study some parameters were considered such as: basic information, decision variables, auxiliary variables, constraints and the objective function, as shown in the following sections.

Basic information

$m \in M$: Set of months.

$y \in Y$: Set of years related to the months of M.

$MoY_{m,y}$: Defined as '1' if month m belongs to year y.

$h \in H = \{'Intensive', 'Semi-intensive'\}$: Animal handling options.

$l \in L = \{'Pasture', 'Confined'\}$: Possible locations for handling animals.

$CW_{m1,m2,m,h}$: Average cattle weight (in kg) purchased on m1 and sold on m2 in month m, according to handling h.

$M_{m1,m2}$: Total mortality for cattle purchased on m1 in month m2.

$CL_{m1,m2,m,h,l}$: Defined as '1' if cattle handled by h purchased in m1 and sold in m2, will be at location l in month m.

$SMin_h$: Minimum number of months for cattle sales with handling h.

$SMax_h$: Maximum number of months for cattle sales handling h.

$WMin$: Minimum sales weight in kg.

$WMax$: Maximum sales weight in kg.

$MaxCap_{l,m}$: Minimum capacity of animals for location l in month m.

$Cost_{m,h}$: Monthly costs to maintain cattle in month m for handling h in R$/animal.

$Sale_m$: Cattle sales price in month m in R$/kg.

$Carc$: Percentage of animal carcass paid for.

Pur_m : Calf (12 month, 180kg) purchase cost in month m in R$/animal.

$i \in I = \{'Hydrolyzed\ Bagasse', 'Raw\ Bagasse', 'Yeast', 'Corn', 'Soybean'\}$: Ingredients used for feed formulation.

$g \in G = \{'Bagasse'\}$: Group of ingredients used for feed formulation.

$IG_{i,g}$: Defines which ingredient i is part of group g.

$FM_{i,h,l,m}$: Quantity (in kg) of ingredient i consumed per kg of cattle live weight in location l with handling h in month m.

IA_i : Quantity (in kg) of ingredient i available annually for feed.

IGA_g : Quantity (in kg) of ingredient group g available annually for feed.

OR_h : Occupancy rate of cattle in pasture (in kg/ha).

$ORExt$: Occupancy rate for extensive handling (in kg/ha).

BFR : Monthly revenue due to biogas and fertilizer use from confined animals (in R$/animal).

LC_y : Yearly land cost (in R$/ha).

YDR_y : Discount rate applied to each year, including perpetuity for post horizon.

Model – Decision variables

$X_{m1,m2,h} \geq 0$: Quantity of cattle purchased in month m1 and sold in month m^2, with handling h. Consistencies for indexes apply, such as, the difference between m1 and m2 must respect parameters

and $SMax_h$ and the minimum and maximum weight for sales, $WMin$ and $WMax$, respectively. This is done by applying the following conditions:

$$SMin_h \leq m2 - m1 + 1 \leq SMax_h$$

$$WMin \leq CW_{m1,m2,m2,h} \leq WMax$$

$F_{m,i} \geq 0$: Use of ingredient i for feed at month m.

$A \geq 0$: Area necessary for cattle pastures in ha.

Model – Defined auxiliary variables

1. *Monthly revenue: includes cattle sales and revenues due to use of biogas and biofertilizers. Can include additional revenue, such as corn and soybean sales, electric energy savings, etc.*

$$MonthlyRevenue_m = \sum_{\substack{m1 \leq m \\ h}} X_{m1,m,h} \times CW_{m1,m,m,h} \times (1 - M_{m1,m}) \times Sale_m \times Carc$$

$$+ \sum_{\substack{m1 \leq m \leq m2 \\ h}} X_{m1,m2,h} \times LC_{m1,m2,m,h,'Confined'} \times (1 - M_{m1,m}) \times BFR$$

2. *Monthly costs: Costs related to calf purchases and handling / feeding costs. Can include additional costs, such as corn or soybean purchase from third party, additional electric energy, etc.*

$$MonthlyCosts_m = \sum_{\substack{m \leq m1 \\ h}} X_{m,m1,h} \times Pur_m + \sum_{\substack{m1 \leq m \leq m2 \\ h}} X_{m1,m2,h} \times (1 - M_{m1,m}) \times Cost_{m,h}$$

3. *Land costs.*

$$LandCosts_y = A \times LC_y$$

4. *Initial revenue due to sales of cattle already available on field. Only valid for year '1'.*

$$InitialRevenue_{'1'} = A \times ORExt \times Carc \times Sales_{'1'}$$

5. *Yearly cash flow.*

$$CF_y = InitialRevenue_y - LandCosts_y + \sum_{m:MoY_{m,y}} (MonthlyRevenue_m - MontlyCosts_m)$$

Model – Constraints

1. *Limits the use of location l for month em according to monthly capacity.*

$$\sum_{em1 \le em \le em2} X_{em1,em2,h} \times CW_{em1,em2,em,h} \times (1 - M_{em1,em}) \times CL_{em1,em2,em,h,l} \le MaxCap_{l,em}$$

2. *Calculates how much of ingredient i is consumed in month em.*

$$F_{em,i} = \sum_{\substack{em1 \le em \le em2 \\ h \\ l}} X_{em1,em2,h} \times CW_{em1,em2,em,h} \times (1 - M_{em1,em}) \times CL_{em1,em2,em,h,l} \times FM_{i,h,l,em}$$

3. *Limits the quantity of ingredients i consumed for each year ey.*

$$\sum_{em:MoY_{em,ey}} F_{em,i} \le IA_i$$

4. *Limits the quantity of group ingredients g consumed for each year ey.*

$$\sum_{\substack{em:MoY_{em,ey} \\ i:IG_{i,g}}} F_{em,i} \le IGA_g$$

5. *Guarantee's pasture area for cattle each month em.*

$$A \geq \sum_{\substack{em1 \leq em \leq em2 \\ h}} \frac{X_{em1,em2,h} \times CW_{em1,em2,em,h} \times (1 - M_{em1,em}) \times CL_{em1,em2,em,h,'Pasture'}}{RO_h}$$

Objective function

$$\max \sum_{y} CF_y \times YDR_y$$

The objective of this mathematical model is to maximize the NPV (Net Present Value) of the cattle rearing business. To do so, all costs and revenue during the planning horizon are calculated. Also, a post horizon scenario is computed and used to project perpetuity for the business.

Optimized results of sugarcane-bioethanol and beef production in Brazil

Assuming that 10% of available bagasse is used for feeding, and limited technology for pasture intensification (1.2 animal units /ha) and other performance and economic parameters are constant throughout the planning horizon, the following results are obtained:

- Plant and sugarcane fields occupy 28.000 ha;
- Ideal intensified pasture area occupies 28.988 ha;
- For 1 ha of planted sugarcane, 1.03 ha of cattle is intensified through the use of confinements and /or supplementary feeding on pasture;
- In total, the integrated system, with 28.988 ha of pasture, produces 51.9% more meat than an extensive cattle farm of 56.988 ha (sum of areas), that is 451,6 kg of live weight/ha instead of 151,2 kg of live weight/ha;
- The profitability of meat production is also higher for the integrated scenario;
- The average number of months from purchasing to selling of cattle decreased from 23 months to 14.2 months;

During the course of the 10 year planning horizon, the system opted to form 52 cattle lots (a cattle lot is characterized by a group of bovine purchased and sold in the same months). The dynamics of purchases and sales are exemplified by Figures 6 and 7, which depict a Gantt chart with the start and end of each lot throughout the planning months, and purchase and sale volumes together with respective prices.

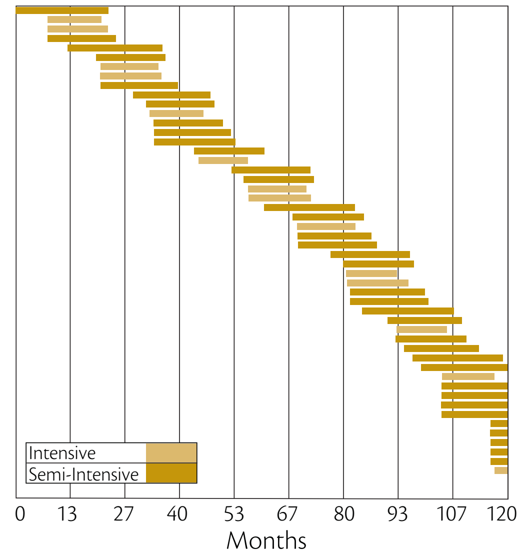


Figure 6. Gantt chart for cattle lots

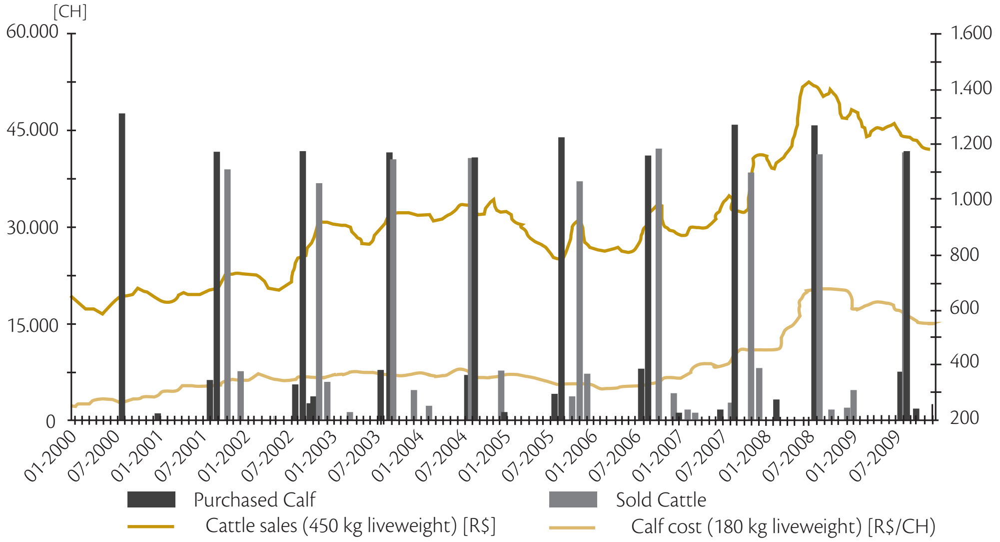


Figure 7. Volumes and prices

A sensitivity analysis, based on more complex pasture technology, with a higher animal density, showed that the corresponding intensification costs are compatible with those shown in practical situations in Brazil.

Further potential applications

Cattle supply to beef plants became a crucial problem for many Brazilian companies, some involving daily slaughters of more than 20,000 animals distributed to many plants. Traditionally, most of this supply comes from extensive pastures with low technology in terms of breed availability and nutrition. Some of the companies are now investing in infrastructure for the termination phase of the growth process in confined feedlots. Given that plants are located in many different states, the investment for the location of this infrastructure, which depends on feed supply, roads and farmers from whom to purchase animals to form the feedlots, must be carefully planned, and hopefully, optimized. Linear integer programming planning models can be developed for optimal investment analysis, as well as for optimal operation of the resulting complex of feeding facilities. This development is now possible due to improved computing power and modeling algebraic languages like AIMMS, GAMS and OPL (Optimization Programming Language, belonging to IBM's ILOG Optimization Suite). Higher levels of integration, as shown in Figure 8, due to [21], considers a potential integration of land and industrial plants.

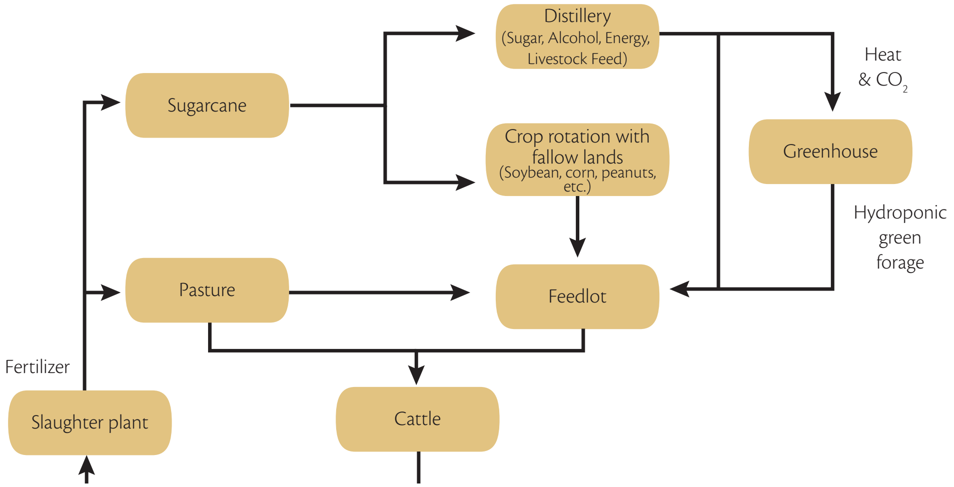


Figure 8. Potential integrations

Conclusions

Brazil is the largest beef cattle producer in the world [22], with cattle herds of more than 171.6 million in 2006, occupying an area of about 158.7 million ha [23]. Sugarcane plantations occupy an area of about 9.2 million ha, with a total annual production of 729.6 million tons in 2010 [24].

Considering the expansion of sugarcane bioethanol to displace 5% of projected gasoline use worldwide by 2025, sugarcane plantations should occupy an equivalent area of 8.7% of total pasture areas (17 million ha).

Moreover, if we assume that all new plants adopt an integrated production system, 17.59 million hectares of degraded pasture could be improved and intensified. This is based on pasture cultivation and feed formulations with soybean and corn (planted in about 60% of the annual sugarcane reform area). 10% of bagasse obtained in the refinery, and the corresponding growing activities resulted from an optimal combination of 17.59 Mha of intensified pasture and confined feedlots. Assuming that total cattle meat production in Brazil will remain the same, the integrated meat production could free up 18.23 million hectares of degraded pasture area for other agricultural activities, considering that the combined area of sugarcane plantations and cultivated pasture (34.59 Mha) produce the same amount of meat as an area of 53 Mha of degraded pasture.

Acknowledgements

The project developed by NIPE researchers was financed by the Center for Management and Strategic Studies (CGEE), and the case study on the integration of sustainable sugarcane bioethanol and beef production has been developed by CTBE (Brazilian Bioethanol Science and Technology Laboratory), a Brazilian institute for bioethanol research and development.

References

[1] WALTER A.; CORTEZ LAB. An historical overview of the Brazilian bioethanol program. Newsletter of the Energy Programme Stockholm Environment Institute v. 11, p. 2-4, 1999.

[2] COELHO, S.T.; GOLDEMBERG, J.; LUCON, O.; GUARDABASSI, P. Brazilian sugarcane ethanol: lessons learned. Energy for Sustainable Development. v.10, n. 2. June 2006.

[3] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS STATISTICS - FAOSTAT. Agriculture statistics. Available in: <www.fao.org/corp/statistics/en/>. Accessed on: Feb. 2012.

[4] CENTER FOR STRATEGIC STUDIES AND MANAGEMENT IN SCIENCE, TECHNOLOGY AND INNOVATION - CGEE. Bioetanol combustível: uma oportunidade para o Brasil. Brasilia, DF: 2009.

[5] US ENERGY INFORMATION ADMINSTRATION - EIA. International energy statistics. Available in: <www.eia.gov >. Accessed on Feb. 2012.

[6] LEITE, R.C.C.; VERDE LEAL, M.R.L.; CORTEZ L.A.B.; GRIFFIN W.M.; SCANDIFFIO, M.I.G. Can Brazil replace 5% of the 2025 gasoline world demand with ethanol? Energy v. 34, p. 655 - 661, 2009.

[7] EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA, Sugarcane Agroecological Zoning. Available in: <www.cnps.embrapa.br>, Accessed on Mar. 2012.

[8] INTERNATIONAL ENERGY AGENCY – IEA. Statistics oil in world in 2009. Available in: <www.iea.org/stats>, Accessed on Mar. 2012.

[9] ENERGY INFORMATION ADMINISTRATION. Annual energy outlook, Table A2. Energy Consumption by Sector and Source, 2003.

[10] CORTEZ, L.A.B. (coord.). Bioetanol de cana-de-açúcar: P&D para produtividade e sustentabilidade. São Paulo, Blucher, 2010. p.8.

[11] SUGARCANE TECHNOLOGY CENTER - CTC. Avaliação de áreas com potencial para produção de cana-de-açúcar no Brasil – Relatório Técnico de Transferência de Tecnologia, Revisão 1, 14p. 2005.

[12] BRAZIL. BRAZILIAN MINISTRY OF ENVIRONMENT. Federal law. n. 4.771, dated Sept. 15, 1965, Art. 16th. Available in: <http://www.lei.adv.br/4771-65.htm>.

[13] INSTITUTE FOR INTERNATIONAL TRADE NEGOTIATIONS - ICONE. Land use modeling in Brazil, Final Report, 2010.

[14] SCARPARI, M.S.; BEAUCLAIR E.G.F. Optimized agricultural planning of sugarcane using linear programming. Revista Investigación Operacional. v. 31, n. 2, p. 126-132, 2010.

[15] PAIVA, R.P.O. Modelagem do planejamento agregado da produção em usinas cooperadas do setor sucroenergético utilizando programação matemática e otimização robusta. PPG in (Ingeneering Production), UFSCar, 2009.

[16] TAUBE-NETTO, M. Integrated planning for poultry production at Sadia. Interfaces, v. 26, n. 1, p. 38-53, Jan-Feb. 1996.

[17] PIRES, V.P. (Ed). Bovinocultura de corte. Piracicaba: FEALQ-Fundação de Estudos Agrários Luiz de Queiroz, 2010. v. I e II.

[18] SANTOS L.M.R. Crop rotation scheduling – modeling and solution methodologies. Doctoral (Thesis), Mathematics and Computation Institute Science, USP, 2009.

[19] SHAPIRO, J.F. Modeling the supply chain. Duxbury Applied Series, 2007.

[20] FLORES, M.T.D. Effect of the sowing density and crop age in the productivity and bromatological composition of maize (Zea mays L.). Master (Thesis), ESALQ/USP, 2009.

[21] CORREIA, P.S. Alternativas sustentáveis para produção integrada entre o setor sucroalcooleiro e frigoríficos. ESALQ/USP, 2009.

[22] ANUALPEC, 2010. Brazilian cattle yearbook. São Paulo: FNP Consulting and Trade, 2010. p. 73.

[23] BRAZILIAN INSTITUTE OF GEOGRAPHY AND STATISTICS – IBGE. Agricultural census 2006. Available in: <http://www.sidra.ibge.gov.br/>.

[24] _____. Systematic research of agricultural production – monthly survey of forecasting and monitoring of annual crop. December 2010. Available in: http://www.ibge.gov.br/home/estatistica/indicadores/agropecuaria/lspa/lspa_201012.pdf. Accessed on Feb. 2011.

Chapter 8

Sugarcane agro-industrial facilities and greenhouses integration

Andrés da Silva[1]

Brazilian greenhouse market

Greenhouse (GH) production in Brazil represents around 20.000 ha (all models of GH, high tunnes, low tunnes) and it is divided into 3 main sectors supplying a mostly internal market. The most important sector is ornamentals with potted and cut flowers concentrated in Holambra (São Paulo State). Holambra Weiling Market is responsible for 30% of BRL $1.3 billon (2009) total sales of this sector. Even if this industry is driven by traditional Dutch people, this sector is still lacking in the use of GH modern technologies.

The second most important sector is FLV (fruits & vegetables) production, of which São Paulo State alone produces 34% of the national product (BRL $9.7 billons). FLV production trade is done by traditional "Ceasa" grower markets. Tomato production corresponds to 23% of FLV production. Only in São Paulo city is this market (Ceagesp) responsible for 25% of the national product in Brazil. Nevertheless, Ceasas is responsible for high losses, poor quality of goods and raised prices manipulated by brokers and dealers that do not add any value to products. For example, a third part of all tomatoes from open field that comes to Ceagesp goes to landfill. Supermarkets and hypermarkets are getting more sales participation in high quality and added value FLV crops and buying directly from growers and farms. This is an opportunity for growers to eliminate intermediate brokers, reduce losses and increase profit margins. These two sectors are supplied by small farms (the majority being less than 1 ha) with low capacities to invest in technology.

---

[1] Estufas Agrícolas Comércio e Assessoria (EACEA) LTDA. EACEA was founded in Brazil in 2010 with more than 15 years accumulated experience from professional activities in greenhouse projects and related commercial business in North America. EACEA promotes and develops greenhouse projects using modern structures with high technology equipments and incorporating the in natura and transformed product trade. Phone: 055 (012) 9613-2171. Email: andresdasilva@live.ca.

The third most important sector is represented by the reproduction of seedling of trees wherein forestry industry has main position. Forestry planted areas (for paper and energy industries) have increased by an average of 4.9% per year between 2004 and 2009, with more than 6 million ha of forestry area (eucalyptus and pinus). For each 10,000 ha of planted forestry we need 1 ha of GH, which shows a huge potential for GH area and technology improvement.

Greenhouse technology

Current Brazilian GH production is still "low tech", offering poor quality and yields for all sectors. Brazilian GH technology is frequently limited to the use of a plastic cover for an "umbrella effect". Most of the GH area is still built with wooden posts and steel wire offering no climate control. Insect barriers are unusual and the use of fertirrigation and technical substrates is very simple. Grower knowledge about hydroponics is still in its beginnings. In addition, these practices stimulate the use of large amounts of pesticides, nutrient losses and finally a high production cost. Modern GH uses more technology and is expensive for the majority of growers.

In this study we visualized that a modern GH is an option to improve quality and yields of this industry. A modern GH is a high steel structure covering wild areas of up to 5 ha. These structures use technical plastic films to improve light quality and to reduce indoor temperatures. Usually, a computerized system controls ventilation windows on the top and the walls, the curtains, air heating/cooling equipments, air circulators, fog, irrigation, and CO_2 enrichment systems, to create an optimal climate for plants. In fact, the use of modern GH with energy and CO_2 input can improve yields up to 10 times more than normal productivity in open field production. In terms of beef tomato production in Brazil, it is possible to achieve an open field average of 600 ton per ha compared to 60 ton per ha (Figure 1). Final price paid to growers can easily be doubled compared to conventional open field production, in accordance with quality improvement, and availability of products all throughout the year. Sales are made directly with the supermarkets.

Advantages using CO_2 & Energy

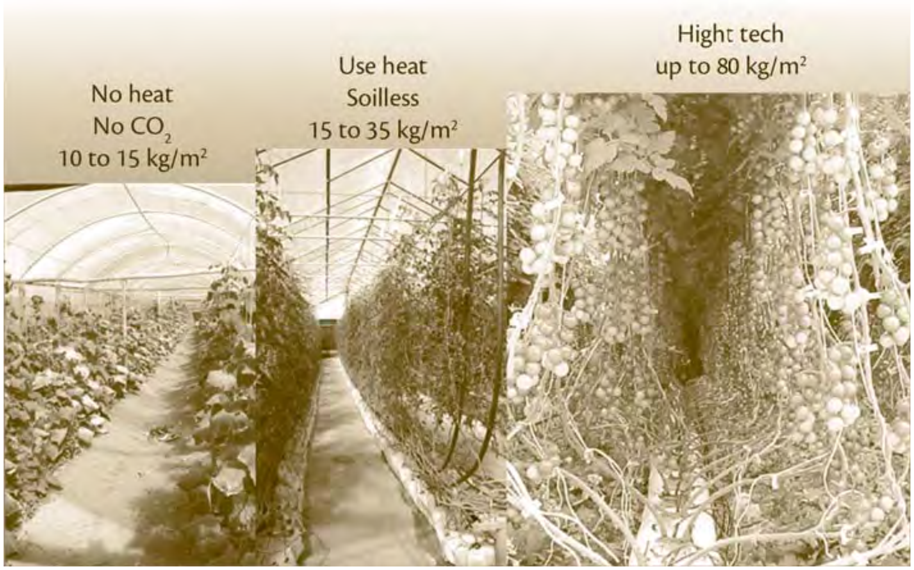


Figure 1. Yield comparison of three different levels of GH technology.

Nevertheless, the use of this technology presents a high initial investment for the majority of growers. Investments, in Brazil, are around BRL $250.00 per s.m.

Although South America has an important population, it is the region with the smallest modern GH area in the world. This means that there are opportunities for growers and enterprises to invest in this sector. The main strengths and concerns about GH production are presented in Table 1

Table 1 – Analysis of strengths and weaknesses of GH production

Strengths	Weaknesses	Comments
Production all throughout the year	High investment	Use of high technology increases initial investment but not always ROI
Opportunity for varieties developed only for GH production	Need of knowledge and specialized labor	Climate control and knowledge on GH production techniques are obligatory. Therefore specialized labor represents less than 3% of total labor.
Increase of yield and quality of crops	Competition with open field products	To avoid competition it is important to add value to products such as packaging, traceability, certifications and offering top quality.
Better control of insects and diseases	Obligation to have a climate control and monitoring program	Use of biological control allows production with no pesticides.
Protection against rain, snow, wind, storms, freezing etc.	GH must be built following standards to resist all conditions.	GH allows keeping productivity and quality all year round independent of outside conditions.
Fixed labor in rural areas.	Intensive labor use (7 days a week).	GH is labor intensive, needing up to 15 people per ha. Labor is not specialized and female labor is welcome.
Specialized products for niche markets	FLV market in Brazil is still developing	The improved economic situation in Brazil creates opportunities for new products with better quality and higher prices.

Source: adapted from SANTOS (2009) e DA SILVA (2010)

Food market trends

The use of GH, especially in FLV production, opens doors for added value products that are in accord with most important food market trends. An increase in urban population and revenues, food service growth, women working, education and globalization of lifestyles worldwide definitely influence FLV consumption. The potential of this market can only be measured by the consumption of vegetables in Brazil. Brazilians consume only 40 kg per capita of vegetables compared to 101 kg for North Americans, 114 kg for Europeans and 125 kg for Asians.

Also, FLV market trends in Brazil are following the same evolution that occurred in Europe or in North America. Customers want goods with attractive presentation and packaging, offering a feeling of security (tracking and certification programs) and pleasure. Food must be tasty, and easy and fun to prepare and consume. Convenience food such as mini tomatoes is a revolution in the snack market all over the world. Beyond just feeling secure against pesticide residues and biological diseases, consumers are looking for comfort food as they ask for "food miles", "carbon footprint" and "fair trade" appellations.

Greenhouses offer high quality and value added products all throughout the year. Organic production, traceability systems and food security policies can be easily integrated in the process. Commercialization is usually done directly to retail chains and supermarkets, reducing losses, maintaining the cold chain and increasing crop shelf life. Therefore a modern GH procures one of the best examples in sustainable development production as it optimizes yields and quality, can eliminate agrochemicals and residues and offers a nice environment for employees. In fact, nowadays it is already possible to have an organic production with the same yields as a conventional hydroponics production.

Integration of bioethanol distilleries with GH production

Brazil´s sugar and bioethanol-processing industry has expanded in the last 10 years, going from 11.5 to 27.5 billon liters of bioethanol between 2001 and 2009. Brazil´s national market growth, in addition to an increased demand worldwide for bioethanol, constrains this sector to offer solutions to land use and sustainability issues to be able to maintain investments and its leadership.

This is an opportunity for investors interested in enterprises to connect with this agro industry where greenhouse and/or aquaculture operations can be paired with power plants to take advantage of inexpensive nutrients, energy and CO_2. As the fuel bioethanol industry matures, operators of individual plants are looking to supply enhancement opportunities.

One option is to co-locate new production facilities for fish, fruits, herbs, vegetables, ornamental plants and even algae production alongside the sugar-bioethanol processing plants. The waste streams from the distillery could potentially supply water, nutrients and energy to both greenhouse and aquaculture operations, and carbon dioxide from distillery process could be captured for the benefit of greenhouse plants, increasing productivity and quality.

Recovering CO_2 from fermentation process

In a modern GH, increasing air concentration of CO_2 from 350 ppm normal atmospheric level up to 2,000 ppm can increase the photosynthetic yield from the majority of FLV and many other plants by about 30%. Jointly taking care of other growing parameters such as nutrient feeding, temperature and humidity, it is possible to enhance yield and crop quality. Wherever CO_2 source is not available, a modern GH must buy liquid CO_2 or burn clean fuel as natural gas (or bioethanol in Brazil´s case) to have this precious gaseous fertilizer that represents an extra cost to operation. A GH integrated with an bioethanol distillery can use CO_2 recovered directly from the fermentation process. Usually, in an bioethanol plant, gases from fermentation tanks pass through a final washer tower to recover traces from bioethanol. Pure CO_2 and water vapor are discharged directly to the environment. Having a GH near to the bioethanol plant allows recovery of this CO_2 without condensing or purifying it.

In Brazilian bioethanol distilleries, around 0.76 kg of CO_2 is released per liter of anidrous bioethanol produced. Nowadays, in Brazil, only two bioethanol plants are recovering, purifying and condensing CO_2 from the fermentation process for commercial and industrial applications. This solution represents investments of around BRL $10 million for a 2 ton/h capacity plant. Integration of a GH with an bioethanol plant offers a better and more cost effective solution for CO_2 recovery from the fermentation process.

Recovering low temperature energy

Using energy at low temperatures (between 35 and 65oC) in GH crop managing allows yield increases of up to 30%. This energy is used for different applications. Firstly, it is used to heat and maintain air temperature at optimum values for plants. This application is not only important in northern countries with freezing temperatures, but is also useful in tropical countries as we need to keep GH air during the night and on cold days at an optimum temperature. Secondly, energy is used to create a slow air movement inside a GH via a convection process. This action provides uniformity of temperature and humidity inside a GH and improves air exchange with the outside for dehumidification of the air inside a GH. Lastly, low temperature energy can be used to activate the foliage transpiration and photosynthesis process. Energy is transferred to a GH, directly heating the air (conventional air heaters) or heating plants directly by radiation (radiating pipes throughout).

In a sugar-cane bioethanol plant, large amounts of low temperature energy are discharged to the environment, creating opportunities to recover this energy in processes that could use it directly.

Thermal energy in vinasse, produced during the fermentation process, represents a huge amount of low temperature energy available. For a typical Brazilian sugarcane bioethanol vinasse, that flows from distillation column at around 110ºC, it needs to be cooled down to 40oC before being discharged to the environment. Instead of using traditional cooling towers to reduce the vinasse temperature, it is possible to use a GH as a "radiator", recovering this energy for useful processes and saving energy operation from cooling towers.

Using vinasse and bagase in GH processes

We can use vinasse to contribute to a hydroponics nutrient solution and bagasse as part of a substrate or as organic material incorporated in the soil. Vinasse is rich in in nutrients and as a pasteurized solution presents no risk for any organic contamination. Studies using vinasse diluted by a ratio of 1:10 as a nutrient solution demonstrate a potential to save up to 30% of total nutrients in a hydroponic solution for tomato production. Vinasse is a good option for some hydroponic applications such as raft-floating and hydroponic green forage. Also, biogas produced from anaerobic biodigestion out of the havest season can supply all the energy and CO_2 for a GH when the bioethanol plants are shut down, as was the case during the summer seasons in operations in southern Brazil.

In the same way, bagasse from processed sugarcane could be incorporated in soil or technical substrates. Some studies and operations in Brazil indicate that a mixture of bagasse and sand and/or other materials gives a substrate with an acceptable water retention capacity for hidroponicapplications. Bagasse as a sterilized material is appropriate for direct use in hydroponic substrate formulas.

Exemples of integrated GH in the world

Although greenhouse vegetable production technology is well developed and applied worldwide, including developing countries, Brazil is still in its beginnings.

The opportunity to reduce operation costs of high technological greenhouses is a way to increase profit margins and support investments in this sector.

Although there are examples, mostly in North America and Europe, of integrating greenhouses with nuclear, natural gas, biogas or biomass driven power plants, little public information exists about the economics and likely problems of this business arrangement. Table 2 presents some examples of integrated facilities in North America and Europe

Table 2 – Examples of GHs integrated with different industries in North America and Europe

Project name	Region	Description
Grand Rapids Greenhouse Complexe	Grand Rapids, Minnesota	5.7 ha for pinus propagation using waste energy from power plant.
Beckers Greenhouse Complexe	Becker, Minnesota	Flower production heated by waste energy from a power plant.
Bryfogle's	Pennsylvania	Lettuce (0.4 ha), tomato (2 ha) and ornamental plants (2 ha) using waste energy from Pennsylvania Power and Light Plant.
Hydrofarm	Decatur, Illinois	4 ha of lettuce production recovering waste thermal energy and CO_2 from ADM (Archer-Daniels-Midland) Distillery. Production of 30,000 heads per day.
N/D	Rifle, Colorado	Recovery of thermal energy from a Power Plant. No more in operation.
N/D	Brush, Colorado	15.8 ha tomatoes recovering energy from a Power Plant.
Mr. Aarie van Wingerden	Fort Lupton, Colorado	15.8 ha tomatoes recovering energy from a Power Plant.
Rutgers Eco-Complex	Bordentown, New Jersey	16.2 ha of GH using electricity and recovering thermal energy from a landfill biogas Power Plant (7MW).
Jardins Nature	New Richmond, QC, Canada	2 ha of tomatoes bio. Project started recovering thermal energy from a paper industry (Smurff-Stone). Today the paper industry is closed and the GH are operating with forestry biomass as fuel.
Savoura	Saint Étiene, QC, Canada	5 ha of GH for tomatoes using landfill biogas.
Les serres Sagami	Rimouski, QC, Canada	3 ha of tomato GH recovering energy through heat pumps from aluminium industry (Elkem Métal Canada Inc.).
Les Jardins de Rabelais	Chinon, França	10 ha tomato GH recovering waste thermal energy from nuclear power plant (Avoine).
British Sugar Destillery	England	3 ha of tomato GH recovering waste energy and CO_2 from the integrated power plant of distillery (Picture 2).
Nitratos Terra Nitrogen	Billinghan, England	38 acres of glass GH recovering waste energy and CO_2 from the integrated power plant of fertilizer industry

Source: adapted from Gladon (2008) e da Silva (2010)

British sugar distillery integrated with a tomatoes greenhouse facility (England)

Figure 2. Photo of a GH project integrated with british sugar distillery in England.

A tomato integrated GH study case

Table 3 presents a detailed evaluation of technical, commercial, social and environmental aspects of the integration between a hypothetical table tomato greenhouse facility and an bioethanol distillery and identifies research opportunities to be pursued in the future.

Table 3 – Impacts for integration of a GH to an bioethanol distillery

Aspects	Impacts
Technical	• Better use of distilleries mass and energy flows. • Creation or integration of local available labor. • GH FLV production liberates open field areas (usually located near cities) to use for other cultures. • Increase of agronomic yield.
Economic	• Better remuneration per kilo of product for growers. • GH and Bioethanol Plant integration costs are small compared to the total cost of a GH and Bioethanol projects. • Integrated GH replace or reduce vinasse cooling towers operation cost.
Comercial	• GH sales up to BRL $1M per ha per year. • Crops are of better quality and could be pesticide free. • Option to apply for carbon credits. • Bioethanol plant has a compensation for recovering by-products.
Social	• Creation of 10 to 15 new direct and permanent rural jobs per ha as a solution for sugarcane harvest mechanization policy. • Use of female labor and people having certain handicaps.
Environmental	• Reduced use of fertilizer and agrochemical. • Recovering CO_2 and avoiding use of other petroleum fuels. • Better use for vinasse.
Corporative	• Upgrade corporative image from sugarcane bioethanol industry to a producer of fuel AND food!

A standard distillery with a capacity of 2 million tons of sugar-cane producing 40 liters of bioethanol per ton of sugar-cane produces 15,200 tons of CO_2 per day and 886.6 GJ of low temperature thermal energy (just from vinasse cooling alone). Economic analysis of a tomato greenhouse facility using the above by-products shows that agronomic yields grow up to 65 kg/m^2 (Brazil´s national average is 6 kg/m^2, including industrial tomatoes) and production costs are 24% lower than in a conventional greenhouse. Production is possible without any pesticide and 50% less water and fertilizer use. Project profits increase by 58% to R$ 1.2 million/ha and ROI is lower than 1 year. Results are presented in Table 4. In this study, the bioethanol distillery was remunerated by BRL $45,000 per ha per year for supplying land, CO_2 and energy.

One hectare of greenhouse creates around 15 direct and permanent jobs that could be a solution to the labor available from sugar-cane harvest mechanization policy. In São Paulo State alone, it is expected that 150,000 people working in the sugarcane harvest will lose their jobs by 2014.

Emissions of 912 tons of CO$_2$/ha per year are avoided. Moreover, the energy available is enough to integrate around 60 ha of greenhouses that can represent up to R$ 2.7 million in extra revenues for the sugarcane facility.

Table 4 – Economic comparison analysis of a NON-integrated GH and a GH integrated with an bioethanol distillery in BraziL.

Description	HG (not integrated)	GH (Integrated)	Units
Area	10.000	10.000	m^2
Yield	50	65	kg/m2
CO$_2$ Demand	134	672	ton CO$_2$/yr/ha
Low temperature energy demand	14.307	14.307	GJ/day/ha
Prevented CO$_2$ (CO$_2$+energy)	0	912	ton CO$_2$/ha.yr
Average tomatoes price	4,00$	4,00$	R$/kg
Investiment			
Total invetiment	850.000 $	1.000.000 $	R$/ha
Annual Operation cost			
Total operation cost	1.408.115 $	1.415.882 $	R$/ha
Total operation cost per kilo	2,85 $	1,18 $	R$/kg
Income			
Total annual sales	2.000.000 $	2.600.000 $	R$/ha
Profitability			
Gross margin	591.885	1.184.118	R$/ha
Gross margin per kilo	1,18 $	1,82 $	R$/kg
Gross margin/sales	30%	46%	R$/kg
ROI	1,4	0, 8	years

Business model and conclusions

EACEA LTDA has been working in Brazil to develop a business model and to implement projects that will integrate GH and sugarcane bioethanol distilleries. In this model (Figure 3) the bioethanol distillery acts as the landlord and supplier of energy, CO_2 and vinasse to an "operator" company that is responsible for GH business. It is important to keep separate the agriculture and industry sugarcane operations from GH operation. Anywhere in the world where the energy and CO_2 supplier industry tried to operate directly, the integrated GH operation failed. Nevertheless, the sugarcane distillery can be a partner or an investor in GH business, creating a highly profitable and sustainable venture.

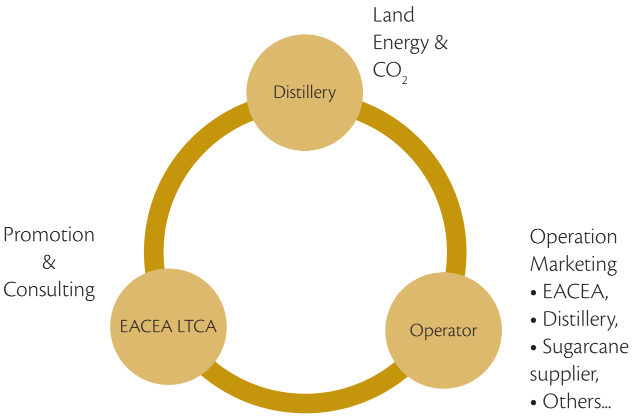


Figure 3. Business model proposed by EACEA LTDA for the integration of GH and sugarcane distilleries in Brazil.

A typical medium sized project of 10 ha of integrated GH can generate about half BRL $0.5 million per year as extra revenue for an bioethanol distillery, representing a much greater profit/ha than a distillery usually receives from bioethanol operation. Brazil, with around 400 sugarcane operating distilleries, has a singular opportunity to develop the largest food and vegetable sustainable program in the world.

More knowledge is needed to help innovators estimate energy availability, requirements, integration interfaces, and to point out other helpful research possibilities and educational policies. Bioethanol industry needs to establish a commercial relationship with greenhouse facilities indicating social and economical local repercussions in terms of sustainable food production.

References

ASSOCIAÇÃO BRASILEIRA DO COMÉRCIO DE SEMENTES E MUDAS – ABCSEM. Pesquisa de mercado de sementes de hortaliças. 2007.

ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FLORESTAS PLANTADAS – ABRAF. Anuário estatístico da ABRAF 2010 - Ano Base 2009. Disponível em: <http://www.abraflor.org.br/estatisticas.asp>, 2010.

AGÊNCIA NACIONAL DE ÁGUAS – ANA. Manual de conservação e reúso de água na agroindústria sucroenergética. Brasília, DF: Ministério do Meio Ambiente, 286 p., 2009.

ANTUNES, L.E.C.; TREVISAN, R.; GONÇALVES, E.D.; FRANZON, R.C. Produção extemporânea de amora-preta. Rev. Bras. Frutic. Jaboticabal. v.28, n.3, Dec. 2006.

ARAUJO, V.S.; COELHO, F.C.; CUNHA, R.C.V.; LOMBARDI, C.T. Forragem hidropônica de milho cultivado em bagaço de cana e vinhoto. Revista Brasileira de Milho e Sorgo, v.7, n.3, p. 251-264, 2008.

BARBOSA, L.; MADI, L.; TOLEDO, M.A. As tendências da alimentação. In: BRAZIL FOOT TRENDS 2020, FIESP/ITAL, São Paulo, S.P., Anais… São Paulo: 174p. 2010.

BIAIS, L.A.; BIBLIA, D.A.C.; SÃO JOSÉ, A.R.; FORNASIERI, J.L., MINAMI, K. Efeito de misturas de turfa e bagaço de cana sobre a produção de mudas de maracujá e tomate. Sci. Agric., Piracicaba, v. 52, n. 2, p.239-243, mai/ago, 1995.

BANCO NACIONAL DE DESENVOLVIMENTO ECONÔMICO E SOCIAL/CENTRO DE GESTÃO E ESTUDOS ESTRATÉGICOS – BNDES/CGEE. Bioetanol de cana-de-açúcar: energia para o desenvolvimento sustentável. Rio de Janeiro: BNDES, 2008, v.1. 316p.

COORDENADORIA DE ASSISTÊNCIA TÉCNICA INTEGRAL – CATI. Distribuição espacial das benfeitorias 2007/2008. São Paulo, SP: CIAGRO, 2008.

COSTA, A.C.P.B.; MACEDO, F.S.; HONCZAN, G. Fatores que influenciam o consumo de alimentos. In: BRAZIL FOOT TRENDS 2020, São Paulo, S.P., FIESP/ITAL, Anais… São Paulo: 174p. 2010.

DA SILVA, A. Comunicação pessoal. Cunha, SP: 2010.

DELCO, J.P.B.; TRUPEL, R. Tomate - gestão sustentável - avaliação do risco da tomaticultura e custo de produção do tomate em Mogi-Guaçu. Rev. Hortifruti Brasil. v. 9, n. 91, p. 5-21, Junho, 2010.

ENSINAS, A.V. Integração térmica e otimização termoeconômica aplicadas ao processo industrial de produção de açúcar e etanol a partir da cana-de-açúcar. Tese (Doutorado), Universidade de Campinas, 2008.

ORGANIZACIÓN DE LAS NACIONES UNIDAS PARA LA AGRICULTURA Y LA ALIMENTACION – FAO. Consomation de fruits e legumes. Citado em: http://www.museum.agropolis.fr/pages/expos/aliments/fruits_legumes/prodconso.htm, 2000.

____. Manual técnico forraje verde hidropónico. Santiago, Chile, v.1, 73 p., 2001.

FEDERAÇÃO DAS INDÚSTRIAS DO ESTADO DE SÃO PAULO – FIESP. Agronegócio Brasileiro. Brasília: MAPA, 119p. 2008.

GALLEGOS, H.M.L. Manual para cultivo de tomate en invernadero. México: 263p., 2006.

GALLEGOS, H.M.L.; ANCHONDO, C.O. Growing hydroponic greenhouse tomatoes in Nuevo Casa Grande – a challenge in Chihuahua´s desert. In: GREENSYS 2009, Québec, QC, Canada. 14 à 19 Junho de 2009, Proceedings… Québec, QC, Canada: 2009.

GIACOMELLI, G.; CASTILLA; N.; VAN HENTEN , E. Innovation in greenhouse engineering. In : GREENSYS 2007, Proceedings…Ed.S. De Pascale et al., Acta Hort. v. 801, ISHS, 2008.

GLADON, R.J. Waste products from ethanol plants as assets for greenhouses. In: Potential to operate greenhouses and aquaculture in conjunction with Iowa's ethanol plants report. Publicado por Leopoldo Center, Iowa State University, 37 p., 2008.

GRASSI F.H.; SANTOS, C.H. Importância da relação entre os fatores hídricos e fisiológicos no desenvolvimento de plantas cultivadas em substratos. In: NUTRIÇÃO e adubação de plantas cultivadas em substrato. Viçosa: UFV, p.78-91, 2004.

HENRIQUES, E.R. Manual de produção-forragem hidropônica de milho. Uberaba: FAZU, 15p , 2000.

HEUVELINK, E. Tomatoes – crop production science in horticulture – 13. CAB Publishing, 339p., 2005.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA – IBGE. Censo agropecuário 2006. Rio de Janeiro, RJ: 2009.

JUNQUEIRA, A.H.; PEETZ, M.S. Mercado interno para os produtos da floricultura brasileira: características, tendências e importância socioeconômica recente. Revista Brasileira de Horticultura Ornamental, v. 14, n.1, p. 37-52, 2008.

KÄMPF, A. Evolução e perspectivas do crescimento do uso de substratos no Brasil. In: NUTRIÇÃO e adubação de plantas cultivadas em substrato. Viçosa: UFV, p.03-10, 2004.

KLAPWIJK, P. Potential of closed greenhouse in North America. In: GREENSYS 2009, Québec, QC, Canada. 14 à 19 Junho de 2009, Proceedings… Québec, QC, Canada: 2009.

LANGHANS, R.W. A manual of greenhouse rose production. Ithaca, N.Y.: Cornell University, 371p., 1987.

MADAIL, J.C.M.; REICHERT, L.J.; MIGLIORINI, L.C. Sistema de Produção de Morango. Sistemas de Produção, 5. Brasília: Embrapa, versão eletrônica, nov., 2005.

MARTINEZ, H.E.P. Manual prático de hidroponia. Viçosa, MG: Ed. Aprenda Fácil, 271p., 2005.

MATHIAS, M.C. Budding Ceará region is craving for cardo space. In: FLOWER TECH. Publicado por Reed Business Information bv., International Agri-& Horticulture. v. 9, n. 3, p. 28-30, 2006.

MORGADO, I.F.; CARNEIRO, J.G.A.; LELES, P.S.S.; BARROSO, D.G. Resíduos agroindustriais prensados como substrato para a produção de mudas de cana-de-açúcar. Rev. Agric., Piracicaba, v. 57, n. 4, Oct./Dec., 2000.

NEDERHOFF, E. Calculating the value of CO2 enrichement. In: FLOWER TECH. Publicado por Reed Business Information bv., International Agri-& Horticulture. v. 3, n. 7, p. 22-25, 2000.

PINTO, C.P.; CORTEZ, L.A.B. Tecnologia da digestão anaeróbia da vinhaça e desenvolvimento sustentável. Dissertação (Mestrado) apresentada à comissão de Pós Graduação da Faculdade de Engenharia Mecânica, como requisito para obtenção do título de Mestre em Planejamento de Sistemas Energéticos. Campinas, S.P., 1999.

PORTALDOMUNDODASFLORES. Informações do mercado ornamental. Disponível em: <http://www.portalmundodasflores.com.br>, Acesso em: 2010.

SANDIA NACIONAL LABORATORIOS PARA NEW MÉXICO Y EL CARIBE - SANDIA. Producción de forraje verde hidropónico. Disponível em: <http://www.sandia.gov/water/USMBpress/gallegosagricultura.pdf>, Acesso em: 2003.

SANTOS, O.S. Produção de forragem hidropônica de cevada e milho e seu uso na alimentação de cordeiros.Santa Maria: UFSM/CCR, 8p. (Informe Técnico 04), 2004.

SCHIAVO, J.A.; MARTINS, M.A. Produção de mudas de goiabeira (Psidium guajava L.) inoculadas com o fungo micorrízico arbuscular Glomus clarum em substrato agro-industrial. Revista Brasileira de Fruticultura, Jaboticabal, v.24, n.2, p.519-523, 2002.

SERRANO, L.A.L.; SILVA, C.M.M.; OGLIARI, J.; CARVALHO, A.J.C.; DETMANN, C.S.M.E. Utilização de substrato composto por resíduos da agroindústria canavieira para producção de mudas de maracujeiro amarelo. Revista Brasileira de Fruticultura, v. 28, n. 03, 2004.

SILVA, D.S.; SPIER, M.; SCHAFER, G.;SOUZA, P.V.D. Caracterização física de bagaço de cana-de-açúucar com diferentes tamanhos de partículas e períodos de compostagem. In: ENCONTRO NACIONAL SOBRE SUBSTRATOS PARA PLANTAS MATERIAIS REGIONAIS COMO SUBSTRATO, 6., 9 a 12 de setembro de 2008, Fortaleza – CE. Trabalho apresentado... Fortaleza: 2008.

SILVA, P.R. Mercado e comercialização de amora, mirtilo e framboesa. TodaFruta para publicação em 21/07/08, 2008.

VILELA, N.J.; HENZ, G.P. Situação atual da participação das hortaliças no agronegócio brasileiro e perspectivas futuras. Cadernos de Ciência & Tecnologia, Brasília, v.17, n.1, p.71-89, jan./abr, 2000.

Chapter 9

Direct and indirect land use change assessment

Marcelo Moreira
André Nassar
Laura Antoniazzi
Luciane C. Bachion
Leila Harfuch

Since the studies carried out by Fargione et al. (2008) and Searchinger et al. (2008), the need for assessing greenhouse gases (GHG) emissions due to changes in land use caused by agricultural-based biofuels has been part of the agenda of stimulus programs for biofuels. The same policy makers who saw in biofuels an alternative to ensuring energy-reducing emissions soon recognized that the indirect effects of Land Use Changes (ILUC) associated with biofuel production might undermine the benefits of biofuel's reduced emissions.

This finding threatened the potential climate benefits of biofuels and diverted topics such as energy security to a secondary priority. Thus, the requirement for measuring ILUC-associated emissions was incorporated in federal legislation in the United States (Renewable Fuel Standard/RFS), in California (Low Carbon Fuel Standard/LCFS), and in the European Union (Renewable Energy Directive/RED), among other locations.

Brazil is currently the greatest exporter of sugarcane bioethanol, with the potential to increase exports even further; its annual growth in sugarcane area and annual crops has been one of the largest in recent years. The country has a huge territory with great abundance of pasture and native vegetation suitable for crops (DE GOUVELLO, 2010), and a history of agricultural production expanding over natural landscapes (MORTON *et al.*, 2006; GIBBS *et al.*, 2010). Brazil is also one of the greatest producers of soybeans, a vegetal oil source that may replace other feedstock oils used for biodiesel. Thus, it did not come as a surprise when the country was placed at the center of the debate on the effects of Land Use Change, emissions, and biofuel production.

Because approximately 63% of the remaining vegetation in Brazil is located in carbon-rich areas (Amazon Forest) a great concern is that the conversion of these areas may be indirectly stimulated by the expansion of biofuel production, undermining the climate benefits of biofuels and threatening the existing biodiversity of Brazilian territory. This is a sound concern that, together with the straightforward rationale supporting the ILUC argument, gained great emphasis in several studies and in the international debate (FRITSCHE *et al*., 2010; LAPOLA *et al*., 2010).

However, the existing methodologies for measuring direct and indirect Land Use Changes (LUC and ILUC) and their impact on total emission of GHG are controversial and under continuous development. This chapter intends to contribute to the debate in two different ways. The first section describes how the debate on LUC and ILUC methodologies has evolved recently, with focus on selected land use models. The second section presents a causal allocation methodology to determine an emission factor associated with Land Use Changes due to the sugarcane bioethanol expansion in Brazil.

Calculating biofuel indirect effects: the evolution of land use models

Although there is a strong trend towards the inclusion of GHG emissions from LUC and ILUC in the life cycle analysis of feedstocks for biofuels, so far there are no significant advances in the development of new specific models for the treatment of ILUC issues. On the contrary, research efforts have been focused on filling lacunas to adapt already existing robust methodologies, used in different scientific areas, for the purposes of ILUC assessments. Overall, the methodologies are a combination of socioeconomic and biophysical models.

Projections and simulations of production, consumption and Land Use Change tendencies are extracted from socioeconomic models, where environmental changes are determined by individual decisions. These models generally cover extensive geographical areas, such as states, countries or groups of countries.

In biophysical models, the analysis is focused on physical and geographical features and human interference is generally exogenous[1]. The main purposes of using biophysical models for ILUC calculation are (i) the use of satellite images and maps to determine land cover and calculate

---

[1] A summary of the main works on the integration of economic and biophysical models may be found in Veldkamp and Verburg (2004). Up until the date of this publication, however, the concept of ILUC was still unclear.

carbon stocks, (ii) to allocate the result of socioeconomic projections using spatially-explicit models; (iii) transforming LUC patterns into GHG emissions. Such models are commonly used in limited geographical areas and the pixel is the analysis unit.

Evaluation of selected land use models

Numerous combinations of the existing socioeconomic and biophysical models generate a set of possible methodologies for ILUC analysis that is too large to be addressed. Therefore, the methodologies used (or with great potential to be used) in the main biofuel laws, such as the US Renewable Fuel Standard (RFS), the Californian Low Carbon Fuel Standard (LCFS), and the Renewable European Directive (RED), are analyzed over the next few paragraphs.

In all methodologies, the concept and approach for ILUC measurement are treated in a very similar way, as follows:

a) a baseline scenario is projected, with no biofuel policies;
b) an alternative scenario is projected considering an expansion of biofuel consumption and production promoted by the policy analyzed;
c) GHG emissions caused by Land Use Change are calculated on both scenarios;
d) the difference in GHG emissions between the scenarios is associated to the biofuel consumption stimulated by the policy.

In LCFS, a combination of the Global Trade Analysis Project (GTAP) and carbon stock maps was used. The results obtained for the 111 GTAP global regions were distributed among the 18 Agro-Ecological Zones (AEZ), which was the major adaptation of the model for land use analyses. Each GTAP region is inserted in at least one AEZ. GHG emission is calculated by multiplying Land Use Change (GTAP result) by the conversion factors between land uses in each of the AEZs (tabulated data derived from carbon stock maps) (CARB, 2009). Recently, a new Agro-ecological Zone Emission Factor Model has been proposed by Plevin *et al* (2011).

GTAP, developed by Purdue University, was originally intended for international trade analysis. Since it is a computable general equilibrium model, the supply, demand and profit are simultaneously determined and different equilibriums are found. Then land demand is determined by substitution functions among production factors.

Although we acknowledge the efforts made in lawmaking transparency, the use of several indexes and parameters in GTAP that are unsuitable for the reality of land use dynamics in Brazil was identified (UNICA, 2009, and UNICA 2011). In addition, in GTAP, Brazil is considered as a single region, not considering local differences between regions, what is not appropriate, given the specificities of Brazilian regions.

In RFS law proposal, EPA has combined the land use analysis developed by CARD/FAPRI´s models and by the Forestry Agriculture Sector Optimization Model (FASOM) of Texas A&M University with analyses of satellite images and geospatial data provided by Winrock International (US-EPA, 2009; HARRIS *et al*., 2009).

FAPRI developed a combination of supply and demand equilibrium models, whose purpose is to project consumption, production, and international trade of agricultural products (FAPRI, 2009). Although its initial purpose was not to analyze land use, the competition for land between crops is explicitly modeled through competition matrixes. In this structure,areas respond to their own, and cross profitabilities. FASOM is an optimization model, and its original purpose is the performance of agricultural and environmental analyses comprised within the USA geographical borderlines (ADAMS *et al* 1996; US-EPA, 2009).

In the case of LCFS, ICONE has analyzed the initial proposal of regulation published by EPA in May 2009 for public consultation, (US-EPA, 2009). ICONE rejects the analysis proposed in the document as appropriate to Brazilian agriculture dynamics, due to the following elements:

a) it is too aggregated an analysis (Brazil is treated as a single region);
b) pastures are not modeled following economic hypotheses;
c) cattle intensification was not appropriately considered and;
d) the analysis of satellite images does not have the appropriate accuracy to differentiate pastures from native vegetation in some Brazilian biomes.

In parallel to the global land use models, ICONE has developed, in collaboration with CARD-FAPRI (Iowa State University), the Brazilian Land Use Model (BLUM). The general idea was to improve the Brazilian module of the FAPRI model, and at the same time build a Brazilian model that could run separately from international models (a standalone model).

During the period of public consultation concerning Draft Regulatory Impact Analysis (DRIA) for RFS, several improvements had already been incorporated into BLUM making it possible to elaborate constructive proposals for improvement of the methodology proposed by EPA. The analysis of LUC proposed in the DRIA original text was reproduced using BLUM, splitting Brazil into six regions and with a substantially more complete analysis of LUC than that of the original text (NASSAR *et al*., 2009).

The results obtained by BLUM indicated the existence of an indirect effect of the expansion of sugarcane bioethanol production, however, the indirect effect was marginal and significantly inferior to the results originally proposed in DRIA. Such verification evidenced the need to improve and adapt the results originally presented in the DRIA[2].

The effort conducted by ICONE has been productive, as the final report of DRIA presents changes that are consequences of the incorporation of BLUM's results. In January 2010, after corrections on the original FAPRI models (by inserting the BLUM model into the world FAPRI model), sugarcane bioethanol was recognized as an advanced biofuel, reducing 61% of GHG emissions contributed to gasoline.

At the time of writing of this chapter, the European Directive had not yet decided on how to deal with LUC and ILUC calculations although the RED makes explicit mention of ILUC. It is expected that the methodology for calculation of GHG emissions due to biofuel ILUC will be supported by the combination of economic models (for global projections of land use in different policy scenarios), spatially-explicit models (for allocation of results of the economic models) and carbon stock maps (for conversion of LUC into GHG emissions) (JRC, 2009)[3].

The review of the proposed models has identified some limitations that are common to all proposed methodologies. Such limitations may be summarized as follows:

- some partial equilibrium models do not consider pasture as a type of land use; general equilibrium models presents elasticities of substitution among production factors and therefore are capable of assuming pasture intensification, however further research on parameters used for substitution elasticities is needed;
- double cropping is generally ignored;
- assumptions regarding native vegetation conversion are not based on reality, generally not using satellite images and overstating land conversion. Some models consider direct conversion to sugarcane which is not observed in reality;

---

[2] In addition to the formal posting of Docket in EPA's site, the results of Nassar et al were directly presented to the members of EPA, in EPA's official visit to Brazil (NASSAR ET AL, 2009).

[3] Deeper analysis of the models reviewed by the EU-JRC initiative is out of the scope of this chapter. For that we recommend reading the set of studies released by the JRC in 2010 and the response to the consultation document (NASSAR ET AL 2010).

- very simplistic assumptions on competition for land (no satellite images and poor representation by transformation elasticity)
- the models provide information on area allocation but not on Land Use Change;
- other native vegetation conversion factors, such as illegal deforestation, expectancy of appreciation in land value, lack of property rights, are not considered, or are just partially considered.

Conceptual model for measuring ILUC and the development of the BLUM model

Brazil's leadership in bioethanol production and its well known land availability for agriculture, along with high rates of Amazon deforestation have brought the country into the center of the debate on ILUC. Ironically, this fact has opened a window of opportunity for Brazilian researchers and research centers to stand out in the methodology development process conduction[4].

Based on the analyses presented above while trying to avoid the recurrent mistakes of international models, an ideal conceptual model for measuring ILUC may be defined (Figure 1).

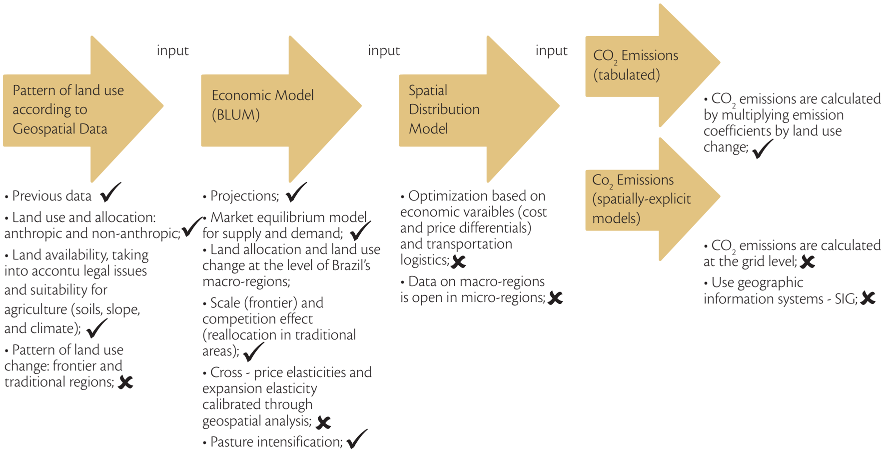


Figure 1. Conceptual model for measuring ILUC

Source: ICONE

---

[4] At this point, it is important to mention the World Bank´s "Brazil Low Carbon Country Case Study" (de GOUVELLO, C., 2010). This study was important for ICONE´s LUC modeling expertise in two ways: (i) stimulating the development of BLUM, not only as part of the necessary financial resources, but also signaling to ICONE that there was a demand for expertise in economic land use projections; (ii) evidencing the need for integration of economic land use modeling with geospatial modeling, both in the evaluation of current land use through satellite imagery or in the measurement of GHG emissions using spatially-explicit models.

Notes: the symbol ✓ indicates that the topic is already connected to BLUM or that it already uses information from BLUM. The symbol ✖ indicates that the topic still needs to be developed.

ILUC measurement is made from the combination of two types of modeling: one based on geospatial techniques and another with an economic basis. The economic modeling has a major role in projecting land allocation and LUC from supply and demand scenarios for agricultural and forest products.

The economic model, however, produces quite aggregated results which, ideally, should be spatially distributed before proceeding to calculate GHG emissions. Therefore, the economic model of market equilibrium is complemented by an optimization model which will distribute land allocation and LUC calculations into more divided geographical units (IBGE micro-regions, for example). The results at micro-region levels may be addressed in spatially-explicit models, operating in a Geographic Information System (GIS) environment, to calculate the emissions.

Economic models of land allocation typically project the area to be allocated for a given crop in the future. In order to generate LUC results, evaluating the effects of replacing other uses due to sugarcane expansion, it is ideally necessary to define patterns of scale (frontier expansion) and competition effects (use replacement). These patterns will serve as a basis to validate cross-price and frontier expansion elasticities used by the economic model. The suggestion here is that the definition of these patterns is performed using satellite images analysis. Therefore, geospatial information is also an input for the economic model. In addition to this, a central piece of information refers to land availability and the suitability of available land for agriculture production (which is also obtained from GIS analysis).

Improving BLUM model

After the publication of Nassar et al (2008), several improvements have been developed and implemented in the methodology for ILUC calculation, such as the connections and integration of BLUM with other models, in addition to internal improvements to BLUM[5]. With respect to structural advances in BLUM, an appropriate methodology was developed to explicitly address the regional distribution of agribusiness production and native vegetation within a context of area restriction. The developed research is detailed in the following paragraphs.

---

[5] Although such distinction is initially didactic, the advances in the connections between BLUM and other models naturally make difficult the separation between improvements in connections and improvements in BLUM itself.

The BLUM was improved to address competition between crops and pastures simultaneous to their expansion over native vegetation. The study “A Linear Approximate Acreage Allocation Model” (HOLT, 1999) was used as an initial reference for such an approach.

The major advantage of this improvement is the possibility of deconstructing elasticities of the total area into individual elasticities, comprising "scale" and "competition" effects. The incorporation of these two effects is particularly interesting because, differently to other existing models, BLUM can capture LUC and not just land allocation for the activities.

Another advantage is the incorporation of geospatial data on land use and land availability in Brazil. This data is processed in the model with nonlinear equations to estimate and project the total area used for agriculture. This combination acknowledges the geographical limits of agriculture production and native vegetation.

It is important to mention the great efforts required to estimate parameters, in addition to the incorporation of GIS modeling inputs with a high level of fidelity, in order to achieve the desired robustness and coherence in results. The necessary GIS inputs are: the available area for agriculture; and the interpretation of satellite images to identify previous patterns of replacement among crops, pastures, and native vegetation.

Such methodological improvements to BLUM have been incorporated according to availability of information. The land availability database is based on the Agricultural Land Use and Expansion Model – Brazil (AgLUE-BR) developed by Professor Gerd Sparovek (SPAROVEK ET AL., 2011).

Compatibility of BLUM with other models

Despite the developed improvements, BLUM continues to depend on an international model of land use (or additional hypotheses) to measure international ILUC.

The compatibility between BLUM and other global models of land use has been reviewed for three international land use models. Two partial equilibrium models (FAPRI and AGLINK-COSIMO) and one general equilibrium model (GTAP) were evaluated. The level of compatibility between BLUM and the three models may be ranked as follows: 1-the FAPRI Model; 2-the AGLINK-COSIMO Model; and 3- the GTAP Model.

Since they are partial equilibrium models, most of the fundamental hypotheses of BLUM, such as the concept of competition for land and path dependence, are similar or identical to those of the FAPRI and AGLINK-COSIMO models. Therefore, the connection between these models may be considered to be more consistent.

The structural similarity between BLUM and FAPRI is, however, significantly superior to that observed between BLUM and AGLINK-COSIMO. The FAPRI and BLUM models individually project each agricultural activity, while in AGLINK-COSIMO some similar activities are grouped. Additionally FAPRI and BLUM models share the same database and can be physically integrated.

Although the concept of competition for land is modeled in a different way in partial and general equilibrium models, the connection between them may be achieved via demanded volume. One possibility is that the general equilibrium model (GTAP) provides the demand projections that should be simulated, while BLUM considers this demand as given and then finds the price vector, which spatially allocates agricultural production. In this case, however, the models would not be integrated, so the equilibrium price vector found by BLUM would have no effects on the general equilibrium model.

The greatest difficulty, however, in making BLUM compatible with GTAP, in addition to the fact that the former is a partial equilibrium model (and therefore assumes as exogenous several variables which are endogenously estimated in general equilibrium models) is the hypothesis of answer of the production to changes in production factors. General equilibrium models treat agricultural production as a function of production factors, especially capital and land. On the other hand, partial equilibrium models treat production (or allocated area) as a function of profitability, i.e., prices minus effective costs. Although partial equilibrium modeling may also use production factors, this is not the case of BLUM, FAPRI, and AGLINK-COSIMO global models.

Additional improvements needed in BLUM

Better treatment of sugarcane industrial phase is an important improvement required of BLUM. The inclusion of revenues from electricity cogeneration is actually in the exploratory phase. Other probable technological pathways (such as 2nd generation biofuels) should be identified, and their probabilities of occurrence quantified. Industrial costs should be mapped, projected, and made compatible with the hypotheses of BLUM.

The inclusion of endogenous projections of productivity and production costs is a topic to be considered to complement and improve projections and simulations of BLUM and the other projection models. Keeney and Hertel (2009) identified significant variations in land use projections considering different hypotheses on productivity.

The main challenges identified in the integration between economic models and biophysical models are: the treatment of economic hypotheses in spatially-explicit models and possible environmental interferences/changes on economic relations.

As presented in this chapter, part of this challenge is being overcome, as in the case of the integration of the BLUM model with AgLUE-BR. On the other hand, the best methodology for spatializing the results of BLUM and the respective calculation of GHG emissions related to LUC is still under analysis.

Although it is possible to directly deconstruct the results of the six BLUM regions through spatially-explicit models, the research conducted so far indicates a preference for the introduction of an intermediate step involving an optimization model. Such an option exists because it is shown to be more appropriate to suit economic decisions on environmental constraints/changes. Additionally, the development of an optimization model may broaden BLUM's possibilities of analysis, such as simulations of storage and logistic improvements. Such simulations may develop into important quantitative tools for public policies analysis, for example, the allocation of infrastructure and logistic investments.

Conclusions and research suggestions

in this section, we presented an evaluation of the main methodologies for ILUC calculation which served as a basis on which to build an ideal conceptual model for making calculations of GHG emissions related to ILUC. Next, we explored specific themes of the Brazilian Land Use Model - BLUM. Its main methodological advances in relation to the version used by Nassar et al. (2008) were reported, its limitations were assessed, and necessary improvements with high priorities were identified.

In the institutional field, important advances in the collaboration between Brazil and the USA, and also with the European Union, were observed. The collaboration went far beyond formal meetings, and technical collaboration in the construction and verification of ILUC methodologies was the major focus of work. In this case there is a significant collaboration between ICONE and CARD-FAPRI, based on the RFS laws.

It is worth noting that, although not immediately related to Brazil-USA collaboration, the collaboration with members of the European Community (and other relevant institutions worldwide) contributes to the consolidation of the appropriate methodological concept for ILUC calculations.

Thanks to the conceptual model for measuring ILUC, it is possible to verify, through the evaluation of international methodologies and improvements implemented in BLUM, that these improvements make it an excellent model for representing and projecting land use dynamics in Brazil. The most important improvement during this period was the introduction of the concepts of "scale effect" and "competition effect", allowing for interpretations of Land Use Change dynamics and not only area allocation.

On the other hand, special attention must be given to the need for improvements in the methodology of land use analysis, especially with respect to the interfaces between BLUM and biophysical models. It may be considered that the main interfaces have been identified and some progress has already been made. However, efforts are still necessary in the following topics:

- development of previous Land Use Change databases using geospatial data;
- development of a methodology which serves as an interface between BLUM and biophysical models (possibly based on optimization models);
- expansion of research related to technological innovation and its application in all agribusiness sectors, and its compatibility with BLUM;
- categorization of the current "cattle raising" sector as 'extensive', 'semi-intensive', and 'intensive', in order to model animal husbandry intensification, and evaluate impacts on production systems and the need for investments.

The above list is not intended to be definitive and all-inclusive in relation to research recommendations, as new topics may emerge throughout the development of ILUC analysis (or other related agro-environmental public policy analysis). However, the maintenance of BLUM at the frontier of knowledge as a strategy for foreign and scientific policies is recommended. Two arguments support this recommendation:

Firstly, whoever is interested in developing other ILUC models and/or is interested in the application of BLUM, will seek to understand the dynamics of its operation. Therefore they will have to understand the features of agribusiness and land use in Brazil, which are quite different from those of developed countries, such as the USA and the EU. This fact will have a very positive effect in disseminating qualified information to the international political and scientific environment about a country that aggregates the greatest potentials for expansion of agricultural production in the world.

In addition, the search for a methodology of GHG emissions associated to ILUC has been initiated due to the impact of biofuels on climate changes. However, the tendency is that the same occurs with other products, especially the agricultural and land-intensive ones. Therefore, the consolidation of BLUM as a methodology of reference for ILUC calculation will serve as an important tool to appropriately guide future negotiations and laws.

An allocation methodology to assess GHG emissions associated with land use change

The current approaches in dealing with the ILUC impact may be divided in three groups (FRITSCHE ET AL., 2010). The first group includes economic forecast models of agriculture and cattle-raising in order to estimate GHG emissions. These models simulate the impact effects of the demand for biofuels according to a scenario and estimate the marginal ILUC (as described in detail in the previous section). The second group, that also estimates GHG emissions, consists of allocation methodologies and establishment of cause-effect relationships in Land Use Changes that are based on historical data. Known as descriptive-causal approaches, these methodologies usually make use of satellite imaging and secondary data (BAUEN, 2010). The third approach is a precautionary one in which the ILUC effect that is considered in the sum of biofuel emissions is potentially high and thus ex ante criteria are applied to ensure that biofuels are cultivated in areas with low probability of causing ILUC.

None of these approaches are considered ideal for establishing the potential impact of ILUC. Whereas the economic models are less intuitive and not very transparent, the allocation approach may be troublesome if data on land use are greatly aggregated. Additionally, a cause-effect relationship needs to be based on satellite imaging as well as on other conjectures in order to reproduce the dynamic complexity associated with the ILUC concept. As for the precautionary approach, it is still too early to claim that the ILUC is indeed high.

To overcome the existing methodological limitations associated with measuring the ILUC, we developed a causal allocation methodology that makes use of the best historical data available in Brazil in order to determine an emission factor associated with Land Use Changes due to the sugarcane bioethanol expansion in the country.

Suggested method

The methodology presented here was developed based on data from 2005 to 2008. During this period a significant growth of sugarcane plantation occurred while little growth was associated with other activities. Additionally, the annual deforestation rate during this period was lower than that of previous years (2003 and 2004) and closer to the current rate, which in 2009 was less than 800,000 ha. (Available at<www.obt.inpe.br/prodes>).

Historical pattern and data collection

A substitution pattern was defined among the 11 activities in the country that use the most land. These are grazing, sugarcane, soybeans, corn, cotton, rice, dry beans (first harvest), and planted forests, besides the sum of perennial crops, other annual crops (except winter crops), and areas of native vegetation. This pattern was represented by a substitution coefficient and an expansion coefficient, and was established based on observations made in the past, considering the evolution of the area used for each activity. Substitution coefficients are presented in two forms: (i) absolute variation in hectares, which represents the expansion of the area for a specific productive activity and its effects on substitution for other activities and for native vegetation; and (ii) the substitution coefficient that is calculated based on the variation of one area unit (one hectare). Agriculture data were obtained from the Brazilian Institute for Geography and Statistics (IBGE – Instituto Brasileiro de Geografia e Estatística).

Data on planted forests (Pinus and Eucalyptus) were estimated from the total area occupied by these forests according to data from the Brazilian Association of Producers of Planted Forests (ABRAF, 2009). The total area of planted forests in Brazil was distributed among the microregions according to the data on forest production obtained from IBGE. To obtain an area flow for the period, the stock area of 2005 was deducted from that of 2008 for both agriculture and forests.

For crops with more than one harvest per year, the total production was divided by the area used in the first harvest. The productivity gain for perennial crops was estimated considering the weighted average per area for the productivity gain of the three main crops in each region. For planted forests we considered the growth of the Mean Annual Increment (MAI) (ABRAF, 2009). The estimated productivity gain of cattle-raising was based on meat production per hectare, according to data from IBGE. Considering that cattle-raising occupies the greatest area extension in Brazil and is the activity with the greatest potential for increasing production, the final results are very sensitive to its estimates in productivity gains.

As for the data related to the conversion of native vegetation, three biomes were considered, namely the Amazon, Cerrado, and Atlantic Forest. Deforestation data for the 2005–2007 period were considered. We assumed that all deforested areas would eventually be converted into croplands or pasture..Thus, for each microregion the pasture area was determined as being the difference between deforestation and the total growth of cropland areas. The substitution rates obtained for each microregion were aggregated for each of the six regions in Brazil, according to the Brazilian Land Use Model (BLUM) (NASSAR *et al.*, 2008) to produce regional matrices for area substitution. For these matrices we assumed that expansion of each hectare of each of the crops would proportionally lead to either a decrease in another cropland or to conversion of native vegetation. These matrices were normalized for the calculation of the substitution coefficient of productive activities and native vegetation. Based on these coefficients we calculated the effects of LUC and ILUC that originated from the expansion of one hectare of sugarcane bioethanol, according to the methodology described in this article.

Study region

The basic unit for analysis was established according to the microregions defined by IBGE, in which the Brazilian municipalities, numbering more than 5000, were aggregated into 558 microregions. The data were presented for the BLUM regions, namely South and Southeast (corresponding to the official borders), Center-West Cerrado (part of the state of Mato Grosso that belongs to the Amazonian biome was removed), Northern Amazon, and Northeast Coast, while the states of Maranhão, Piauí, Tocantins, and Bahia comprised the Northeast Cerrado. The state of Mato Grosso was divided in two, according to a list of municipalities provided by IBGE that indicates which ones belong to the Amazon and which ones to the Cerrado biomes. Municipalities located on the borders of these biomes were split in the middle arbitrarily and thus appear twice in our database.

Applied methodology

Direct Land Use Changes (LUC)

The methodology follows a shift-share approach. When expansion of the total area was greater than that of cropland (which we assume leads to pasture expansion), it was considered as an expansion of cropland plus pasture. In this case a proportional allocation of cropland and pasture over native vegetation was assumed. When expansion of cropland was greater than that of the total area (which we assume leads to pasture reduction), the expansion was proportionally allocated between pasture and native vegetation. When a reduction in cropland was observed, then we considered that the pasture expanded over cropland and native vegetation. We also considered that expansion of a specific crop could be allocated to another crop that had a reduction in its planted area in the same microregion (when it applied) (Table 1).

To estimate the land-use substitution (LUC), we assumed a priority for sugarcane in expanding over pasture and cropland, as satellite imaging data show that sugarcane expands over crops and pasture in the same proportion, but not over native vegetation (NASSAR *et al*., 2008). We considered sugarcane expansion over native vegetation only when there were no other available areas (Table 1). The expansion

The first column shows whether or not the expansion of sugarcane fits into the total area released by cropland and pasture. The second column shows whether or not half of the sugarcane expansion fits into the reduction of pasture area, and the third column, into the cropland area. Columns 4, 5 and 6 describe how sugarcane allocation was defined in each case. When sugarcane expansion was less than the sum of reduced cropland and pasture areas, but half of the sugarcane expansion was greater than that of either the reduced areas (cropland or pasture), sugarcane expansion was attributed to the total of the smaller reduced area (marked as “no” in column 2 or 3) and the remainder was attributed to the other reduced area. When sugarcane expansion fits in the total reduced area (cropland + pasture) and in less than 50% of reduced cropland areas, but not in less than 50% of reduced pasture (line 2 below), its expansion was considered to have allocated all of the reduced pasture with only the remainder being allocated to cropland-reduced areas. area of a given crop was distributed over other crops displaced during the same period.

Table 1 – Procedures adopted to allocate sugarcane bioethanol area expansion, according to sugarcane expansion in each of the 558 micro regions of Brazil.

Sugarcane expansion and reduced areas			Allocation of sugarcane bioethanol expansion occurred…		
Sugarcane => total area	**50% sugarcane => pasture**	**50% sugarcane => cropland**	**Over pasture**	**Over cropland**	**Over native vegetation**
Yes	Yes	Yes	50% of sugarcane expansion	50% of sugarcane expansion	None
Yes	No	Yes	Total reduced pasture	Sugarcane expansion minus reduced pasture	None
Yes	Yes	No	Sugarcane expansion minus reduced cropland area	Total reduced cropland area	None
No	Yes	No	Total reduced pasture	Total reduced cropland area	Sugarcane expansion minus reduced pasture and cropland area
No	No	Yes			

Source: ICONE

Indirect Land Use Changes (ILUC)

To estimate the ILUC we first considered which land changes were caused by the activities directly replaced by sugarcane. Deforestation caused by other activities replaced by sugarcane was assessed in the sugarcane ILUC. The demand effect is then partially eliminated.

Gains in productivity allowed for a higher production in 2008 as compared to 2005. For this reason, we deducted the productivity gain during the 2005–2008 period, with the conclusion that the area replaced by sugarcane in 2005 corresponded to a smaller area in 2008.

For cattle-raising productivity, we considered the regional slaughtering rate, carcass yield, and stocking rate. Dairy cattle was considered for calculating stocking rates only. The area for each of the activities to be restored in 2008 was calculated and allocated according to the expansion pattern of each crop replaced by sugarcane.

To avoid inconsistencies when calculating the matrices of indirect substitution in absolute values, which represent how much area for each activity was indirectly displaced by sugarcane (having considered the gain in productivity), we calculated how much of the production for each activity should be restored in other areas. Next, we checked whether the reallocation would require an area expansion, or whether the gain in productivity itself would be enough to incorporate the reallocated production.

Greenhouse emissions associated with ILUC factor

We considered greenhouse emissions for Land Use Changes of perennial crops, annual crops, and pasture over native vegetation. The area of native vegetation converted due to sugarcane expansion (whether directly or indirectly) was multiplied by an emission factor associated with the soil use after conversion. Emission factors used were calculated according to Harris et al. (2009) and for the six Brazilian regions for which the substitution matrices were established. Emissions and removals due to conversion between agriculture and cattle-raising were also considered. These emission factors represent the carbon deficit – above and below the soil – among different land activities. To establish an emission factor associated with a change in land use due to sugarcane bioethanol, we divided all estimated emission factors associated with these changes (after discounting the area expansion caused by sugar production) by the total production of bioethanol. Finally, we determined a marginal emission factor associated with Land Use Changes (LUC + ILUC) that represents the amount of greenhouse gas (GHG) for each additional unit of bioethanol that is produced. This factor was calculated in terms of carbon content per energy unit (g CO_2 eq./ MJ) and the converted area per energy unit (kha/MTOE).

Results

Definition of a historical substitution pattern among several activities in Brazil and their expansion over the natural vegetation

Substitution matrices associated with the use of soil for cropland, pasture, and natural vegetation are shown for each of the six Brazilian regions. Absolute values and coefficients correspond to the 2005–2008 period.

Region 1 – South

Table 2 reveals that an increase of 210,529 ha of sugarcane took place. Most of this expansion occurred over soybean areas (109,597 ha). The sugarcane also substituted pasture (39,695 ha) and other annual activities (20,831 ha). The most expanded activity in this region was pasture, with an increase of 569,152 ha during the 2005–2008 period. This growth occurred mainly over soybean areas (245,588 ha) and corn areas to a lesser extent (101,921 ha). Note that for each expanded hectare of sugarcane there is a substitution of 0.52 ha of soybeans, 0.04 ha of corn and 0.19 ha of pasture. A total of 188, 260 ha of deforestation took place in this region.

Region 2 – Southeast

Table 3 reveals that the greatest expansion of sugarcane in this region occurred over pasture. The sugarcane also expanded over the soybean area (371,119 ha), the corn area (115,590 ha), and over other crops to a lesser extent. Note that in this region sugarcane expanded 5,091 ha over native vegetation. For each expanded hectare of sugarcane 0.52 ha of pasture was displaced, while virtually no expansion occurred over the native vegetation. A total of 775, 044 ha of deforestation took place in this region.

Region 3 – Center-West Cerrado

Table 4 shows that the greatest expansion in this region was due to pasture, while the sugarcane area increased much less. For each expanded hectare of sugarcane, 0.62 ha of soybeans and only 0.01 ha of native vegetation were displaced. A total of 3, 980, 087 ha of deforestation took place in this region.

Region 4 – Northern Amazon

Large expansions of pasture also occurred in this region, while sugarcane expansion was much less (Table 5). Pasture had a great impact on deforestation in this area, in that for each expanded hectare of pasture, 0.87 ha occurred over native vegetation. A total of 188, 260 ha of deforestation took place in this region in this case.

Region 5 – Northeast Coast

This is a region with adverse conditions for agriculture and cattle-raising. In this region, sugarcane expanded by 146,740 ha, mostly over pasture (133,142 ha; Table 6). The substitution coefficient was very high (0.91) in this case. No deforestation took place in this region.

Region 6 – Northeast Cerrado

Sugarcane area expanded by 42,843 ha, mostly over pasture and rice (Table 7). Pasture expanded the most in the region and intense displacement of native vegetation occurred. A total of 857,911 ha of deforestation took place in this region in this case.

Table 2 – Land-use substitution matrix (ha) (left columns) and coefficient matrix (right columns) for each of the 11 activities in the South region of Brazil during the 2005–2008 period.

	Sugarcane		Soybean		Corn		Cotton		Rice		Dry beans		Comm. Forest		Perennial		Other annuals		Pasture	
Sugarcane	210,529	1.00	323	0.00	3,528	0.01	328	0.62	95	0.00	10	0.00	324	0.00	92	0.00	102	0.00	10,084	0.02
Soybeans	109,597	0.52	118,991	1.00	204,513	0.54	105	0.20	37,922	0.61	2,948	0.12	39,317	0.11	4,721	0.13	16,040	0.53	245,588	0.43
Corn	9,132	0.04	39,912	0.34	377,953	1.00	0	0.00	2,838	0.05	5,206	0.21	22,116	0.06	2,147	0.06	903	0.03	101,921	0.18
Cotton	22,431	0.11	894	0.01	7,509	0.02	533	1.00	471	0.01	153	0.01	4,408	0.01	261	0.01	618	0.02	14,446	0.03
Rice	2,490	0.01	3,128	0.03	11,376	0.03	9	0.02	62,464	1.00	480	0.02	9,576	0.03	2,131	0.06	1,704	0.06	40,576	0.07
Dry beans	2,950	0.01	6,163	0.05	11,994	0.03	21	0.04	489	0.01	25,093	1.00	19,814	0.06	2,078	0.06	860	0.03	25,628	0.05
Commercial forest	1,534	0.01	19,808	0.17	14,362	0.04	1	0.00	4,509	0.07	3,136	0.12	345,896	1.00	2,111	0.06	418	0.01	67,341	0.12
Perennial crops	1,869	0.01	1,232	0.01	3,696	0.01	68	0.13	706	0.01	154	0.01	4,654	0.01	37,181	1.00	892	0.03	11,836	0.02
Other annual crops	20,831	0.10	2,308	0.02	19,540	0.05	0	0.00	4,426	0.07	508	0.02	21,898	0.06	1,909	0.05	30,362	1.00	33,197	0.06
Pasture	39,695	0.19	42,695	0.36	96,966	0.26	0	0.00	10,727	0.17	11,441	0.46	210,680	0.61	20,550	0.55	8,606	0.28	569,152	1.00
Deforestation	0	0.00	2,529	0.02	4,468	0.01	0	0.00	282	0.00	1,057	0.04	13,109	0.04	1,182	0.03	219	0.01	18,535	0.03

Note: Numbers in the main diagonal (bold) correspond to the expansion of activity in the region. Underlined numbers (first line) correspond to the areas that sugarcane conceded to other crops in the region. The coefficient matrix (right columns) shows the displacement impact that an expansion of 1 hectare of a given crop has caused to other crops in the region.

Table 3 – Land-use substitution matrix (ha) (left columns) and coefficient matrix (right columns) for each of the 11 activities in the Southeast region of Brazil during the 2005–2008 period.

	Sugarcane		Soybean		Corn		Cotton		Rice		Dry beans		Comm. Forest		Perennial		Other annuals		Pasture	
Sugarcane	1,736,552	1.00	0	0.00	597	0.00	0	0.00	245	0.19	8	0.00	2,007	0.00	199	0.00	185	0.00	32,205	0.04
Soybeans	371,119	0.21	37,754	1.00	42,022	0.32	9	0.03	19	0.02	2,137	0.10	38,708	0.04	7,161	0.06	16,253	0.31	63,860	0.07
Corn	115,590	0.07	751	0.02	132,536	1.00	24	0.07	117	0.09	1,834	0.09	33,201	0.04	18,001	0.16	7,483	0.14	51,755	0.06
Cotton	85,239	0.05	4,722	0.13	9,024	0.07	323	1.00	337	0.27	1,403	0.07	11,506	0.01	2,976	0.03	2,587	0.05	10,847	0.01
Rice	16,666	0.01	3,491	0.09	3,020	0.02	1	0.00	1,271	1.00	175	0.01	10,304	0.01	4,628	0.04	2,714	0.05	16,403	0.02
Dry beans	9,118	0.01	6	0.00	1,050	0.01	1	0.00	60	0.05	20,884	1.00	11,621	0.01	5,566	0.05	646	0.01	8,882	0.01
Commercial forest	76,348	0.04	1,791	0.05	4,635	0.03	287	0.89	10	0.01	2,426	0.12	866,293	1.00	5,346	0.05	2,333	0.04	517,210	0.58
Perennial crops	75,936	0.04	52	0.00	3,050	0.02	1	0.00	60	0.05	935	0.04	24,371	0.03	115,798	1.00	956	0.02	66,809	0.07
Other annual crops	81,315	0.05	7,318	0.19	3,458	0.03	0	0.00	60	0.05	211	0.01	4,279	0.00	3,701	0.03	53,162	1.00	11,689	0.01
Pasture	900,131	0.52	2,825	0.07	61,056	0.46	0	0.00	249	0.20	10,671	0.51	697,684	0.81	62,063	0.54	16,154	0.30	897,594	1.00
Deforestation	5,091	0.00	16,798	0.44	4,624	0.03	0	0.00	114	0.09	1,082	0.05	32,611	0.04	6,157	0.05	3,850	0.07	117,933	0.13

Note: Numbers in the main diagonal (bold) correspond to the expansion of the activity in the region. Underlined numbers (first row) correspond to the areas that sugarcane ceded to other crops in the region. The coefficient matrix (right columns) shows the displacement impact that an expansion of 1 hectare of a given crop has caused to other crops in the region.

Table 4 – Land-use substitution matrix (ha) (left columns) and coefficient matrix (right columns) for each of the 11 activities in the Center-West region of Brazil during the 2005–2008 period.

	Sugarcane		Soybean		Corn		Cotton		Rice		Dry beans		Comm. Forest		Perennial		Other annuals		Pasture	
Sugarcane	344,825	1.00	3	0.00	261	0.00	271	0.01	0	0.00	0	0.00	77	0.00	340	0.03	389	0.00	9,350	0.00
Soybeans	214,366	0.62	65,289	1.00	162,111	0.57	26,146	0.50	0	0.00	7,663	0.63	42,490	0.42	2,700	0.20	75,522	0.47	934,823	0.48
Corn	8,291	0.02	45	0.00	284,921	1.00	157	0.00	0	0.00	10	0.00	1,771	0.02	286	0.02	1,212	0.01	8,101	0.00
Cotton	21,652	0.06	1,651	0.03	21,388	0.08	51,802	1.00	11	0.05	764	0.06	2,331	0.02	483	0.04	7,089	0.04	73,885	0.04
Rice	32,361	0.09	42,712	0.65	31,224	0.11	24,542	0.47	235	1.00	1,212	0.10	8,149	0.08	5,538	0.41	36,771	0.23	159,151	0.08
Dry beans	422	0.00	23	0.00	216	0.00	18	0.00	0	0.00	12,181	1.00	183	0.00	13	0.00	284	0.00	806	0.00
Commercial forest	17,558	0.05	548	0.01	1,282	0.00	27	0.00	0	0.00	96	0.01	100,292	1.00	79	0.01	2,306	0.01	49,483	0.03
Perennial crops	428	0.00	10	0.00	279	0.00	126	0.00	16	0.07	27	0.00	213	0.00	13,460	1.00	453	0.00	2,563	0.00
Other annual crops	21,582	0.06	0	0.00	6,026	0.02	151	0.00	0	0.00	243	0.02	527	0.01	375	0.03	160,991	1.00	40,781	0.02
Pasture	25,962	0.08	1,746	0.03	40,278	0.14	299	0.01	0	0.00	1,280	0.11	7,104	0.07	300	0.02	14,485	0.09	1,946,946	1.00
Deforestation	2,203	0.01	18,551	0.28	21,855	0.08	67	0.00	208	0.88	886	0.07	37,446	0.37	3,345	0.25	22,479	0.14	668,002	0.34

Note: Numbers in the main diagonal (bold) correspond to the expansion of the activity in the region. Underlined numbers (first row) correspond to the areas that sugarcane ceded to other crops in the region. The coefficient matrix (right columns) shows the displacement impact that an expansion of 1 hectare of a given crop has caused to other crops in the region.

Table 5 – TLand-use substitution matrix (ha) (left columns) and coefficient matrix (right columns) for each of the 11 activities in the Northern Amazon region of Brazil during the 2005–2008 period.

	Sugarcane		Soybean		Corn		Cotton		Rice		Dry beans		Comm. Forest		Perennial		Other annuals		Pasture	
Sugarcane	21,255	1.00	3	0.00	11	0.00	9	0.00	0	0.00	1	0.00	0	0.00	1,125	0.02	140	0.00	5,229	0.00
Soybeans	8,108	0.38	139,205	1.00	5,617	0.08	6,067	0.18	187	0.11	466	0.11	0	0.00	3,262	0.06	25,291	0.30	121,256	0.03
Corn	3,047	0.14	262	0.00	66,632	1.00	337	0.01	1,219	0.74	469	0.11	811	0.02	10,201	0.17	8,938	0.11	82,875	0.02
Cotton	10	0.00	63	0.00	3	0.00	33,992	1.00	0	0.00	0	0.00	0	0.00	12	0.00	5	0.00	2,016	0.00
Rice	9,294	0.44	96,718	0.69	37,953	0.57	27,444	0.81	1,638	1.00	1,857	0.42	6,896	0.20	26,158	0.44	37,264	0.44	319,346	0.07
Dry beans	4	0.00	234	0.00	88	0.00	26	0.00	0	0.00	4,402	1.00	0	0.00	28	0.00	32	0.00	1,933	0.00
Commercial forest	173	0.01	1,479	0.01	2,165	0.03	8	0.00	0	0.00	0	0.00	34,941	1.00	79	0.00	1	0.00	523	0.00
Perennial crops	85	0.00	58	0.00	706	0.01	0	0.00	0	0.00	746	0.17	0	0.00	59,241	1.00	2,277	0.03	24,930	0.01
Other annual crops	536	0.03	828	0.01	3,323	0.05	102	0.00	6	0.00	0	0.00	0	0.00	4,498	0.08	84,244	1.00	35,671	0.01
Pasture	0	0.00	0	0.00	12	0.00	0	0.00	13	0.01	0	0.00	0	0.00	743	0.01	2,117	0.03	4,467,933	1.00
Deforestation	0	0.00	39,560	0.28	16,755	0.25	0	0.00	213	0.13	862	0.20	27,233	0.78	13,134	0.22	8,177	0.10	3,874,152	0.87

Note: Numbers in the main diagonal (bold) correspond to the expansion of the activity in the region. Underlined numbers (first row) correspond to the areas that sugarcane ceded to other crops in the region. The coefficient matrix (right columns) shows the displacement impact that an expansion of 1 hectare of a given crop has caused to other crops in the region.

Table 6 – Land-use substitution matrix (ha) (left columns) and coefficient matrix (right columns) for each of the 11 activities in the Northeast Coast region of Brazil during the 2005–2008 period.

	Sugarcane		Soybean		Corn		Cotton		Rice		Dry beans		Comm. Forest		Perennial		Other annuals		Pasture	
Sugarcane	146,740	1.00	0	0.00	1,603	0.01	1	0.00	204	0.02	753	0.01	1	0.00	813	0.01	1,008	0.01	32,018	0.47
Soybeans	46	0.00	302	1.00	16	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	88	0.00	0	0.00
Corn	2,545	0.02	0	0.00	282,653	1.00	3	0.00	57	0.01	1,396	0.01	0	0.00	1,267	0.02	5,740	0.05	9,986	0.15
Cotton	1,614	0.01	23	0.08	13,663	0.05	723	1.00	277	0.03	3,303	0.02	742	0.08	2,751	0.05	6,224	0.06	8,328	0.12
Rice	287	0.00	0	0.00	5,144	0.02	102	0.14	8,534	1.00	2,467	0.02	0	0.00	2,083	0.04	739	0.01	778	0.01
Dry beans	53	0.00	0	0.00	386	0.00	4	0.01	32	0.00	136,903	1.00	0	0.00	571	0.01	613	0.01	4,568	0.07
Commercial forest	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	9,393	1.00	0	0.00	0	0.00	0	0.00
Perennial crops	5,233	0.04	0	0.00	5,460	0.02	16	0.02	20	0.00	1,642	0.01	419	0.04	54,559	1.00	3,242	0.03	7,666	0.11
Other annual crops	3,820	0.03	0	0.00	10,770	0.04	110	0.15	87	0.01	8,144	0.06	1,169	0.12	2,989	0.05	108,327	1.00	5,132	0.07
Pasture	133,142	0.91	279	0.92	245,611	0.87	486	0.67	7,858	0.92	119,198	0.87	7,063	0.75	44,084	0.81	90,672	0.84	68,476	1.00
Deforestation	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Note: Numbers in the main diagonal (bold) correspond to the expansion of the activity in the region. Underlined numbers (first row) correspond to the areas that sugarcane ceded to other crops in the region. The coefficient matrix (right columns) shows the displacement impact that an expansion of 1 hectare of a given crop has caused to other crops in the region.

Table 7 – Land-use substitution matrix (ha) (left columns) and coefficient matrix (right columns) for each of the 11 activities in the Northeast Cerrado region of Brazil during the 2005–2008 period.

	Sugarcane		Soybean		Corn		Cotton		Rice		Dry beans		Comm. Forest		Perennial		Other annuals		Pasture	
Sugarcane	42,843	1.00	27	0.00	227	0.00	2	0.00	8	0.00	118	0.00	1	0.00	1,037	0.00	1,244	0.01	412	0.00
Soybeans	1,501	0.04	151,919	1.00	2,892	0.02	2,002	0.02	73	0.01	381	0.01	17	0.00	671	0.00	2,167	0.02	28,525	0.03
Corn	3,334	0.08	744	0.00	119,150	1.00	1,225	0.01	9	0.00	1,744	0.03	729	0.01	7,614	0.03	6,813	0.06	51,422	0.06
Cotton	1,395	0.03	200	0.00	3,504	0.03	108,866	1.00	8	0.00	3,201	0.06	0	0.00	8,296	0.04	5,664	0.05	24,472	0.03
Rice	10,531	0.25	31,666	0.21	13,162	0.11	14,213	0.13	14,309	1.00	8,830	0.15	2,082	0.02	6,233	0.03	13,725	0.12	72,976	0.08
Dry beans	2,888	0.07	709	0.00	11,919	0.10	37	0.00	55	0.00	57,989	1.00	236	0.00	14,278	0.06	2,376	0.02	103,622	0.11
Commercial forest	1,896	0.04	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	89,482	1.00	2	0.00	0	0.00	2	0.00
Perennial crops	314	0.01	56	0.00	374	0.00	32	0.00	0	0.00	329	0.01	3	0.00	220,101	1.00	569	0.00	1,477	0.00
Other annual crops	2,109	0.05	1,714	0.01	10,319	0.09	202	0.00	9	0.00	2,760	0.05	0	0.00	19,653	0.09	116,305	1.00	77,068	0.08
Pasture	16,438	0.38	23,920	0.16	23,429	0.20	273	0.00	5,736	0.40	13,795	0.24	86,354	0.97	158,838	0.72	63,668	0.55	919,502	1.00
Deforestation	2,437	0.06	92,883	0.61	53,325	0.45	90,881	0.83	8,410	0.59	26,830	0.46	61	0.00	3,479	0.02	20,078	0.17	559,528	0.61

Note: Numbers in the main diagonal (bold) correspond to the expansion of the activity in the region. Underlined numbers (first row) correspond to the areas that sugarcane ceded to other crops in the region. The coefficient matrix (right columns) shows the displacement impact that an expansion of 1 hectare of a given crop has caused to other crops in the region.

Estimate of indirect Land Use Changes caused by sugarcane bioethanol expansion

Table 8 shows that conversion of native vegetation caused by sugarcane was 8% of the sugarcane area expansion, and almost all conversion was indirect (7.6%), although not homogenously distributed among regions. The conversion of native vegetation that was directly caused by sugarcane bioethanol was close to zero. In the Northeast Cerrado the total converted area of native vegetation was almost half of the expansion area of sugarcane, while in the Southeast, the region with the largest sugarcane expansion, total conversion was around 8% of the sugarcane area expansion.

Table 8 – Sugarcane area net expansion (ha) and associated conversion of native vegetation in Brazilian Land Use Model (BLUM) regions during the 2005–2008 period.

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

Estimate of direct and indirect Land Use Changes caused by sugarcane bioethanol expansion (ILUC factor)

As shown in Table 9, direct Land Use Changes due to the expansion of sugarcane for bioethanol during the 2005–2008 period captured approximately 47 thousand tons of carbon equivalent, while indirect Land Use Changes emitted 2.4 million tons of carbon equivalent. For the same period, sugarcane for bioethanol was responsible for 78% of sugarcane expansion (in sugar equivalent), the rest being devoted to sugar production. Based on this information, a LUC + ILUC marginal factor for sugarcane bioethanol was estimated at 7.63 g CO_2eq/MJ. When only the emissions due to the conversion of native vegetation are considered, the LUC + ILUC factor is 6.48 g CO_2eq/MJ. The natural vegetation areas converted directly and indirectly represent 25 kha/Mtoe (million tons of oil equivalent) of sugarcane bioethanol.

Table 9 – Greenhouse gas emissions due to Land Use Changes and ILUC factor associated with sugarcane expansion in Brazil during the 2005–2008 period

Emissions associated with LUC (Ton CO_2eq)	-46,884
Emissions associated with ILUC (Ton CO_2eq)	2,462,069
Total emissions (LUC + ILUC) (Ton CO_2eq)	2,415,186
Share of sugarcane expansion due to bioethanol	79%
Additional bioethanol production (tons of total recoverable sugar)	19,672,059
Energy content of additional bioethanol production (Giga Joule)	248,330,532
LUC + ILUC factor (g CO_2eq / MJ)	7.63

Discussion

Here we estimated a marginal factor for the emissions due to Land Use Changes (LUC + ILUC factor) of 7.63 g CO_2eq per MJ of additional produced bioethanol, for a production of 248 million Giga Joules or 25kha/Mtoe. Together with the additional demand for sugar during the study period (2005–2008), this expansion represents a growth of 2.4 million ha of sugarcane and a total deforestation area (direct and indirect) of 191,000 ha. It should be noted that the LUC + ILUC factor is considerably lower than other estimates previously calculated (AL-RIFFAI *et al.*, 2010; TIPPER *et al.*, 2009).

The methodology presented here assumes that, if deforestation had taken place, each activity would necessarily contribute, even indirectly, to a conversion of native vegetation to other uses. Thus, during periods of greater deforestation this indirect contribution becomes overestimated. Also, the occupation of deforested areas by any other activity usually occurs in the year following deforestation (MORTON *et al.*, 2006). In this study we assumed that any deforested area would lead to greater areas of agriculture in the following year, even though the occupation of new areas also depends on factors associated with climate and market and not solely on land availability.

The methodology presented here has shown to be an appropriate alternative for measuring the LUC and ILUC. Also, the methodology is very sensitive to the deforestation that occurred during the studied period. According to our findings, activities other than sugarcane bioethanol contribute more intensively to converting land usage. The lower the sugarcane expansion, when compared to deforestation, the greater the expansion impact of one hectare of sugarcane. Likewise, the lower the cropland expansion for a given deforestation, the greater the pasture expansion. Thus, deforestation attributed to cropland is higher.

The sensitivity of the LUC + ILUC to deforestation does not come as a surprise. The rationale behind the allocation methodology assumes that the total deforested area needs to be allocated among productive activities. Considering that some activities represent a net reduction of the total area, but require an area increase in some regions, greater deforestation should always result in a greater effect caused by any activity under expansion.

Comparing the study period with previous years, we observed that deforestation rates in Brazil are falling (NEPSTAD *et al.*, 2009). If the same rate is maintained in the next few years ILUC factors in the future are expected to be lower than the factor estimated here for the 2005–2008 period. Additionally, due to improved yield, for a corresponding growth resulting from an bioethanol demand higher than that observed in 2005–2008, sugarcane bioethanol will require a lesser expanding area. This should result in a lower LUC + ILUC factor.

Our LUC and ILUC estimation methodology and the data we considered to calculate the conversion of native vegetation are available in user-friendly spreadsheetsi, which are available at www.iconebrasil.org.br. Besides being transparent, our study minimizes potential errors resulting from allocation criteria, as the allocation criteria applied here consider the microregions previously established by the IBGE. Therefore, our data for crops and deforestation are less aggregated than those of other studies (FRITSCHE *et al.*, 2010; LAPOLA *et al.*, 2010). This contributes to a greater accuracy in our methodology when compared to others (BAUEN *et al.*, 2010). Additionally, this is the only current deterministic methodology that is focused exclusively on Brazil, thereby avoiding several problems associated with aggregated analysis.

Although we have calculated the LUC and ILUC for sugarcane bioethanol only, the same procedure should be adopted for other activities, as some of them, as shown here, present a LUC + ILUC factor that is higher than that of sugarcane bioethanol. Additional information on the conversion of native vegetation and on crop substitution as shown by satellite imagery could greatly improve the results obtained with the methodology presented here, as estimates for allocation could be more precisely defined instead of being proportionally estimated.

Finally, our methodology may be applied to different periods in order to evaluate the emission factor sensibility resulting from deforestation. Also, the LUC + ILUC factor may be applied in a number of other ways. It may be used in life-cycle analyses that do not take into account Land Use Changes. The ILUC factor may also be used to help develop certification criteria for biofuels. For instance, the ILUC factor may be added to the biofuel production of producers who do not follow pre-established environmental protection measures. This measure may help to ensure that the benefits of reduced greenhouse gas emission thanks to biofuels do not come at the expense of other environmental impacts.

References

ADAMS, D.M. et al. The Forest and agricultural sector optimization model (fasom): model structure and policy applications. Washington, DC. Sep. 1996. PNW-RP-495.

AL-RIFFAI, P.; DIMARANAN, B.; LABORDE, D. Global Trade and Environmental Impact Study of the EU Biofuels Mandate. Final report. IFPRI and ATLASS Consortium. 2010.

ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FLORESTAS PLANTADAS – ABRAF. Anuário Estatístico da ABRAF ano base 2008. Brasília, 2009.

BAUEN, A.; CHUDZIAK, C.; Vad, K.; WATSON, P. A causal descriptive approach to modelling the GHG emissions associated with the indirect land use impacts of biofuels - Final report, A study for the UK Department for Transport. E4Tech. Available in: <http://www.dft.gov.uk/pgr/roads/environment/research/biofuels/pdf/report.pdf>.2010.

FARGIONE, J.; HILL, J.; TILMAN D.; PLASKY, S.; HAWTHORNE, P. Land Clearing and the Biofuel Carbon Debt. Available in: <http://www.sciencexpress.org / 7 / Page 1 / 10.1126/science.1152747>. 2008.

FRITSCHE, U.R.; HENNENBERG, K.; HÜNECKE, K. The "ILUC Factor" as a means to hedge risks of ghg emissions from indirect land use change. Öko-Institut working paper. 2010.

FOOD AND AGRICULTURAL POLICY RESEARCH INSTITUTE – FAPRI. FAPRI Models. Ames: FAPRI-CARD, 2008. Available at: <http://www.fapri.iastate.edu/models/>.Accessed on 2009.

GIBBSA, H.K.; RUESCHB, A.S.; ACHARDC, F.; CLAYTOND, M.K.; HOLMGRENE, P.; RAMANKUTTYF, N.; FOLEYG, J.A. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. PNAS, v.107, n. 38, Sep. 21 de 2010.

GOUVELLO, C. Brazil low carbon country case study. Washington: World Bank, 2010. Available at: <http://siteresources.worldbank.org/BRAZILEXTN/Resources/Brazil_LowcarbonStudy.pdf>

HARRIS, N.; GRIMLAND, S.; BROWN, S. Land use change and emission factors: updates since the rfs proposed rule. report to epa. Winrock International. 2009.

HOLT, M.T. A linear approximate acreage allocation model. Journal of Agricultural and Resource Economics, v. 24, n. 2, 383-397 p. 1999.

JOINT RESEARCH CENTRE OF THE EUROPEAN COMMISSION – JRC. Workshop on Marginal yields and land allocation in ILUC emissions estimates. European Commission - DG Environment. Brussels, 2009.

KEENEY, R.; HERTEL, T.W. The indirect land use impacts of United States biofuel policies: the importance of acreage, yield, and bilateral trade responses. American Journal of Agricultural Economics. v. 91, n. 4, nov 2009, p. 895–909.

LAPOLA, D.; SCHALDACH, R.; ALCAMO, J.; BONDEAU, A.; KOCH, J.; KOELKING, C.; PRIESS, J.A. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Proceeding of the National Academy of Sciences - PNAS. 2010.

MORTON, D.C.; DEFRIES, R.S.; SHIMBUKURO, Y.E.; ANDERSON, L.O.; ARAI, E.; DEL BON ESPIRITO-SANTO, F.; FREITAS, R.; MORISETTE, J. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. Proceeding of the National Academy of Sciences – PNAS, v. 103, n. 39, Sep. 26, 2006. p. 14637–14641.

NASSAR, A.M.; RUDORFF, B.F.T.; ANTONIAZZI, L.B.; AGUIAR, D.A. de; BACCHI, M.R.P.; ADAMI, M. Prospects of the sugarcane expansion in Brazil: impacts on direct and indirect land use changes. In: ZUURBIER; VOOREN (coord.), Sugarcane ethanol: contributions to climate change mitigation and the environment. Wageningen: Wageningen Academic Publishers, 2008.

NASSAR, A.M.; HARFUCH. L.; MOREIRA, M.R.; BACHION, L.; ANTONIAZZI L.B. Impacts on land use and ghg emissions from a shock on Brazilian sugarcane ethanol exports to the United States using the Brazilian land use model (blum). Report to the U.S. Environmental Protection Agency Regarding the proposed changes to the Renewable Fuel Standard Program. Docket EPA-HQ-OAR-2005-0161. 2009

NEPSTAD, D.; SOARES-FILHO, B.S.; FRANK MERRY LIMA, A.; MOUTINHO, P.; CARTER, J.; BOWMAN, M.; CATTANEO, A.; RODRIGUES, H.; SCHWARTZMAN, S.; MCGRATH, D.G; STICKLER, C.M.; LUBOWSKI, R.; PIRIS-CABEZAS, P.; ALENCAR, A.; ALMEIDA, O.; STELLA, O. The End of deforestation in the Brazilian Amazon. Science v. 326, p. 1350-1351. 2009.

PLEVIN, R.J.; GIBBS, H.K.; DUFFY, J.; YUI, S.; YEH, S. Agro-ecological zone emission factor model. Available at: <http://www.arb.ca.gov/fuels/lcfs/09142011_aez_ef_model_v15.pdf>. Access on: 2011.

SEARCHINGER, T.; HEIMLICH, R.; HOUGHTON R.A.; DONG, F.; ELOBEID, A.; FABIOSA J. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science v. 319, p. 1238–1240. 2008.

SPAROVEK, G.; BARRETO, A.; KLUG, I.; PAPP, L.; LINO, J. A revisão do código florestal brasileiro. Novos Estudos, v. 89, Mar 2011, p. 181-205.

TIPPER, R.; HUTCHISON, C.; BRANDER, M. A practical approach for policies to address ghg emissions from indirect land use change associated with biofuels. Technical Paper by ecometrica and Greenergy. 2009.

UNIÃO DA INDÚSTRIA DA CANA-DE-AÇÚCAR – UNICA. UNICA comments on California's low carbon fuel standard. Available at: <http://www.unica.com.br>. Access on: 2009.

____. Comments on developments in land - use change analysis (LUC) for the low carbon fuel standard (LCFS). Available at: <http://sugarcane.org/resource-library/unica-materials/UNICA%20comments%20to%20CARB%2020111005.pdf>. Access on: 2011.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY - US-EPA. Draft regulatory impact analysis: changes to renewable fuel standard program. EPA-420-D-09-001. May 2009.

VELDKAMP, A.; VERBURG P.H. Modeling land use change and environmental impact. Journal of Environmental Management v. 72, Apr 2004. p. 1–3.

Part IV

Indicators and certification issues

Chapter 10

Evolution of environmental, social and economic indicators

André Tosi Furtado
Terezinha de Fátima Cardoso
Marcelo Pereira da Cunha

The technological, economic, social and environmental indicators can help specialist and public actors to analyze the bioethanol production process more broadly and indicate the best attitudes and decisions to put into action for sustainable development.

Technological indicators

For over 30 years the growth of sugarcane cultivated land in Brazil was impressive. Between 1975 and 2008 expansion of cultivated land with sugarcane increased 4.3 times while harvested land improved 4.7 times.

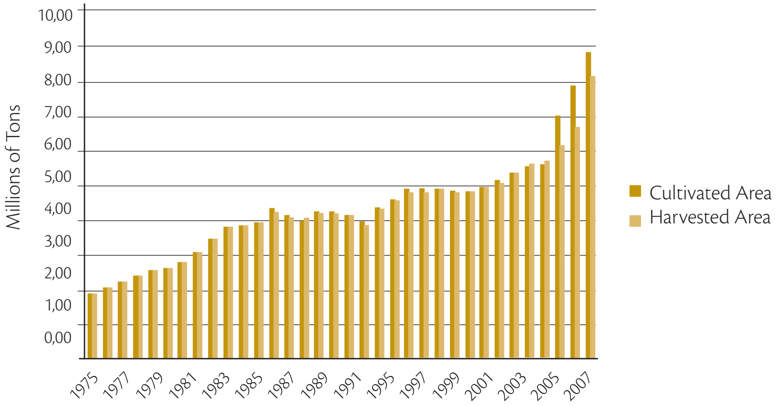


Figure 1. Evolution of sugarcane area in Brazil

Source: Agroenergy Statistical Annuary – Ministry of Agriculture (2009), IBGE data

The production of sugarcane had an expansion of 7.3 times in this period (Figure 2), due to an increase of 65% in land productivity (Figure 3).

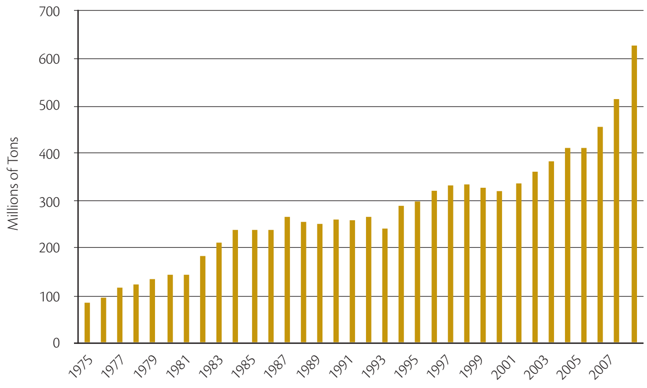


Figure 2. Brazil sugarcane production

source: Agroenergy Statistical Annuary – Ministry of Agriculture (2009), IBGE data

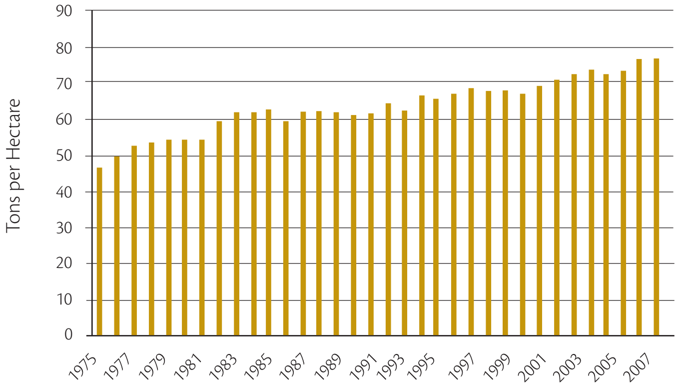


Figure 3. Sugarcane land productivity in Brazil

Source: Agroenergy Statistical Annuary – Ministry of Agriculture (2009), IBGE data

The CTC (Sugarcane Technology Centre) is a private civil association, without profit purpose, directed towards the technological development of sugarcane culture, sugar, bioethanol and bioenergy, acting in the sugarcane value chain from agriculture to industrial process. Numerous entities are associated with CTC (sugar mills, distilleries, energy companies, sugar planters associations) in the state of Alagoas, Pernambuco, Minas Gerais, São Paulo, Mato Grosso, Mato Grosso do Sul, Goiás, Espirito Santo and Paraná.

Taking into account the evolution of sugarcane productivity in the last 35 years, it is possible to see that new technologies applied in sugarcane production were responsible for 6.4 million hectares of land saving in 2010 compared with 1975 (Figure 4).

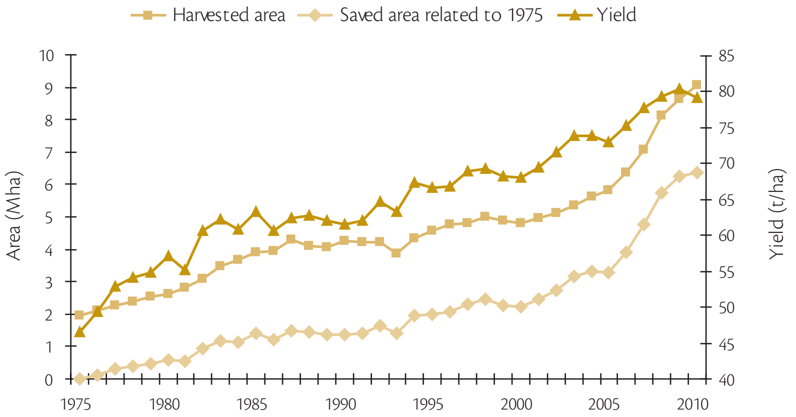


Figure 4. Saved area by technological progress in sugarcane

Social indicators

Aggregate social indicators by territorial unity

There is a whole set of socio-economic indicators that help to capture the impact of sugarcane production and related industrial processes in the sustainability of Brazilian regions. These indicators are used to calculate the Municipal Human Development Index published by the UNDP (United Nation Development Program). The great advantage of these indicators is due to their Municipal coverage. However, these figures are only published every decade, based on the Brazilian Demographic Census of IBGE (Brazilian Statistic and Geographic Institute).

We have only selected seven sources from a large number of UNDP indicators that could be useful to measure the level of socioeconomic wellbeing in a territorial unity. These indicators are listed below.

Table 1 – Socioeconomic Indicators

Category	Indicator
Education	1) Percentage of illiterate among of 15 or more years population
	2) Percentage higher education students among 18 to 24 years population
Income	3) Per capita Income
	4) Gini Index
Social	5) Poverty Intensity
	6) Mortality until 5 year old population
Synthetic	7) Municipal Human Development Index

Source: UNDP, Human Development Atlas

The indicators 1, 2, 5 and 6 are less influenced by small improvements in the life conditions of poor people in middle income countries like Brazil. They better represent the life conditions of low income people. An improvement in these indicators reveals a substantial evolution of the living conditions of this population. In the case of educational indicators, the reduction of the percentage of adult illiteracy is even more difficult to obtain. The same can be said about the population with access to higher education, which is very low in Brazil, but is worth even more in rural and peripherical municipalities. For the social indicators, the poverty index measures the share of the population without access to all the basic needs, not only food. The five years mortality index is a broader indicator than the usual infant mortality index, which is restricted to less than a one year representation in the population. The others two indicators, the Gini Index and the Human Development Index synthesize a whole set of elements. The first concerning income distribution and the other concerning the human development of a population.

Above is an example of these indicators for the Municipalities of the Ribeirão Preto Micro-region[1] between 1991 and 2000[2], which was until that date the main sugarcane productive micro-region of the state of São Paulo. The analysis of these figures is extremely informative about the kind of development that is happening in these Municipalities, where the sugarcane production and process is very concentrated. In the first instance we notice a strong improvement in the socio-educational and income indicators in most of the Municipalities, the most basic being a reduction in illiteracy

---

[1] Micro-region is an intermediary geographical scale between the State and the Municipality used by IBGE, generally polarized by a main city, like in this case Ribeirão Preto.

[2] The more recent figures of the 2010 Demographic Census are not yet available.

and infant mortality. The most advanced being an increase in higher education enrolment. The income level improved in most of the Municipalities, although in two of them it decreased. This reflected positively in the evolution of HDI throughout the decade.

However, two elements weight against this generally positive diagnostic. On one hand the increase of the Gini Index in 9 of the 16 Municipalities of Ribeirão Preto the Micro-region. This index measures the income distribution of the resident population. The increase in income inequality wasn't only evident in the rise of the Gini Index but can also be recognized through the increase of the gap between the average incomes of the Municipalities.

On the other hand, we can observe an increase of the level of the poverty index in most these Municipalities. This evolution can be related to the macroeconomic behavior of the Brazilian economy. During the latter part of the 1990's there was a general decrease in the workers revenues. This evolution is certainly very worrying, as the basic need indicator measures longevity, the educational level and the minimum income necessary to satisfy basic needs of the population.

A very similar evolution happened in other important Municipalities of the State of São Paulo, where sugarcane is responsible for an important share of agriculture production. It signifies that a systematic follow-up on the agricultural and industrial outcomes (at micro-regional and municipal level) of this economic activity is needed, to inform social and economic policies that are searching to mitigate undesirable income concentration effects.

Table 2 – Human development indicators of Municipalities from the micro-region of Ribeirão Preto

Municipality	Percentage of illerate among of 15 or more years population, 1991	Percentage of illerate among of 15 or more years population, 2000	Percentage of higher education students among 18 to 24 years population, 1991	Percentage higher ecucation students among 18 to 24 years population, 2000	Per capita income, 1991	Per capita income, 2000	Gini Index, 1991	Gini Index, 2000	Poverty Intensity, 1991	Poverty Intensity, 2000	Mortality until 5 years old population, 1991	Mortality until 5 years old population, 2000	Municipal human development Index, 1991	Municipal Human development Index, 2000
Barrinha (SP)	18,4	12,24	1,63	2,08	232,91	216,39	0,43	0,47	26,56	44,57	23,95	17,36	0,725	0,766
Brodósqui (SP)	12,09	7,6	4,79	7,93	274,37	315,9	0,45	0,43	26,59	34,16	26,25	13,49	0,753	0,805
Cravinhos (SP)	13,34	9,05	5,98	8,17	319,13	351,42	0,55	0,51	26,76	38,62	26,08	12,08	0,755	0,815
Dumont (SP)	14,81	9,56	2,1	3,97	316,99	332,75	0,47	0,49	32,79	39,51	26,25	15,19	0,752	0,802
Guatapará (SP)	15,34	12,48	3,88	1,76	318,87	234,81	0,53	0,51	36	28,83	26,16	15,46	0,752	0,776
Jardinópolis (SP)	12,63	7,58	5,11	6,34	278,03	323,88	0,51	0,51	32,01	34,54	26,25	13,64	0,747	0,808
Luís Anotônio (SP)	10,45	8,58	0,65	2,02	223,93	286,33	0,43	0,52	36,68	45,63	37,85	17,36	0,717	0,795
Pontal (SP)	18,01	12,32	3,38	2,28	249,63	355	0,45	0,63	37,37	40,24	24,51	17,36	0,732	0,792
Pradópolis (SP)	15,62	11,5	2,03	5,1	277,43	280,04	0,42	0,44	33,51	42,53	18,22	13,64	0,765	0,798
Ribeirão Preto (SP)	6,64	4,44	10,74	16,5	465,2	539,84	0,53	0,56	36,56	46,67	18,22	11,99	0,822	0,855
Santa Rita do Passa Quatro (SP)	14,56	8,43	6,65	13,01	259,36	471,37	0,48	0,57	33,07	36,29	19,44	11,99	0,764	0,832
Santa Rosa de Vierbo (SP)	10,39	7,31	6,11	6,6	267,13	298	0,48	0,54	32,27	37,8	24,47	15,87	0,762	0,804
São Simão (SP)	10,3	6,38	5,61	6,39	287,24	312,81	0,55	0,53	35,55	41,35	26,16	17,36	0,764	0,801
Serra Azul (SP)	18,88	12,85	0,35	1,45	201,69	214,25	0,41	0,49	30,9	36,24	38,03	25,39	0,691	0,742
Serrana (SP)	13,88	9,19	0,01	3,06	256,23	237,34	0,44	0,45	32,52	38,67	26,16	17,36	0,75	0,775
Sertãozinho (SP)	11,77	8,39	5,29	11,77	339,68	397,11	0,51	0,52	29,43	40,56	21,85	11,99	0,776	0,833

Source: UNDP, Human Development Atlas

Level and employment qualification indicators

The implementation of mechanization, mainly on the sugarcane harvesting, enables an increase of production using a smaller number of workers involved in activities of sugarcane production in the agricultural sector, as shown in Figure 5. Despite the increase in production in recent years, it turns out that the number of employees has been tending to fall During the last 30 years the production of sugarcane has more than doubled but the number of employees remain almost the same as 1981 as shown in Figure 5.

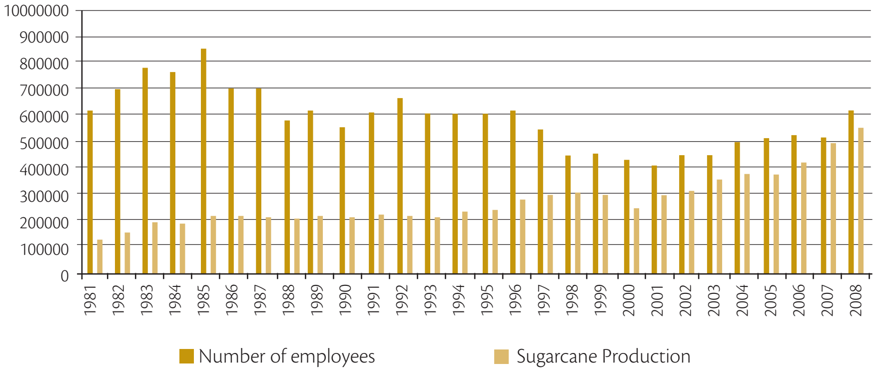


Figure 5. Evolution of the number of employees and sugarcane production.

Source: Prepared by Moraes (2011) from PNAD (several years)

From this data, it verifies that the productivity per worker in 1985, which was 260 tons per harvest, rose to nearly 920 tons in 2008. This expressive increase (250%) of worker productivity per harvest is due the implementation of mechanization and also of other technologies such as new sugarcane varieties and fertilizers.

The data used by Moraes (2007, 2009, 2011), were obtained from the National Research by Household Sampling (PNAD), over several years, CD ROM, considering the number of employees (formal) but not workers (informal) of the sugarcane activity/production (activity code 01105). It is highlighted on Moraes´s work (2007) that PNAD provides an overview of formal and informal occupations and has a sampling character, allowing expansion of the results for all areas of the country, in development since 1967. Other data sources used by Moraes (2007, 2009, 2011) were the Brazilian Institute of Geography and Statistics - IBGE for many years, and the Administrative Records of the Ministry of Labour and Employment (RAIS) - Ministry of Labour.

RAIS has information of socio-demographic and professional characters and can be aggregated / disaggregated along the time (1986-2000) spatial (national, regional, state, local) and economic axis, legal nature of employers, establishments and establishments sizes, using classes 01139 (sugarcane cultivation), 15610 (sugar mills), 15628 (refining and milling of sugar) and 23400 (alcohol production), as note Moraes (2007).

The evolution of mechanical harvesting is well observed in center-south region, mainly in São Paulo state, where the Agro-Environmental Protocol firmed by the mills anticipates the end of burning sugarcane crop.

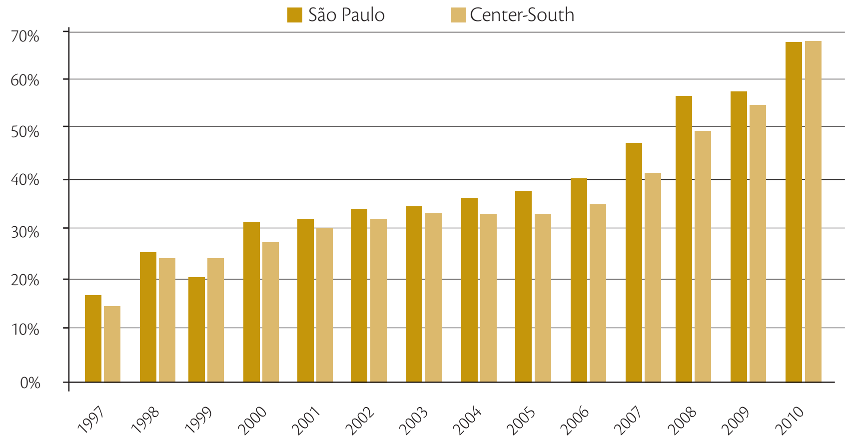


Figure 6. Evolution of mechanical harvesting.

Source: CTC (2008, 2011).

The rate of mechanization on the northeast region is still quite small due to limitations of the existing machines to operate on steep slopes (those of over 12%).

The age of workers is concentrated between 20 and 50 years with mechanization, with greater emphasis on the range from 20 to 30 years. This increase in the age group also indicates a reduction of child labor (OLIVEIRA, 2009).

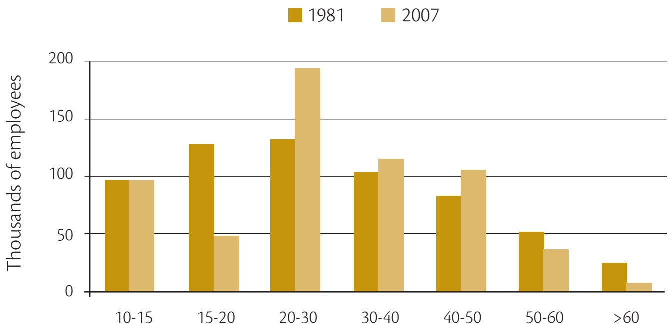


Figure 7. Number of employees by age group in sugarcane.

Source: Adapted of Moraes (2009) prepared from PNAD (several years).

With the introduction of technology the educational level required of workers is higher, which therefore results in an increase in the number of schooling years involved in cultivation of sugarcane, as shown in Figure 8.

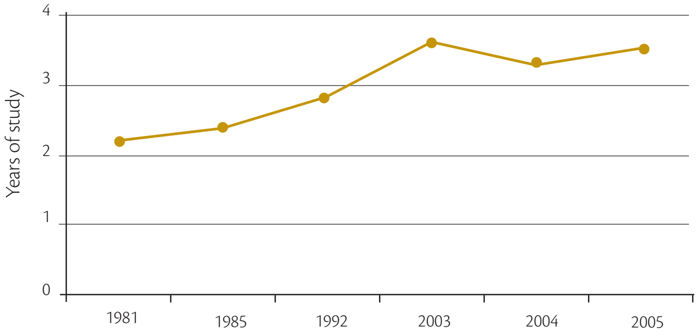


Figure 8. Evolution on the years of study of sugarcane workers in Brazil.

Source: Adapted of Moraes (2007) prepared from PNAD (several years).

In the period from 1992 to 2007, Figure 9 shows a significant increase in the number of qualified employees in the sugarcane industry. Oliveira (2009) analyzed two groups: unskilled (day-workers, lanyard, laborer and general worker) and skilled (supervisor, administrator, tractorist, technicians and other functions).

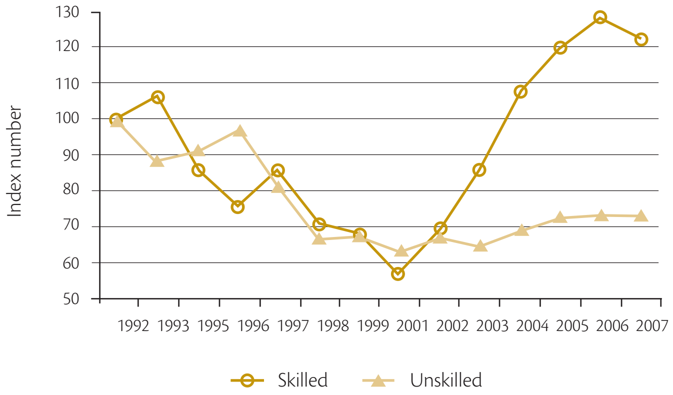


Figure 9. Employees in the sugarcane industry according to their skills, Brazil.

Source: IBGE (1992-2007) cited Oliveira (2009).

People who are employed in the mechanized production of sugarcane (machine operators) and those with skills have higher pay than those who have no skills, as shown in Figure 10.

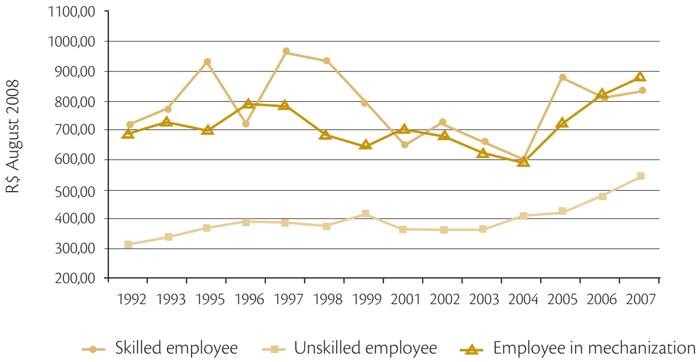


Figure 10. Average earnings of people employed in sugarcane by occupation, Brazil.

Source: IBGE (1992-2007) cited by Oliveira (2009).

It appears that over the years the industry has demanded more highly educated workers and, in counterpart, has been offering better working conditions. The rate of registered workers (formal) shows a significant increase.

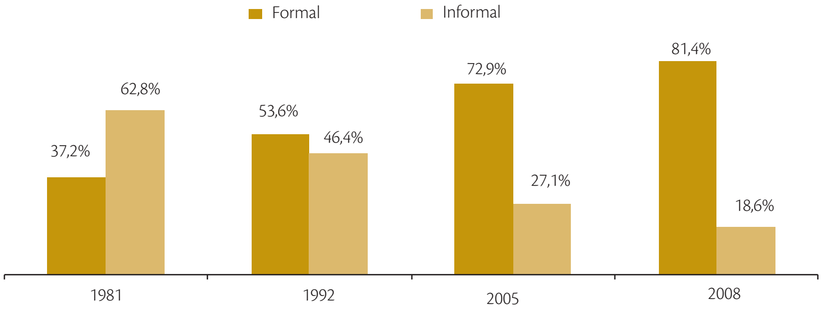


Figure 11. Evolution of the sugarcane job formalization in Brazil.

Source: Adapted from Moraes (2007, 2010) prepared from PNAD (several years).

When analyzing the state of São Paulo, the rate of formal workers is even more significant, as shown in Figure 12.

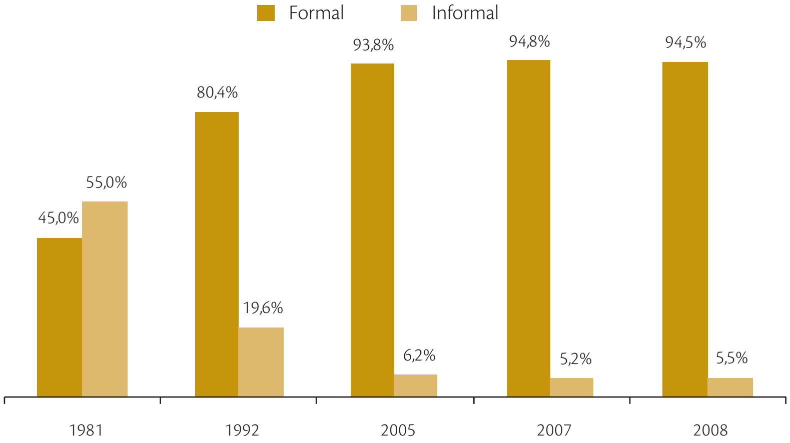


Figure 12. Evolution of the sugarcane job formalization in the state of São Paulo, Brazil.

Source: Adapted from Moraes (2007, 2009) prepared from PNAD (several years).

Environmental indicators

In mechanical harvesting chopped cane is harvested, which disables the water sugarcane washing, since the loss of sugar would be much higher in a process like this. Although, dry sugarcane washing presents a decrease on the water consumption, as shown on Figures 13 e 14, such a fact has been increasing the mineral impurities on the sugarcane feedstock.

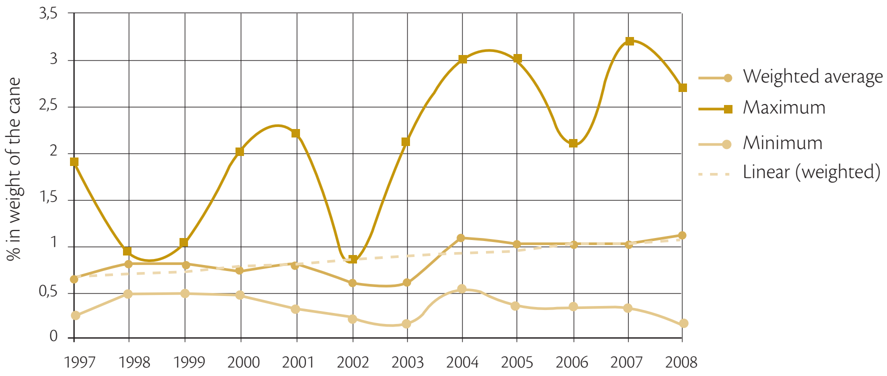


Figure 13. Mineral impurities in the sugarcane – feedstock.

Source: Elia Neto (Mutual Industrial Control - South Central - annual 2008/2009,CTC).

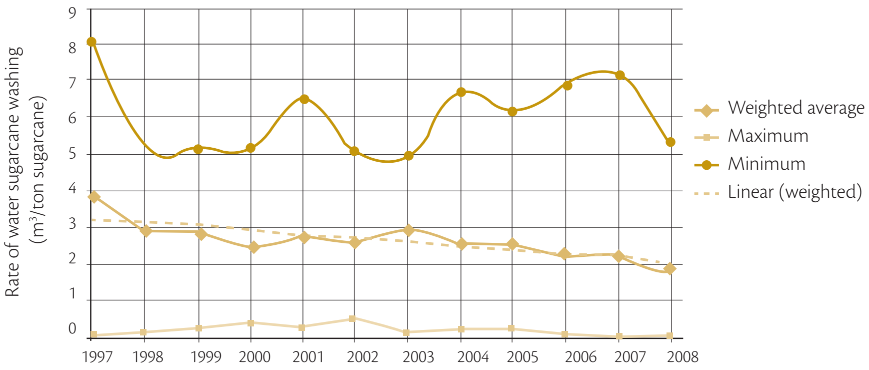


Figure 14. Rate of water sugarcane washing – reception and preparation.

Source: Elia Neto -(Mutual Industrial Control - South Central - annual 2008/2009, CTC).

In recent years there has been a rationalization of water consumption and greater concern for water reuse, making a possible water catchment of 1m ^{3} per ton of produced sugarcane on average in the medium term (ELIA NETO, 2005).

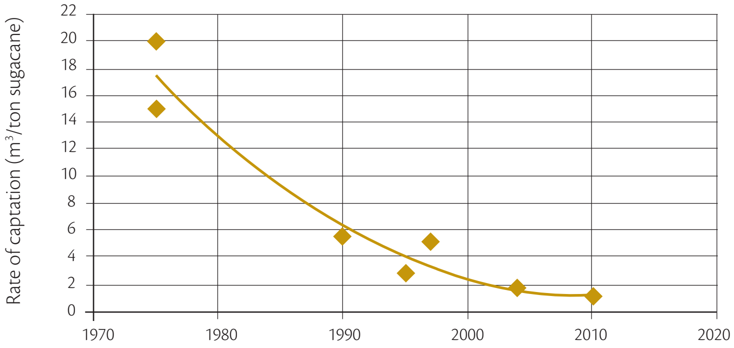


Figure 15. Trend rate curve of water catchment in industry.

Fonte: Elia Neto - CTC (2009).

Sustainability indicators synthesis

As a final result of this chapter we present a set of indicators that can be important to follow the sustainability of biofuels agroindustry in several dimensions. These indicators are classified by their geographical coverage Brazil, States, Micro-regions, Municipalities, plant scale.

Name	Formula	Information Sources	Territorial Unity
Energy Intensity Impact Ratio	Economic Direct and Indirect PIB/MJ de Bioethanol	Input-Output IBGE Matrix and Energy Balance	Brazil
Social Impact Ratio	Direct and Indirect Employment /MJ of Bioethanol	Input-Output IBGE Matrix and Energy Balance	Brazil
Net Energy Ratio	MJ of Bioethanol/(MJ Bioethanol + Direct and Indirect Costs)	Input-Output IBGE Matrix and Energy Balance	Brazil
Energy Cost Ratio	Energy Direct and Indirect Costs /MJ of Bioethanol	Input-Output IBGE Matrix and Energy Balance	Brazil
Renewable Degree Ratio	Renewable Energy Costs/ Direct and Indirect Energy Costs	Input-Output IBGE Matrix and Energy Balance	Brazil
Fossil Energy Costs Ratio	Fossil Direct and Indirect Energy Costs /Bioethanol	Input-Output IBGE Matrix and Energy Balance	Brazil

Name	Formula	Information Sources	Territorial Unity
CO2 Emissions Ratio	CO2 Direct and Indirect/MJ Bioethanol	Input-Output IBGE Matrix and Energy Balance	Brazil
Sugarcane Land Occupation Ratio	Sugarcane cultivated Area/ Temporary Crops Cultivated Area	PAM-IBGE	Brazil States Micro-regions Municipalities
Sugarcane Land Ratio	Sugarcane cultivated Area/ Total farm area	PAM-IBGE Agriculture Census IBGE	Brazil States Micro-regions Municipalities
Land Substitution Ratio	Change of Sugarcane Area / Change of Agriculture	PAM-IBGE Agriculture Census IBGE	Brazil States Micro-regions Municipalities
Sugarcane Production Cost	Operational and Capital Costs/Total Production Value	Farms or Consecana	São Paulo
Bioethanol Production Cost	Operational and Total Costs/ Total Production Value	Mills or Cepea	
Agriculture Productivity	Tsc/cultivated hectare	PAM-IBGE MAPA	Municipality Micro-Region Estado Brazil
Sugarcane sugar rate	ATR/Tsc	Statistical Yearbook MAPA	Mill Estado Brazil
Rate of Mechanized Harvest	Mechanized Crop Area / Total Area	UNICA	São Paulo
Sugarcane Impurities	Impurities Weight/Sugarcane Weight	CTC	Mills/São Paulo
Washing Water Rate	M3 of washing water/tons of sugarcane at the mill	CTC	Mills/São Paulo
Water Capture Rate	M3 of captures water/tons of sugarcane at the mill	CTC	Mills/São Paulo
Sugarcane Energy Content in field	Sugarcane Energy content before harvest (sugar juice + bagasse + straw)	To be done	Mills/Estado/ Brazil
Sugarcane energy content at the Mill	Sugarcane Energy content (sugar juice + bagasse+ recuperated straw)	To be done	Mills/Estado/ Brazil
Total Energy Cost	Total sugarcane used in industrial process/sugarcane energy content	To be done	Mills/Estado/ Brazil

Name	Formula	Information Sources	Territorial Unity
Sugarcane Energy Cost	Energy Cost by unity of bioethanol, sugar, export electricity	To be done	Mills/Estado/ Brazil
Employment Level	No of Workers	PNAD	Brazil
Scholarship Level	No of Workers by scholarship years	PNAD	Brazil
Workers Level of Income	No of Workers by income level	PNAD	Brazil
Adult Illiteracy Rate	Illiteracy Percentage with 15 years or more	Human Development Atlas	Brazil States Micro-regions Municipalities
Higher Education Enrolment rate	Percentage of 18 to 24 years enrolled in Higher Education	Human Development Atlas	Brazil States Micro-regions Municipalities
Infant Mortality	Deaths under 5 year/ Population under 5 years	Human Development Atlas	Brazil States Micro-regions Municipalities
Per Capita Income	Income/Number of inhabitants	Human Development Atlas	Brazil States Micro-regions Municipalities
Gini Index	Distribution of income by the population	Human Development Atlas	Brazil States Micro-regions Municipalities
Poverty Index	Percentage of Population living under poverty level	Human Development Atlas	Brazil States Micro-regions Municipalities
HDI	Synthetic Indicator (life expectancy at birth, adult illiteracy, Gross Literacy rate, Per Capita Income)	Human Development Atlas	Brazil States Micro-regions Municipalities

Chapter 11

Certification for sugarcane production processes

Camila Ortolan F. de Oliveira
Arnaldo Walter

Introduction

Sustainability has been recognized as an essential aspect of the consolidation of biofuels in the international markets. The discussion about sustainability has become even more important as biofuels production has grown and, in particular, gained momentum during and after the food crisis of 2007-2008.

So far, the main driving forces have come from specific actions in the European Union (EU) and in the United States. In the US, due to initiatives in California[1] and at the Federal level[2], the focus has been exclusively on avoiding GHG emissions with regards to fossil fuels, while the EU Renewable Energy Directive (RED) also addresses potential impacts on biodiversity, on water resources and on food supply, as well as main social aspects (e.g. the respect of human, labour and land use rights).

These sustainability initiatives, and mainly the European one, have motivated the proposition and development of certification schemes, since the accomplishment of sustainability principles and criteria shall be certified by independent auditors.

Certification is an independent seal that shows that a product, system or service reaches a certain standard. Certification has become an important tool for governments and companies to show their sustainability performance. There are certification schemes for almost every product and service, and here it is worth mentioning existing certification schemes for forest products (e.g.

---

[1] Regulation was defined by the California Air Resources Board – CARB, in the context of the Low Carbon Fuel Standard (LCFS) program.

[2] Regulation defined by the Environmental Protection Agency – EPA, under the revised Renewable Fuel Standard (RFS) program.

FSC and PEFC), food (e.g. GlobalGAP), agriculture products (RSPO for soy, and BONSUCRO for sugarcane), energy (e.g., for pellets, Laborelec and GGL) and fair trade (e.g. FairTrade)[3] (NL Agency, 2011). These schemes include sustainability criteria that could be adapted for bioenergy and biofuels certification and provide a useful experience for the development of a biofuels certification scheme, or for benchmarking (VAN DAM *et al*., 2010).

This chapter presents an overview of sustainability initiatives and certification schemes applied to bioenergy. The text is divided into seven sections, besides this introduction. The following section is devoted to assessing certification schemes and the third section deals with sustainability of bioenergy. The fourth addresses the main (currently available and ongoing) sustainability initiatives and certification schemes for bioenergy. The fifth section is devoted to summarising the recent tendencies of certification of sugarcane supply chains in Brazil. The sixth section addresses the challenges of fulfilling certification schemes, mainly considering developing and new producer countries. Finally, the final remarks are presented.

What is certification about?

Biofuels have been presented as one of the most important alternatives for reducing GHG emissions in the transport sector. However, due to different reasons[4], biofuels production has been blamed for negatively impacting food supply, for the destruction of forests and biodiversity, for high water consumption, for inadequate working conditions and so forth. In addition there are still doubts regarding the benefits of biofuels concerning the reduction of GHG emissions.

Certification schemes have been developed to assure conformity regarding sustainability principles and criteria imposed by some countries,. In principle, certification aims at avoiding undesirable production conditions, and is also an instrument for reducing risks for some stakeholders (e.g., traders, distributors). In some countries, depending on the level of consciousness, consumers could claim certification to be sure about the products they buy.

---

[3] FSC – Forest Stewardiship Council; PEFC – Programme for the Endorsement of Forest Certification; RSPO – Roundtable on Sustainable Palm Oil; GGL – Green Gold Label.

[4] Biofuels and biofuels production are greatly heterogeneous, and it's easy to find bad examples/cases. General sense, bad examples give support to so many criticisms. On the other hand, the spectrum of interests on biofuel business is also very heterogeneous (e.g. besides reduction of GHG emissions, driving forces for biofuels production include enhancing the security of energy supply, supporting local agriculture, developing new technologies, etc.) and the debate regarding sustainability reflects these positions. Finally, the discussion is in a large extent emotional, the issue is new and the scientific knowledge is not consolidated.

In this sense, biofuels certification is not an aim in itself, but rather the consequence of imposed sustainability initiatives. Besides, certification is a market instrument that can only be applied on a voluntary basis and this would only be required by markets that would impose specific sustainability principles/criteria. Certification schemes are also understood as being complementary tools to policies that would foster sustainable production of bioenergy.

Table 1 presents a view based on van Dam et al. (2008) of the interests of different stakeholder groups regarding certification of biomass.

It is worth noting that until recently such sustainability initiatives were also accused of being strategies to impose trade barriers, shielding the production in regions where competitiveness is constrained. However, sustainability requirements are a clear tendency and most economic operators have no doubt that they are necessary to fulfil their principles and criteria. The question is to what extent certification schemes are able to effectively promote sustainable production.

Table 1 - Interests of different stakeholders for biomass certification

Stakeholders	Interests for biomass certification
National governments and transnational organizations	Instruments to promote sustainable managements and sustainable consumption patterns;
Provides information for policy makers.	
Intergovernmental organizations (e.g. UN, FAO, UNEP)	Reference for negotiations between all kinds of stakeholders.
Producers, traders and users	Instruments for environmental marketing, risk management and market access;
Instruments for controlling origin and quality of feedstocks;	
Instruments to differentiate products.	
NGOs	Provides information on the impact of products;
Instruments to promote sustainable management;	
Instruments to disseminate information and to educate the consumer market.	
International bodies	Instruments to promote sustainable management;
Information for policy consultation.	
Certification bodies	Business opportunity.

Source: based on van Dam et al. (2008)

Figure 1 is a schematic representation of the driving forces and the possible impacts of certification schemes. The legitimacy of such processes would be based on sustainability requirements imposed due to genuine concerns regarding social, environmental and economic aspects of bioenergy production and its use. In this sense, certification schemes should be created and applied while aiming at assuring sustainable production, at reasonable costs, indentifying the responsibilities of the economic operator and promoting trade. As will be analysed in section "The challenge for fulfilling sustainability criteria" (ahead), constrained bioenergy production in certain countries, and consequently reduced trade opportunities, could be detrimental effects of certification schemes due to different reasons.

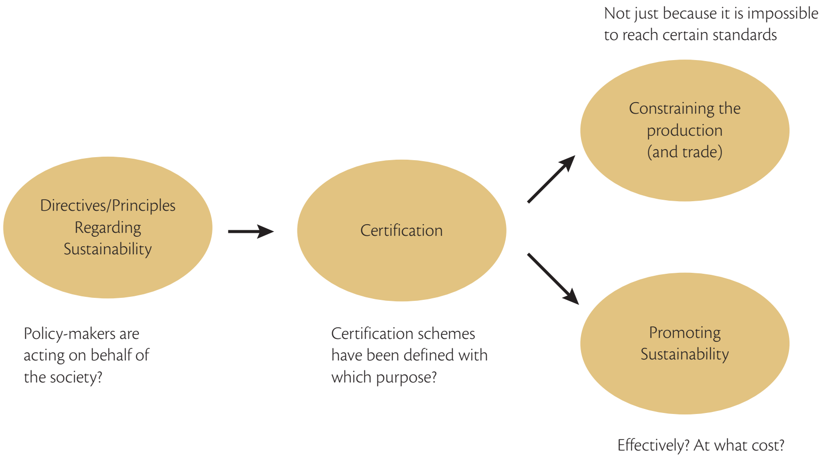


Figure 1. Driving forces and possible consequences of bioenergy certification

Sustainability of bioenergy

Sustainability has a wide meaning and its definition is not an easy task. Sustainability and sustainable production are expressions that have aimed at characterizing the adequacy of human activities and production systems to a certain number of relevant aspects, taking into account their social, economic and environmental dimensions.

As a normative concept[5], i.e. a concept that is related to values, perceptions and wishes[6], there are different visions about sustainability and, as a consequence, about what should be made relevant in order to characterize sustainable production. In the case of bioenergy in particular, there is no clear consensus about the basic principles but rather a set of most often mentioned aspects that should be considered, and principles that should be stated (RSB, 2008).

It is a commonly understood that a sustainable activity must be founded on three pillars, corresponding to the three dimensions of sustainability: it must be economic feasible, socially desirable, and ecologically sustainable[7] (UNITED NATIONS, 2005).

As far as biofuels are concerned, economic sustainability corresponds to two complementary aspects: feasibility vis-à-vis the fossil fuel displaced (i.e. gasoline and diesel), and the cost-effectiveness of biofuels as an alternative for GHG mitigation. Feasibility implies that biofuels should be competitive in the medium term regarding fossil fuels, without adoption of continuous subsidies; this is an important advantage of bioethanol produced from sugarcane in Brazil, as it is, so far, the only biofuel economically viable vis-à-vis fossil fuels as long as international oil prices are higher than 45-50 US$/barrel[8]. The second part of the statement implies that the costs of avoided emissions – for instance, expressed in units of $\$/tCO_2$ avoided – would be low compared to other mitigation options; here there is also an important advantage of bioethanol from sugarcane produced in Brazil, firstly because of its low production costs regarding gasoline, and secondly because of the significant amount of avoided emissions, taking into account the full life cycle of bioethanol and gasoline (IEA, 2004). As long as both facts are widely accepted, there is no doubt as to the economic sustainability of bioethanol from sugarcane produced in Brazil, but this is not the case of bioethanol produced from corn and wheat, for example, as well as biodiesel produced from oil seeds.

As long as the social dimension is concerned, the main aim is the improvement of the standard of life of the segments directly involved with the production of biofuels (e.g., RSB, 2008). The aspects

---

[5] A normative concept is a prescriptive condition that evokes values. It can be understood that a normative concept is an affirmation of the ways things ought be in the world (Penn State, 2012).

[6] Normative approaches combine evaluations derived from ethical foundations and prescriptions for their implementation (Renn et al. 2007)

[7] However, for some authors sustainability has a fourth dimension, which is the preservation of cultural values: an activity must be culturally appropriate for being considered sustainable.

[8] Supposing bioethanol production costs between 590 and 660 R$/m3, that the equivalent ratio is 1 litre of bioethanol = 0.85 litre of gasoline, exchange ratio 1 US$ = 2.2 R$, and that the cost of one barrel of gasoline is 12% higher than the price of one barrel of crude.

that have been considered as important are working conditions, upholding human rights, labour rights, land use rights and access to natural resources.

A second important issue is the potential risks of bioenergy production to food supply, due to competition for land and water and to the rising prices of feedstocks. Indeed, this is one of the main reasons for the efforts of developing the technological routes of biofuels production from lignocellulosic materials (the second generation of biofuels). In 2007 and 2008, the growth of biofuels production was attributed as being the main cause of higher food prices, and concerns still exist even after the final conclusion that a greater production of biofuels was only one of the factors that impacted food supply at that time.

Conversely, a large number of environmental aspects have been considered relevant, and these are more closely related to the agricultural side of the supply chain than to the industrial conversion and to the end-use stage. A frequent concern is related to the hypothesis that biofuels production could cause deforestation, with either direct or indirect impacts. For instance, for some years the growth of palm oil production in Malaysia and Indonesia has been related to deforestation (in this case, a detrimental direct impact of Land Use Change) (FRIENDS OF EARTH, 2005; WWF, 2002). In addition, there are concerns that biofuels production could cause indirect impacts on natural vegetation: a hypothesis frequently raised is that the expansion of sugarcane in the Southeast region of Brazil could induce deforestation in the Amazon region.

Indirect effects are a controversial aspect of sustainability initiatives and certification schemes. Firstly, the knowledge available on this issue is not yet consolidated and the results of the economic models used for this purpose vary a lot. Secondly, it has been generally accepted that the economic operator, which is the focus of a certification process, cannot be blamed for effects (indirect) that are outside of his/her control. However, in US the sustainability initiatives (CARB and EPA; see section 13.4) included indirect effects within the methodologies for evaluating greenhouse gas (GHG) emissions, while in Europe this issue is still under discussion.

Aimed at minimizing direct impacts, a basic principle is that biomass production should not jeopardize sensible biomes and areas of high conservation value (HCV) (RSB, 2008), and should not occur in areas of high carbon stocks (e.g., tropical forests), wetlands and areas of high biodiversity (EUROPEAN PARLIAMENT, 2008)[9].

The most common principle regarding sustainability of biofuels is the required reduction of GHG emissions, taking into account the displaced fossil fuel and, in this respect, certain thresholds have

---

[9] The EU-RED defines areas where biomass production cannot occur – the so-called "no-go areas".

been defined. In the EU-RED, considering the direct impacts of Land Use Change, the current threshold is 35% minimum reduction of GHG emissions vis-à-vis gasoline or diesel (since 2010) but the target will be 50% from 2017 onwards (60% in the case of new producing units).

Other environmental aspects frequently dealt with by the sustainability initiatives are related to minimizing the impacts on water resources and biodiversity, and keeping air quality and soil properties. The criteria are, for instance, related to the minimum use of fertilizers, non-contamination of water bodies, the adoption of practices that minimize soil erosion, etc.

Sustainability initiatives and certification schemes

There are several sustainability initiatives and certification schemes related to bioenergy in general, or specifically to biofuels. These initiatives can be classified as multinational (e.g. the EU-RED), national (e.g. the RFS and LCFS, in the US, and the RTFO – Renewable Transport Fuel Obligation, in the UK[10]), supranational (e.g. the GBEP – Global Bioenergy Partnership), from multi stakeholders (e.g. the RSB – Roundtable on Sustainable Biofuels and the ISO – International Standardization Organization) and from organizations of producers and/or consumers.

The leading initiatives are the EU-RED and those from US; the EU-RED being wider in scope. In 2009 the EU introduced binding sustainability criteria for biofuels and bioliquids under the Renewable Energy Directive and the Fuel Quality Directive. These criteria apply to biofuels produced in the EU or imported to the EU. Economic operators can use recognised voluntary schemes to show compliance with some or all sustainability criteria (NL AGENCY, 2011).

The US RFS has a different approach, as it requires that renewable fuels emit fewer GHG than the petroleum fuel being replaced. RFS sets restrictions on the type of feedstock and on the land used to grow the feedstock. US producers have reporting obligations based on default values for each feedstock, while for production outside the US reporting requirements are necessary to show compliance. The CARB legislation is also based upon reporting requirements using default carbon intensity values per type of biofuel. The enforcement of regulation in the US does not rely on certification schemes (NL AGENCY, 2011).

Some of the existing certification schemes have been proposed, aimed at fulfilling EU-RED criteria

---

[10] RTFO is an initiative in the UK through the Renewable Fuels Agency (RFA) on Carbon and Sustainability guidance.

precisely; such is the case of the ISCC scheme – International Sustainability and Carbon Certification –, in existence since 2010. Other certification schemes have been adapted in order to be recognised by the European Commission[11].

A specific case is RSB, which is wider in scope and was developed in a more stringent way. In this case it seems that the focus has been on fulfilling the expectations of the consumer markets that have more stringent concerns about biofuels sustainability (SCARLAT AND DALLEMAND, 2011). Some analysts refer to RSB as a premium certification scheme.

There are also certification schemes developed by producers and by the main consumers of agricultural commodities, as is the case of the Roundtable on Sustainable Palm Oil – RSPO (established in 2004) – and the Bonsucro Production Standard, regarding sugarcane products (former Better Sugarcane Initiative, whose standard was published in 2010) (SCARLAT AND DALLEMAND, 2011).

In addition, other certification schemes have been developed and these can potentially have a larger impact on international trade due to the traditional organizations that are promoting them. These are the cases of the ongoing initiatives by CEN (European Committee for Standardisation) and ISO (International Organisation for Standardization). The CEN/TC 383 Committee for Sustainable Produced Biomass for Energy Applications was established in 2008 and deals specifically with standards that assist the economic operators in implementing the EU-RED. It is forecast that the standard will be available in the fall 2012 (CEN, 2012). The current focus has been on liquid biofuels, as the EU has decided in the short-term not to prioritize the certification of solid and gaseous biomass used in electricity, heating and cooling.

The ISO initiative aims at creating a global standard able to deal with the sustainability of all bioenergy sources and their uses; the standard will be identified as ISO 13065 – Sustainability Criteria for Bioenergy. The standard was proposed in 2009 by the German (DIN) and the Brazilian (ABNT) standardization bodies and, currently, 30 countries act as participant members (around 50% of them are developing countries). The goal is to publish the standard by April 2014.

The Global Bioenergy Partnership – GBEP – is not a certification scheme, and its indicators do not require a certification process to be checked or implemented. GBEP is rather a forum to develop

---

[11] The seven voluntary certification schemes recognized by European Commission in 19 July 2011 are: ISCC – International Sustainability and Carbon Certification; Bonsucro EU; RTRS EU RED – Round Table on Responsible Soy EU RED; RSB EU RED – Roundtable on Sustainable Biofuels EU RED; 2BSvs – Biomass Biofuels voluntary scheme; RBSA – Abengoa RED Bioenergy Sustainable Assurance; and Greenergy – Greenergy Brazilian Bioethanol verification programme. Ensus – Ensus bioethanol production was recognized in April 2012 (European Commission, 2011).

policy frameworks to (a) promote sustainable biomass and bioenergy development, (b) facilitate investments in bioenergy, (c) promote project development and implementation, and (d) foster R&D and commercial bioenergy activities. With regards to sustainability, GBEP is working to develop a set of voluntary and science-based criteria and indicators that shall be used for facilitating the sustainable development of bioenergy (GBEP, 2011).

The existing/proposed certification schemes deal with different aspects (environmental, economic and social), and their principles and criteria were defined depending on their main goals. The inclusion of certain aspects in certification schemes are controversial as (a) in some cases the scientific knowledge is not solid enough (e.g., the indirect impacts of Land Use Change in GHG emissions) and/or in other cases (b) the economic operator cannot be blamed for the potential or identified impacts (e.g., food security).

Table 2 summarizes non-detailed information about some certification schemes and the EU-RED sustainability initiative. The most controversial aspects regarding biofuels sustainability, from the point of view of the authors of this paper, are highlighted in this table, including (a) the inclusion of indirect impacts of Land Use Change (LUC) on the evaluation procedure of avoided GHG emissions, (b) restrictions applied to the use of lands with high conservation values, (c) constraints applied to the production of feedstocks derived from genetically modified organisms (GMO), and (d) whether and how food security should be addressed.

From the point of view of the authors the controversy comes from the following reasons. Firstly, the scientific knowledge available for some aspects does not support final decisions, as is the case of indirect effects such as the impacts of ILUC on GHG balances and the potential impacts of biofuels on food security. The second point is related to these two aspects, in addition to the lack of scientific background. It is that the responsibility of a single economic operator – which should be identified in a certification process – is not clear. The third point, also related with the two aspects mentioned above, is that comprehensive methodologies for evaluating these impacts are still lacking.

Another controversial issue is the definition of no-goal areas as far as feedstock production is concerned (e.g., as is the case of the EU-RED, regarding the target of protecting biomes with High Conservation Values – HCV). The Conference of Biological Diversity in 2010 decided that it is up to the country where the project is developed to define which areas should be preserved, and not up to other countries (e.g., the EU) and/or to certification bodies (CBD, 2010). In addition, the constraints to production based on GMO are also controversial, due to the fact that the product would not be used as food or feed, and to the difficulties on tracking the material.

Table 2 - Table Synthesis of some sustainability initiatives and certification schemes

Scheme/ Initiative	EU-RED	RSB	ISCC	Bonsucro	RSPO
Aim	Sustainability initiative that requires third-part certification	Certification scheme that mainly targets the consumer market	Certification scheme with focus on the EU-RED	Certification scheme for sugarcane products	Certification scheme for palm oil products
Product	Biofuels	Bioenergy	Biofuels	Sugarcane products	Palm oil products
# of principles and criteria		12 / 37	6 / 45	5 / 20a	8 / 38
Does it address GHG?	Yes	Yes	Yes	Yes	Yes
Thresholds on GHG	35%-60%	50%	35% (currently)	No	No
Considers direct effects of LUC on GHG	Yes	Yes	Yes	Yes	Yes
Considers indirect effects of LUC on GHG (ILUC)	Possibly	Possibly – importance recognized	Possibly	No	No
Biodiversity – restrictions applied to HCV	Yes	Yes	Yes	Yes	Yes
Does it address GMO?	No	Yes	No	Yes	Yes
Does it address food security?	Issue to be reported	Yes, there is a principle	Yes, there is a principle	No	Issue mentioned
Scope of economic aspects considered	Not considered	Includes impacts over the community	Only energy efficiency is considered	Only focused on the operator viewpoint	Includes impacts over the community
Scope of social aspects considered	No specific criteria but to be considered	Detailed criteria	Moderated detailed	Less detailed	Less detailed
How are labour conditions addressed?	No specific criteria but to be considered	Addressed in detail	Addressed in detail	Addressed in detail	Addressed, but in less detail

Sources: based on Scarlat and Dallemand (2011), and complemented by RSB (2011), ISCC (2010), BONSUCRO (2010), and RSPO (2007).

Note: a plus 2 criteria in the additional section "Additional mandatory requirements under EU-RED" and 6 criteria in the section "Chain of custody requirements"

Certification tendencies in Brazil

The sugarcane industry in Brazil is the main producer and exporter of sugar worldwide, and the main exporter of bioethanol, and intends to produce and export in large-scale materials, such as plastics, produced from bioethanol. Despite being in its initial stage, the certification of the supply chain is a clear trend, as can be concluded from checking the registers of the main certification schemes.

From July 2011 to March 2012 14 sugarcane mills (all them producers of sugar and bioethanol; only one located outside the state of São Paulo) were certified according to the Bonsucro standard, while land tanks, industrial plants, port terminals and trading companies in four different locations countrywide were certified in the same period (BONSUCRO, 2012). Among the companies that decided on using the Bonsucro standard is the biggest sugarcane production group worldwide (the Raízen Group). It seems that in the short-term, sugarcane companies will prefer the Bonsucro standard, which was specially created for sugarcane products, developed with strong participation of sugarcane industry, and is accepted for certifying sustainable production of both sugar and bioethanol.

Conversely, the largest producer of plastics from bioethanol worldwide (Brasken) has certified its industrial plant of green polyethylene based on the ISCC standard; this was in 2011. The company has produced certified polyethylene made from sugarcane bioethanol since 2010, and was the first company worldwide to get this certification. Some bioethanol producers and traders have certification according to ISCC, but none in Brazil (ISCC, 2012).

The Greenergy Brazilian Bioethanol verification programme was originally developed under the UK RTFO, since supply companies were required to report the environmental performance of biofuel feedstocks against the RTFO sustainable biofuel meta-standard. This meta-standard was used by Greenergy to develop its own criteria. According to the information provided by Greenergy in its annual report (2011), 91% of the Brazilian sugarcane mills that supplied bioethanol to the UK between April 2010 and April 2011 were successfully audited against the Greenergy Gold Label. The number of audited bioethanol suppliers is not mentioned in the report.

No information was found regarding certification of bioethanol production in Brazil based on the other certification schemes previously mentioned.

As a summary, it can be concluded that only about 5% of the bioethanol producers in Brazil have a sustainability certification scheme, but the number of certified companies is growing, and this is a clear trend for the most important groups. In addition, considering average conditions of bioethanol production in Brazil, it seems that it is not a difficult task to be certified and to reach the European market, taking into account the current EU Directives.

The challenge for fulfilling sustainability criteria

Initiatives aimed at sustainability requirements can impose barriers for the production in new producer countries due to limited human skills, lack of appropriate data, lower competitiveness of small scale production, and extra costs. Obviously, developing countries would face more difficulties to fulfil required criteria. A detrimental consequence would be a higher risk perception of investors, constraining investments in these countries.

Once more, it is worth noting that sustainability criteria and, indirectly, certification schemes, have been imposed by developed countries (mainly in the EU) and that these requirements should be observed in order to reach their markets, which are by far the main ones. It is also important to bear in mind that, in theory, certification schemes should be developed to foster trade, and not for setting barriers.

On the other hand, it's currently clear that the public perception in developed countries is that biofuels would be an acceptable option if only the main concerns about their sustainability were suitably addressed. And there is no reason to suppose that this behaviour will dramatically change in the short to mid-term.

For developing countries, with no tradition of large-scale production of biofuels, lacking accurate data and having weaker institutions and poor governance, the compliance of sustainability criteria won't be an easy task. Firstly, capacity building is an issue to be addressed in the short-term. Second, planning and coordinated actions are required, as the production of biofuels aimed at exports will require, besides the accomplishment of sustainability criteria, fulfilment of technical standards and a reliable supply. For instance, a good result in terms of avoided GHG emissions requires high yields (site-specific development of species are necessary), coordinated actions, good logistics, etc.

In this respect, it seems that the only way for moving forward, in a consistent basis, is with a strong participation of developing countries throughout the whole process. This should give them the opportunity to understand such initiatives, for evaluating what it is possible to do in the short-term, and the opportunity to define priorities for themselves. It is also crucial to give developing countries opportunities for creating and expanding a really sustainable production of biofuels but, once again, according to their own priorities.

It is not possible to foster a larger consumption of biofuels without real international trade and, in addition, large-scale production will require a strong participation of developing countries. Also, it is fundamental to understand that sustainability is all about continuous improvement. Moreover, the sustainability of biofuels production should be induced throughout the years and principles and criteria should be defined, not aimed at an ultimate short-term standard, but rather at rational and feasible solutions.

Final remarks

In the last 10 years the debate regarding biofuels sustainability has gained momentum. Firstly because biofuels have been presented as a silver bullet, although clearly this is not the case. Secondly because the benefits of biofuels are case specific, depending on the feedstock and the production conditions. Thirdly because there are many interests behind the debate, and opinions on the potential role of biofuels for improving energy security and reducing GHG emissions are to some extent biased.

In this context, sustainability initiatives and certification schemes have been proposed. Due to the speed given to the implementation process, the wide scope of many initiatives and also the history of trade barriers imposed by developed countries with regards to agricultural products, such mandatory initiatives have sometimes been blamed to act as trade barriers, aimed at preserving the interests of local producers in industrialised countries. Indeed, many developing nations therefore view attempts to introduce sustainability criteria as a form of "green imperialism" (SMEETS AND FAAIJ, 2009). However, these initiatives can obviously be driven by honest concerns that large-scale production of biofuels only makes sense if its negative impacts are minimized.

It seems crucial to take into account the limits of a process that is naturally long, as it is aimed at developing a sustainable energy option that can only be produced and consumed on a large-scale. Moreover it should take in account strong contribution that should come from developing countries within regimes that are completely different from the existing ones.

The legitimacy of these sustainability initiatives and the possibility of keeping biofuels as a sustainable energy option requires a rational step-by-step approach – and a participative one at the same time. In summary, sustainability principles and criteria for biofuels should be aim for a stable and reliable energy solution. In the case of very ambitious short-term targets on sustainability, biofuels production in developing countries will be deeply constrained, with negative impacts on international trade. The consequences will be the reduction of biofuels in the future energy matrix and the reduction of their contribution to minimizing climate change impacts

References

BONSUCRO. Production Standard; 2011. Version 3.0, March. Available at <www.bonsucro.com>.

____. Bonsucro 2012. Information available at: <www.bonsucro.com>.

CONVENTION ON BIOLOGICAL DIVERSITY - CBD. Tenth meeting of the Conference of the parties to the convention on biological diversity (COP 10). Nagoya, Japan. 2010.

EUROPEAN COMMITTEE FOR STANDARDIZATION. CEN - 2012. Available at: <www.cen.eu/cen>.

EUROPEAN COMMISSION. First EU sustainability schemes for biofuels get the go-ahead. European Commission – Press Release. 19 July. 2011.

EUROPEAN PARLIAMENT. European Parliament legislative resolution of 17 December 2008 on the proposal for a directive on the promotion of the use of energy from renewable sources. 2008.

FRIENDS OF EARTH. The oil for ape scandal. Available at: <http://www.foe.co.uk/resource/reports/oil_for_ape_full.pdf>. Access on: 2005.

GLOBAL BIOENERGY PARTNERSHIP - GBEP. The Global bioenergy partnership. 2011. Available at <www.globalbioenergy.org>. April 2011.

GREENERGY. Annual report to the Department for Transport – Biofuels supplied under the RTFO. 2011.

INTERNATIONAL ENERGY AGENCY – IEA. Biofuels for transport—an international perspective. Paris: 2004.

INTERNATIONAL SUSTAINABILITY AND CARBON CERTIFICATION - ISCC. Sustainability Requirements for the Production of Biomass. 2010. Available at: <www.iscc-system.org>.

____. 2012. Available at: <www.iscc-system.org>.

NL AGENCY. How to select a biomass certification scheme? Ministry of Economic Affairs, Agriculture and Innovation. May. 2011.

PENN STATE UNIVERSITY. Notes on sustainable energy entrepreneurship. overview of sustainability and ethics of sustainability. 2012. Available at: <https://www.e-education.psu.edu/engr312/node/113>.

RENN, O.; DEUSCHLE, J.; JÄGER, A.; WEIMER-JEHLE, W. A normative-functional concept of sustainability and its indicators. Preprint Series Issue No. 2009-74. Stuttgart Research Centre for Simulation Technology (SRC SimTech). Stuttgart.

ROUNDATABLE ON SUSTAINABLE BIOFUELS - RSB. Version zero of global principles and criteria for sustainable biofuels production. 2008. Available at: <http://EnergyCenter.epfl.ch/Biofuels>.

_____. Indicators of compliance for the RSB principles & criteria. Available at: <www.rsb.epfl.ch>. 2011.

ROUDTABLE ON SUSTAIANABLE PALM OIL – RSPO. RSPO Principles and Criteria for Sustainable Palm Oil Production. 2007. Available at: <www.rspo.org>

SCARLAT, N.; DALLEMAND, J.F. Recent developments of biofuels/bioenergy sustainability certification: A global overview. Energy Policy, v. 39, p. 1630–1646. 2011.

SMEETS, E.; FAAIJ, A. Third periodic activity report; Annex 5-3-1: Synthesis report on international trade opportunities in Africa. 2009. Available at: <www.compete-bioafrica.net>.

UNITED NATIONS GENERAL ASSEMBLY - UN. World Summit Outcome, 2005. Resolution A/60/1.

VAN DAM, J.; JUNGINGER, M.; FAAIJ, A.; JURGENS, I.; BEST, G.; FRITSCHE, U. Overview of recent developments in sustainable biomass certification. Biomass and Bioenergy, v. 32, p. 749 -780. 2008.

WWF. Oil palm plantations and deforestation in Indonesia. 2002. Available at: <http://assets.panda.org/downloads/oilpalmindonesia.pdf>.

Part V

Life cycle analysis, energy and greenhouse gases balance

Chapter 12

Energy and GHG emissions in Brazil and worldwide

Arnaldo Walter

Introduction

This chapter presents an overview of Greenhouse Gas (GHG) emissions due to energy production and consumption worldwide and in Brazil. The text is divided into four sections, besides this introduction, the first two being devoted to assessing the evolution of GHG emissions worldwide, in general, and in Brazil, since 1990 in particular. The aim of the next section is to analyse the perspectives of GHG emissions worldwide, considering 2050 as a reference. The last section deals with the analysis of the Brazilian scenario, 2030 being the time-horizon considered.

GHG emissions worldwide

Greenhouse Gases (GHG) are those that trap heat in the atmosphere (EPA, 2012); it is believed that the phenomenon of Climate Change[1] occurs because some gases absorb and emit radiation within the thermal infrared range. Some of the GHGs exist in nature while others are man-made; some gas flows are due to natural processes and others are due to human activities (anthropogenic effects). According to the Kyoto Protocol, the gases that can directly cause a greenhouse effect are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Sulphur hexafluoride (SF6), and two families of industrial gases: Hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs)[2]. In addition, other gases are considered as indirect GHGs, as they result from the six gases previously mentioned. They are: Sulphur dioxide (SO_2), Nitrogen oxides (NOx), Carbon monoxide (CO) and Non-Methane Volatile Organic Compounds (NMVOC).

---

[1] Climate Change refers to any significant change in measures of climate – such as temperature, precipitation or wind – that lasts for an extended period of time (EPA, 2012).

[2] Carbon monoxide, methane and nitrous oxide are natural gases, while the other three are man-made.

The emissions of GHGs shall be reported by the Parties (i.e., countries that have signed the UN Climate Convention) through regular inventories. The countries that belong to the Annex I (i.e., countries that have targets for reducing GHG emissions within the first commitment period of the Kyoto Protocol – for the period of 2008-2012) need to present their report each year, while the countries that are non-Annex I need to report their emissions through National Communications. Brazil, as a non-Annex I country, presented its second communication of GHG emissions, for the period of 2000-2005, in 2010.

Data of the UNFCCC (United Nations Framework Convention on Climate Change) regarding GHG emissions are available for the period of 1990 to 2007[3]. The information presented is official but, as the sources are different and correspond to various years (due to the two different statuses of the countries), some inconsistency is observed. Updated estimates are available, mostly regarding GHG emissions due to energy production and use, such as those published by the International Energy Agency (IEA). The emissions due to fossil fuel combustion are further described in detail.

The most important anthropogenic GHG is Carbon dioxide (CO2). Its concentration increased from 280 ppmv in the pre-industrial era to 379 ppmv in 2005. Throughout the period of 1995-2005 the average annual growth rate was 1.9 ppmv/year, while from 1960 to 2005 it was 1.4 ppmv/year. Based on these values it is estimated that the CO_2 concentration in the atmosphere surpassed 390 ppmv in 2011.

The concentration of Methane in the atmosphere increased from 715 ppbv in the pre-industrial era to 1,774 ppbv in 2005 (IPCC, 2007). The anthropogenic emissions of Methane are mostly due to the burn of fossil fuels and to agriculture and livestock activities. On the other hand, the concentration of Nitrous oxide in the atmosphere grew from 270 ppbv to 319 ppbv in the same period (IPCC, 2007). More than one third of the emissions of Nitrous oxide are anthropogenic and mainly due to agricultural activities.

Figure1 shows the growth of the concentrations of Carbon dioxide (a), Methane (b) and Nitrous oxide (c) in the atmosphere throughout the years (before 2005; 2005 corresponds to year zero in the figures). The boxes in each figure highlight the growth of atmospheric concentration of these three gases from the Industrial Revolution to today.

---

[3] For countries that are Annex I the most recent document available is the FCCC/SBI/2011/9 ("National greenhouse gas inventory data for the period of 1990–2009"), while for countries that are non-Annex I the most recent document available is the FCCC/SBI/2005/18/Add.2 ("Sixth compilation and synthesis of initial national communications from Parties not included in Annex I to the Convention"). Both reports are available at <www.unfcc.int>.

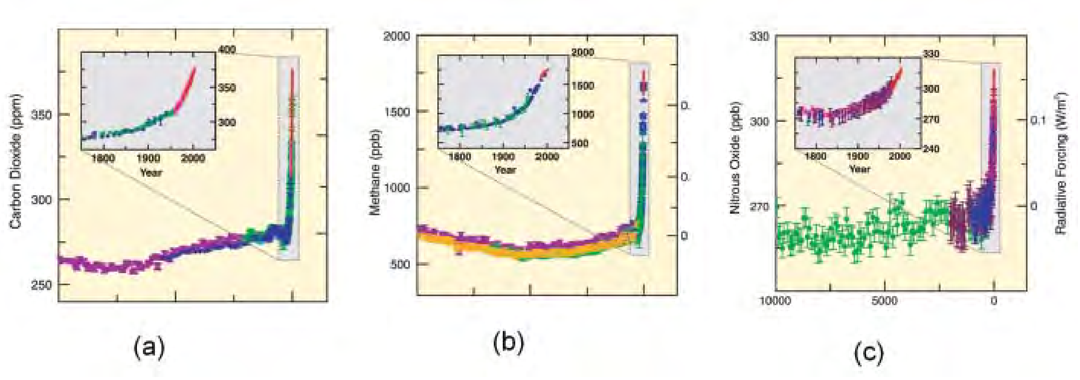


Figure 1. Evolution of the emissions of the main GHGs (a) Carbon dioxide, (b) Methane, (c) Nitrous oxide.

Notes: Year 0 is 2005; the scale indicates years before 2005.

Source: IPCC (2007).

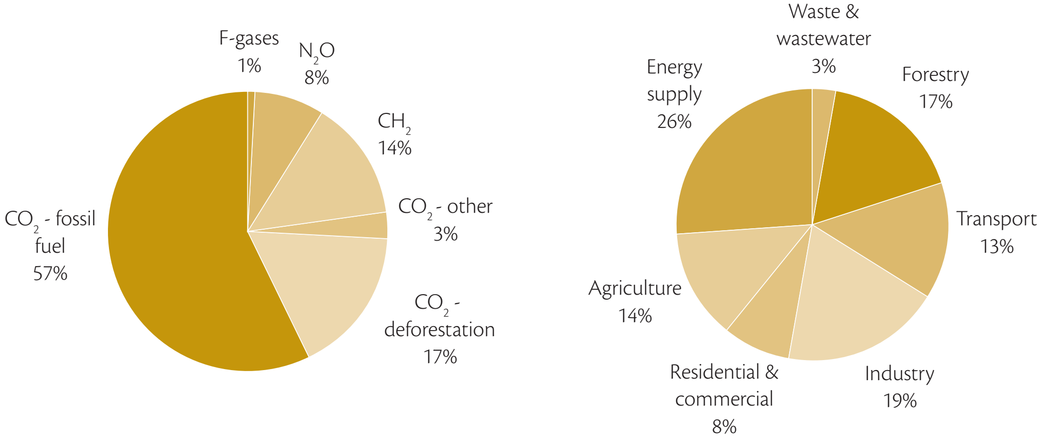


Figure 2. Emissions of the main GHG (a) and emissions per socio-economic sector (b)

Source: IPCC (2007)

Figure 2 shows the profile of GHG emissions in 2004 according to the origin and the contribution of each main gas (16.2a) and according to the social-economic activity (16.2b). It can be seen that the emissions of Carbon dioxide are by far the most important (more than two thirds of the total emissions) while the emissions that correspond to energy production and use surpassed 60% of the total emissions (those due to energy supply and transport, plus most of the emissions in the residential, commercial and industrial sectors[4],[5]).

Total GHG emissions in 2005 were estimated at 44.2 $GtCO_2eq$ and a significant share was due to agricultural activities (about 14%) and to Land Use Change (LUC) (12% - these emissions are included in Forestry in Figure 16.2b). In the Agricultural sector important emissions are those of Nitrous oxide (more than 5% of the total emissions) and Methane, from livestock and manure (also more than 5%). GHG emissions due to deforestation (more than 11% of the total in 2005) are classified as LUC emissions (BAUMERT ET AL., 2005).

Regarding energy production and use, the main emissions occur along the supply chains of electricity and heat (energy supply in Figure 2b) and in the transport sector, reaching about 40% of the total. In the transport sector, emissions tend to grow faster than in any other economic sector, as a consequence of the economic growth and also because of the low amount of mitigation options in the mid to long-term[6].

Between 2008 and 2009, due to the financial crisis, energy-related global CO2 emissions decreased by 0.5 $GtCO_2$, which represented a decline of 1.5%. The emissions of developed countries (mainly Annex I countries) decreased, whereas the emissions of developing countries increased, principally in Asia and the Middle East. Since 2008 the energy-related CO2 emissions of developing countries are higher than their counterparts, and their share reached 54% in 2009 (IEA, 2011).

Global CO_2 emissions from fuel combustion in 2009 were estimated at 29 $GtCO_2$ and about 65% of these emissions were due to the top ten emitting countries (see Table 1). Currently China is the leading country, followed by the United States; together these two countries are responsible for more than 41% of total emissions.

Besides the absolute energy-related CO_2 emissions, Table 1 presents values of emissions per capita and per unit of GDP. It A huge variance can be seen even among the top 10 emitting countries, with

---

[4] 57% due to the combustion of fossil fuels (see Figure 16.2a). Fugitive emissions in the energy supply chain represent about 4% of the total GHG emissions (WRI, 2009).

[5] The emissions that occur in the industrial processes represented about 5% of the total (in 2005), mainly in cement and chemical industries (WRI, 2009).

[6] There are more alternatives for reducing the emissions of GHG in electricity production, some of them being cost-effective in the short-term (e.g., electricity efficiency, wind power, cogeneration based on biomass) while others could reach a commercial stage in about 20-30 years (e.g., carbon capture and storage – CCS – in thermal power plants based on coal and natural gas).

a ratio of 1:12 between the CO_2 emissions per capita of India and the US, and 1:3.7 between the emissions per unit of GDP of Russia and the UK.

Table 1 – Main emitting countries of CO2 from fuel combustion in 2009

Country/region	Emissions ($MtCO_2$)	% regarding the world	per person (tCO_2/capita)	per GDP ($kgCO_2$/ US$)a
China	6,877.2	23.7	5.14	0.55
United States	5,195.0	17.9	16.90	0.46
India	1,585.8	5.5	1.37	0.35
Russia	1,532.6	5.3	10.80	1.00
Japan	1,092.9	3.8	8.58	0.32
Germany	750.2	2.6	9.16	0.33
Iran	533.2	1.8	7.31	0.92
Canada	520.7	1.8	15.43	0.51
South Korea	515.5	1.8	10.57	0.45
United Kingdom	465.8	1.6	7.54	0.27
World	28,999.4		4.29	0.45

Source: IEA (2011)

Note: a GDP weighted by the power purchase power (PPP), in US$ from 2000

As long as the emissions due to agriculture, deforestation and Land Use Change are taken into account, Brazil assumes a position among the top emitting countries. According to an estimate based on data provided by the World Bank, International Energy Agency and World Resources Institute, Brazil would be the fifth largest emitting country, with more than 2 $GtCO_2$ in 2005, i.e. about 5% of the total GHG emissions that year (CBC, 2009).

Figure 3 illustrates the contribution of the main emitting countries/regions to the total of GHG emissions in 2005. It can be seen that China, the US and EU-27 are responsible for about 50% of the emissions, and that 14 countries plus the EU-27 are responsible for almost 80% of the GHG emissions. Among them, China, India, Brazil, Mexico, Indonesia, Iran and South Africa do not have commitments under the Kyoto Protocol.

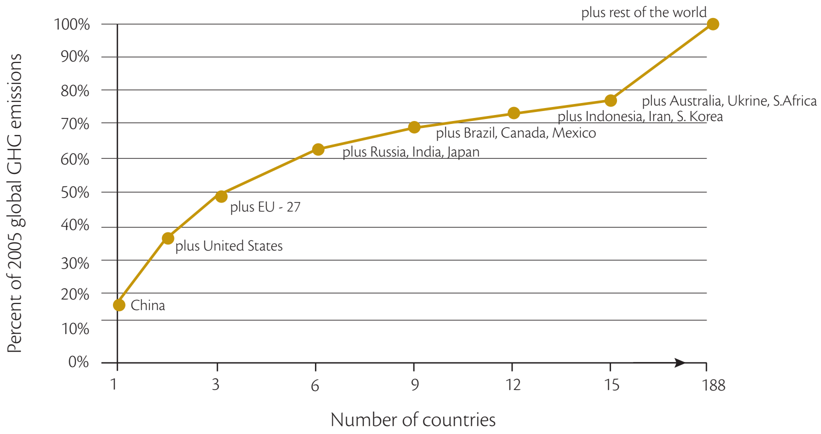


Figure 3. Main emitting GHG countries in 2005

Source: WRI (2009)

Not considering the LULUCF (Land Use, Land Use Change and Forestry), GHG emissions of Annex I countries decreased by 11.5% in 2010 compared to those in 1990, a result that was impacted by the deep economic changes in the EIT countries (Economies in Transition) after 1989. Not considering these countries, GHG emissions grew by 2.1% in 2010 compared to emissions in 1990. Considering LULUCF, GHG emissions were reduced by 17.6% from 1990 to 2010 in the whole set of Annex I countries, and grew 0.6% when EIT countries are not considered (IPCC, 2011).

Table 2 presents estimates of changes in GHG emissions between 1990 and 2010 (including LULUCF) for some Annex I countries.

Table 2 – Changes of GHG emissions (including LULUCF) between 1990 and 2010

Country/Region	Changes (%) (regarding emissions in 1990)
Turkey	102
Australia	29.9
Canada	29.8
Spain	28.3
United States	5.6
Japan	-5.0
France	-12.9
European Union	-20.2
Germany	-23.0
United Kingdom	-27.7
Russian Federation	-57.2

Source: IPCC (2011)

GHG emissions in Brazil

The following information regarding GHG emissions in Brazil is mainly based on the Second Communication from Brazil to the UNFCC (BRASIL, 2010), released in October 2010. In the Second Communication the period covered is 2000-2005. The First Communication, with data for the period of 1990-1994, was released in 2004 (BRASIL, 2004).

Between 1990 and 2005, GHG emissions in Brazil grew 61.5%, from 1.36 $GtCO_2$ to about 2.2 $GtCO_2$. The bulk of emissions in Brazil is due to Land Use Change (LUC) and deforestation, which represented 55% and almost 61% of the total emissions in 1990 and 2005, respectively. Considering 2.2 $GtCO_2$ emitted in 2005, and that global emissions that year were about 44.2 $GtCO_2eq$ and GtCO2, Brazil was responsible for about 5% of world emissions and this justifies the highlight given in Figure 3. Table 3 presents the GHG emissions in Brazil (in $MtCO_2eq$) and its profile in both years.

Table 3 – Profile of GHG emissions in Brazil, 1990 and 2005 – emissions in $MtCO_2eq$, considering the GWP-100 of different gases

Sector	1990	2005	Variation (%)	Share 1990 (%)	Share 2005 (%)
Energy	214.92	328.81	53.0	15.8	15.0
Industrial processes	26.69	77.94	192.0	2.0	3.6
Agriculture	342.07	415.75	21.5	25.2	18.9
LUC & forests	746.43	1,329.05	78.1	55.0	60.6
Wastes	27.66	41.05	50.9	2.0	1.9
Total	1,357.77	2,192.60	61.5	100	100

Source: Brasil (2004) and Brasil (2010)

According to the inventory of GHG emissions, in 2005 74.7% of the total emissions were due to CO_2, 17,3% due to CH_4, and 7.7% due to N_2O. The emissions of other gases represented only 0.3%. It is estimated that 77% of the CO_2 emissions in 2005 were due to LUC and deforestation, a share that is very different in other countries. This is due to the large share of renewable energy sources in the Brazilian energy matrix, and mainly to the high deforestation rates. Deforestation and LUC in the Amazon region were responsible for 38% of the total emissions in 2005 (more than 2% of GHG emissions worldwide), while the share due to deforestation and LUC in the Cerrado contributed 13% of the total GHG emissions (less than 1% of the world's emissions).

Figure 4 presents the evolution of GHG emissions in Brazil from 1990 to 2005, considering only the emissions of CO_2, CH4 and N_2O. It can be seen that the peaks of emissions were in 1995 and 2004, mainly due to deforestation in the legal Amazon region[7], almost reaching 2.6 $GtCO_2$.

Figure 5 shows the evolution of deforestation rates in the legal Amazon region, from 1988 to 2011. It draws attention to the huge decline of deforestation rates since 2004, due to specific policies and control.

---

[7] CO_2 emissions due to LUC and deforestation in 1995 are estimated as 1.8 $GtCO_2$, while in 2004 the emissions in the same category are estimated as 1.7 $GtCO_2$ (1.26 $GtCO_2$ in 2005) (Brasil, 2010).

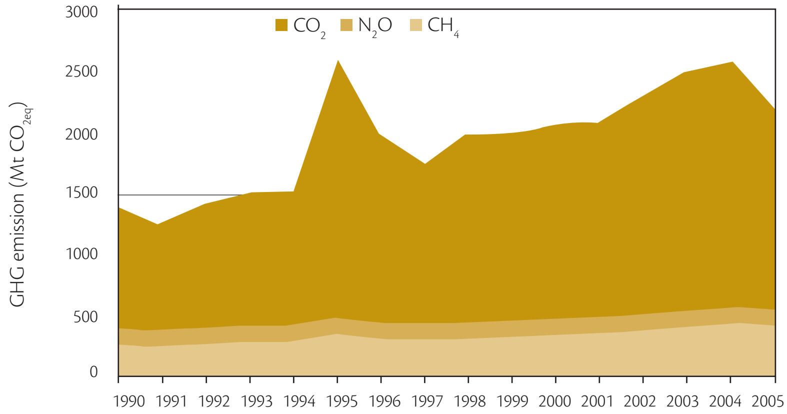


Figure 4. GHG emissions in Brazil – contributions of the main gases

Source: Brasil (2010)

During the period of 1994-2002, the average net anthropogenic CO_2 emissions in the category of LUC and Forests were estimated at 1,296.4 $MtCO_2$/year, i.e. larger than the emissions from Japan in 2009 (see Table1). Only in the Amazon biome the emissions were estimated at 860.9 $MtCO_2$/year, larger than the emissions of Germany in 2009 (see Table 1).

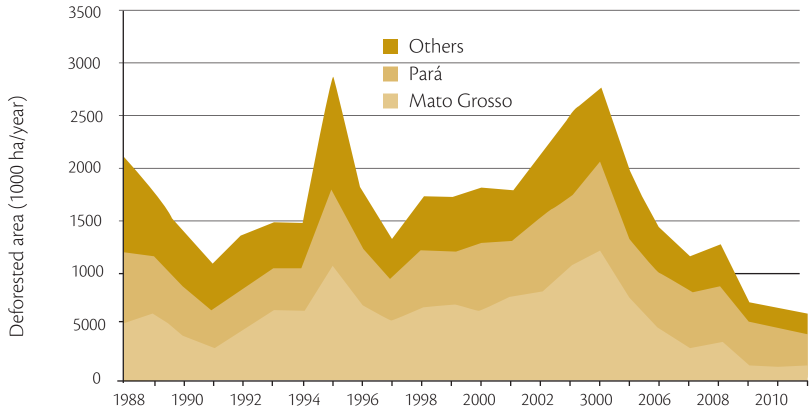


Figure 5. Deforestation rates in Legal Amazon region from 1988 to 2011

Source: INPE (2012)

In the energy sector, emissions are mostly related to CO_2 due to the burning of fossil fuels and the main emitters are the sub-sectors of road transport (39%) and industry (24%). Together, these two sub-sectors were responsible for almost 10% of total GHG emissions in Brazil in 2005.

The share of agriculture among total GHG emissions in 2005 declined compared to 1990 (see Table 3), and a large share in this group is due to livestock activities in Brazil. According to the inventory, in 2005 63.2% of the emissions of methane were due to cattle and this corresponded to about 11% of total GHG emissions. Manure disposal is the second most important share of emissions due to livestock, and this is roughly equivalent to 4% of total emissions. Thus, GHG emissions due to livestock in Brazil are equivalent to those of the energy sector.

Figure 6 shows the evolution of GHG emissions in Brazil with details of the main emitter activities. For the reported period, CO_2 emissions due to LUC and deforestation were always above 50% of the total emissions, and reached 71% and 67%, respectively, in 1995 and 2004. On the other hand, the emissions of CH_4 and N_2O due to agriculture and livestock (A&L) varied between 13% and 25% for the period, and reached 19% in 2005.

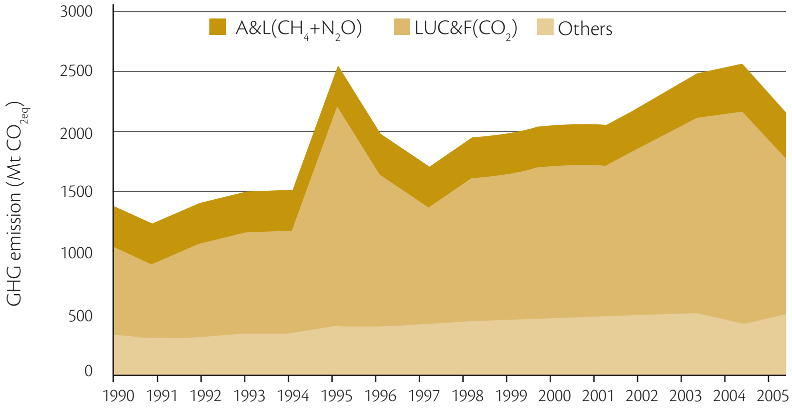


Figure 6. GHG emissions in Brazil – shares of the main activities

Source: Brasil (2010)

Perspectives and options for cutting GHG emissions - world

Due to the large share of energy-related GHG emissions, the perspectives analyzed here only take into account its possible evolution in the time horizon of 2030 and 2050. The results presented are based on studies by the International Energy Agency (IEA)[8].

In the Reference scenario of the IEA study that takes 2030 as the time horizon (IEA, 2009), 1.3 billion people would still lack access to electricity, compared with the current figure of 1.5 billion. Despite this, the total primary energy supply (TPES) could grow about 60% by 2030, compared to the TPES in 2007. In this scenario, the energy-related emissions of CO2 would increase from 28.8 $GtCO_2$ in 2007 to 40.2 $GtCO_2$ in 2030 and, as consequence, the annual growth rates of CO_2 concentration in the atmosphere would surpass 5 ppmv in 2030 (to be compared with 1.9 ppmv/year during the period of 1995-2005). It is estimated that about 2/3 of the growth in energy demand would occur in developing countries, mainly in Asia, and as a consequence it is expected that the net increase of CO_2 emissions would be mainly in China (about 50%) and India (almost 18%). The bulk of the growth in energy demand would be due to electricity production and to the transport sector.

The study of the IEA that takes 2050 as its time horizon (IEA, 2010) follows the same Reference scenario for 2030 mentioned above (IEA, 2009) and then expands it to 2050. The energy-related CO_2 emissions would reach 57 $GtCO_2$ in 2050, as a consequence of a primary energy use that would rise by 84% compared to 2007. In this scenario the Non-OECD countries would be responsible for almost 90% of the growth in energy demand and would account for about ¾ of global CO_2 emissions. The CO_2 emissions from power generation would more than double by 2050, despite a slight decline of CO_2 intensity (e.g. gCO_2/kWh, due to a larger share of electricity production from natural gas and renewable sources). In this scenario, by 2050 almost 80% of light-duty vehicles would rely on conventional gasoline and diesel technologies and petroleum products would meet more than 90% of the transport energy demand; the CO_2 emissions would by slightly more than double by 2050.

Considering the warnings of the IPCC (UN Intergovernmental Panel on Climate Change) that reductions of at least 50% in global CO_2 emissions compared to levels in 2000 should be achieved by 2050 to limit the long-term global average temperature rise to between 2.0°C and 2.4°C (i.e. CO_2

---

[8] Results of the World Energy Outlook 2009 (IEA, 2009) that has 2030 as its time horizon, and of the Energy Technology and Perspectives 2010 report – Scenarios & Strategies for 2050, which considers 2050 as reference (IEA, 2010).

concentration in the atmosphere should be stabilized as 450 ppmv[9]), IEA explored low-emission scenarios in its studies.

Figure 7 summarizes the evolution of energy-related CO_2 emissions from 2010 to 2050, considering a scenario in which the emissions would reach 50% of those estimated for 2010 (i.e. reaching 14 $GtCO_2$). The final result would require a drop in GHG emissions equal to 3.8 $GtCO_2$ in 2020 and 13.8 $GtCO_2$ in 2030 (reducing emissions to 26.4 $GtCO_2$) regarding those predicted in the Reference scenario (IEA, 2009). The technologies for reducing CO_2 emissions were selected based on the predicted marginal costs of avoided emissions, and these would reach 175 US$/tCO2 in 2050 (up to 65 US$/$tCO_2$ and 110 US$/$tCO_2$ by 2030 in Non-OECD and OECD countries, respectively) (IEA, 2010).

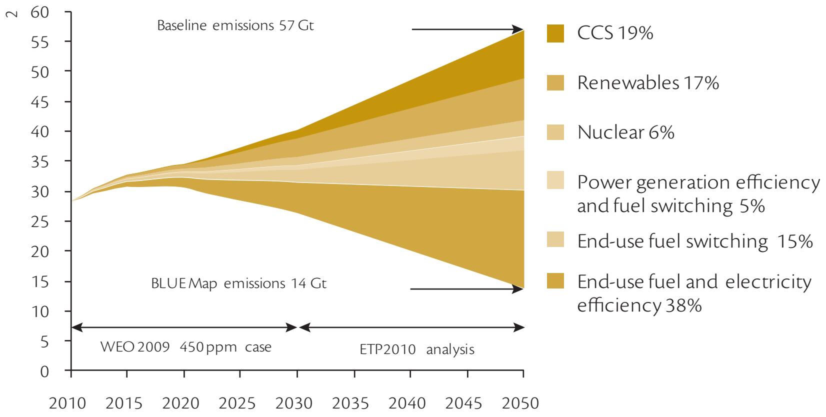


Figure 7. Key technologies for drastically reducing CO2 up to 2050

Source: IEA (2010)

The large contribution of end-use fuel and electricity efficiency is due to the lower costs of associated technologies (in most cases the costs are negative, as they are already cost-effective or predicted to be in the short-term). Another important aspect to be mentioned is that the final results are impacted by the hypothesis that it would be cost-effective to drastically decarbonise electricity generation through the adoption of (a) Carbon, Capture and Storage systems (CCS), (b) electricity generation from renewable sources, and (c) large-scale generation from nuclear energy. The IEA study was released before the accident in Fukushima, Japan, and following the decisions made by various countries, the required annual rate of 30 GW/year from new nuclear power plants will be barely achieved.

---

[9] However, some analysts believe that due to very high risks, the mitigation efforts should target a concentration as low as 350 ppmv. It is important to note that the current CO2 concentration in the atmosphere is about 390 ppmv.

Table 4 presents the estimates of CO_2 emission reduction by sector, in 2050, which correspond to cutting by half the emissions corresponding to 2007. As can be seen, the largest contribution would come from the power and transport sectors.

Table 4 – Predicted reductions of CO2 emissions by 2050

Sector	Reduction from 2007 levels	Reduction from 2050 baseline
Power	76%	88%
Transport	28	64
Industrya	27	51
Buildings	40	57
Totalb	52	75

Source: IEA (2010)

Notes: [a] includes emissions (reductions) from non-energy use of petrochemical feedstocks and excludes industrial processes emissions;
[b] includes reduction in fuel transformation.

Regarding the transport sector, it's important to highlight the hypothesis and the results presented by IEA (IEA, 2010) for 2050. Firstly, the hypothesis is that it would be possible to drastically cut CO_2 emissions from light-duty vehicles by improving the efficiency of the engines and the vehicles. Secondly, public transport systems would be improved in most of the cities, mainly in developing countries. Thirdly, hybrid, electric and fuel-cell vehicles would reach cost-effectiveness during this period and would dominate the sales of new vehicles after 2030. It is estimated that biofuels would cover about ¼ of the energy demand of the transport sector by 2050, but about 50% of its production would be for meeting the demands of aviation and maritime transports. According to the results, the demand of biofuels for light-duty vehicles would begin to decline after 2030 owing to the strong shift towards electricity and hydrogen fuels.

The IEA predicts that 32 EJ of biofuels will be used globally by 2050, mostly produced from lingo-cellulosic feedstocks. Potentially, if sustainably produced, the projected use of biofuels could mitigate around 2.1 $GtCO_2$ in 2050, contributing about 5% of the required emission reductions (43 $GtCO_2$). According to IEA's point of view, the production of conventional bioethanol (except bioethanol from sugarcane) and conventional biodiesel would be completely phased-out between 2040 and 2045, due to the low efficiency of energy production (e.g. litres per area) and to the expected deployment of advanced biofuels (IEA, 2011b).

Perspectives and options for cutting GHG emissions – Brazil

Concerning energy-related GHG emissions in Brazil, the analysis of perspectives presented here is based on the results of the National Energy Plan 2030 (EPE, 2007), despite the fact that this study is not updated vis-à-vis the most recent tendencies of the Brazilian energy sector. One of the scenarios considered in this study (the B1) was taken as an illustration.

On the other hand, for assessing the mitigation options of GHG emissions in Brazil, also considering 2030 as a reference, a study developed by the World Bank (released in June 2010) was considered (GOUVELLO, 2010). Regarding energy use, the World Bank also considered the National Energy Plan 2030 as a reference.

The World Bank report took the emissions in 2008 as a baseline, and a direct comparison with Brazilian emissions in 2005 (see section 16.3) is not possible. Firstly, in the World Bank report only some sources of emission were considered. Secondly, emissions are aggregated in different ways in both studies. And thirdly, the emissions in the category Land Use Change and Deforestation have drastically changed since 2004, as previously mentioned.

Table 5 presents the estimated GHG emissions in 2005 and 2008, for both studies. Despite the difficulties of comparison, it's clear that there was a severe reduction of emissions, mainly because of the reduced deforestation. However, the emissions due to Land Use and Deforestation are still by far the largest in Brazil[10].

In Table 5 the estimated GHG emissions in 2030, considered as the Business-as-Usual scenario, are also presented. The growth (%) between 2008 and 2030 is presented in the last column on the right side of the table.

The results for 2030 reflect some current and short-term tendencies in Brazil. The growth of emissions in the Energy sector is mostly due to the hypothesis that thermal power plants (some burning coal and others heavy oil) would operate more frequently, as the construction of new hydro power plants, mainly ones with large reservoirs, will be constrained.

---

[10] Gouvello (2010) mentions that this is very particular to Brazil: deforestation is due to the large extension of lands available, the tradition of extrativism, the economic importance of agriculture and livestock, and to a whole set of driving forces for deforestation (e.g. the expansion of frontiers, the growing market of food and meat, the lack of appropriate conditions for keeping control, and institutional weakness).

Table 5 – Emissions of GHG in 2005 and estimated figures in 2008 and in 2030 (share of them between parentheses)

Sector	20051	20082	20302	Growth (%)
Energy3	329 (15.0%)	232 (18.0%)	458 (26.7)	97
Transport3		149 (11.6%)	245 (14.3)	64
Waste	41 (1.9%)	62 (4.8%)	99 (5.8)	60
LUC and forests	1,329 (60.6%)	536 (41.6%)	533 (31.0)	0
Livestock4		237 (18.4%)	272 (15,8)	15
Agriculture4	416 (18.9%)	72 (5.6%)	111 (6.5)	54
Industrial process4	78 (3.6%)			
Total	2,193 (100%)	1,288 (100%)	1,718 (100)	33

Source: 1 Brasil (2010); 2 Gouvello (2010)

Notes: [3] In Brasil (2001) the emissions of the Energy sector are those due to the production, conversion and end-use of energy; in Gouvello (2010) the emissions in the transport sector were disagreagated. The comparison should be roughly 328.8 MtCO2 in 2005 and 381 MtCO2 in 2008 (232 + 149).

[4] inGouvello (2010) the GHG emissions were classified as due to Agriculture and due to Livestock; In Basil (2010) they are in the same category. The comparison should be roughly 415.8 MtCO2 in 2005 and 309 MtCO2 in 2008 (237 + 72).

[5] inGouvello (2010) the emissions due to Industrial processes were not taken into account.

In the Transport sector, the current trend of increased bioethanol use was considered, while in the case of biodiesel the hypothesis is that blends would be B10 by 2030 (10% biodiesel, volume basis; currently B5 is used); the increase in emissions is mainly due to the assumption that no drastic changes in the transport modes would be observed.

Regarding the emissions due to LUC and deforestation, the results of the Business-as-Usual scenario presented in Table 5 are coherent with the hypothesis that deforestation rates will stabilize in the next two decades (in fact, there is a trend of reduction, as can be seen in Figure 5).

The same study by The Wold Bank (GOUVELLO, 2010) explores a scenario of low GHG emissions. The results are presented in Table 6, compared with the results of the Business-as-Usual scenario previously mentioned.

Table 6 – Emissions of GHG in 2030 in a low emission scenario (shares between parentheses)

Sector	20051	20082	20302	Growth (%)
Energy3	329 (15.0%)	232 (18.0%)	458 (26.7)	97
Transport3		149 (11.6%)	245 (14.3)	64
Waste	41 (1.9%)	62 (4.8%)	99 (5.8)	60
LUC and forests	1,329 (60.6%)	536 (41.6%)	533 (31.0)	0
Livestock4		237 (18.4%)	272 (15,8)	15
Agriculture4	416 (18.9%)	72 (5.6%)	111 (6.5)	54
Industrial process4	78 (3.6%)			
Total	2,193 (100%)	1,288 (100%)	1,718 (100)	33

Source: Gouvello (2010)

Obviously, reducing deforestation is a crucial course of action for the reduction of GHG emissions in Brazil. Comparing the results presented in Table 6, almost half of the avoided emissions in 2030 (695 $MtCO_2$) would be a contribution of lower deforestation rates. Gouvello (2010) suggests actions to achieve the results presented in Table 6: (a) reducing the demand for new areas, through enhancement of productivity in agriculture and livestock and recovery of degraded pasturelands; (b) fostering forest protection, through control of illegal deforestation and promoting economic activities based on sustainable management of natural resources.

Regarding agriculture, the reduction of GHG emissions could be achieved with positive impacts of no-tillage practices, i.e. keeping carbon stocks in the soil and reducing diesel consumption. Concerning livestock, the main actions would be intensifying activity (enlarging animal density) and improving genetics, for reducing animal life times. It's important to note that the small contribution to the reduction of GHG emissions is due to the hypothesis that livestock will continue to grow in Brazil.

The main alternatives considered for reducing energy-related emissions (except for transport) were: (a) enhancing energy efficiency in different sectors, (b) changing the fuel mix in industries, (c) producing liquid fuels from natural gas, and (d) electricity generation from sugarcane residues and wind.

Opportunities for reducing GHG emissions abroad were also considered, such a large-scale production and exports of fuel bioethanol. In the BAU scenario, the amount exported in 2030 was estimated at 13 billion liters, while in the Low Emission scenario the volume exported could reach 70 billion liters. This additional volume would mitigate 73 $MtCO_2$ per year, considering the conditions of bioethanol use overseas, i.e. 667 $MtCO_2$ over 20 years. It was estimated that the production of 70 billion liters would require 6.4 Mha of additional area with sugarcane cropping.

Comparing both scenarios for 2030, the contribution of the transport sector would be modest: only 10% of the estimated mitigated emissions (695 $MtCO_2$/year). One of the reasons for this is that the bioethanol consumption in the BAU scenario would already be very large (63.5 billion liters) with a small impact of maximizing bioethanol consumption in the Low Emission scenario (74.4 billion liters).

Finally, it is important to notice that the marginal abatement cost of enlarging the consumption of fuel bioethanol in Brazil would be -2 US$/$tCO_2$, which reflects the economic viability of this biofuel vis-à-vis automotive gasoline. In the case of using bioethanol overseas, due to the lower efficiency of bioethanol use and higher costs of its transportation, the marginal abatement cost was estimated at 9 US$/$tCO_2$, i.e. still very low compared with other options of reducing GHG emissions (GOUVELLO, 2011).

References

BRASIL. MINISTÉRIO DE CIÊNCIA E TECNOLOGIA - MCT. Primeira comunicação nacional do Brasil. 2004. Available at <www.mct.gov.br>.

_____. Segunda comunicação nacional do Brasil à convenção - Quadro das Nações Unidas sobre Mudança do Clima. 2010. Available at: <www.mct.gov.br>.

BAUMERT, K.A.; HERZOG, T.; PERSHING, J. Navigating the numbers - greenhouse gas data and international climate policy. World Resources Institute, 2005.

CANADIAN NEWS SPORTS ENTERTAINMENT KIDS DOCS RADIO TV - CBC. The world's 12 largest GHG emitters. 2009. Available at: <www.cbc.ca>.

EMPRESA DE PESQUISA ENERGÉTICA – EPE. Plano nacional de energia (PNE 2030). Brasília: Ministério das Minas e Energia, 2008.

GOUVELLO, C. Estudo de baixo carbono para o Brasil. Washington: Banco Mundial. 2010.

INTERNATIONAL ENERGY AGENCY – IEA. Energy technology and perspectives 2008 – scenarios & strategies to 2050. Paris: 2008.

_____. World energy outlook 2009. Paris: IEA. 2009.

_____. CO_2 emisisons from fuel combustion – highlights. Paris: 2011a.

_____. Technology roadmap – biofuels for transport. Paris: 2011b.

INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS (National Institute for Space Research) – INPE. PRODES Project. 2012. Available at: <http://www.obt.inpe.br/prodes/prodes_1988_2011.htm>

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE – IPCC. Climate change 2007: the scientific basis. Cambridge: Cambridge University Press, 2007.

_____. Figures and tables. 2011. Available at: <www.ipcc.ch/publications_and_data/>.

UNITED NATIONS FRAMEWORK ON CLIMATE CHANGE – UNFCC. 2012. National greenhouse gas inventory data for the period 1990–2009. Document FCCC/SBI/2011/9. Available at:<www.unfcc.int>.

_____. Sixth compilation and synthesis of initial national communications from parties not included in annex I to the Convention. Document FCCC/SBI/2005/18/Add.2. Available at: <www.unfcc.int>.

WORLD RESOURCES INSTITUTE – WRI. Charts & maps. 2009. Available at: <www.wri.org/charts-maps>.

Chapter 13

Life cycle GHG emissions of sugarcane bioenergy

Joaquim Eugênio A. Seabra
Isaias C. Macedo

Introduction

Since 2007, sugarcane has been the main renewable energy source in Brazil, representing 18.2% of the country's total energy supply or 18.8% of the total primary energy in 2009. Bioethanol represented 5.7% of the final energy consumption while electricity produced at the sugarcane mills was responsible for 4.75% (5.6 GW) of the total installed capacity in 2009 (EPE, 2010). The electricity surplus is now an important and strategic energy product for the country, as temporal and spatial (geographic) complementarities of bagasse-derived electricity and hydroelectricity (especially during the dry season) enable integration of renewable resources in electricity generation, off-setting fossil resources that would otherwise be dispatched.

Brazil is the world's largest producer and exporter of sugar; in 2008, production reached 31 Mt, with exports close to 19.5 Mt (MAPA, 2009). The sugarcane industry is expanding the production of renewable plastics and also the types of transport fuels provided, such as high energy content hydrocarbon fuels to replace other carbon-intensive fossil fuels.

Due to the importance of the cane industry and its contribution to a wide range of bio-based energies and other products, LCA studies regarding cane-derived products are needed to assess their environmental benefits. The environmental advantages of sugarcane-based bioethanol, regarding gasoline substitution and GHG emissions mitigation, have been known since the first comprehensive energy balance and GHG emissions in the bioethanol life cycle were available (Silva et al., 1978; Nogueira, 1987; Macedo, 1992; Macedo, 1998; Macedo et al., 2004). Updated studies have been published ever since, following the evolution of agricultural practices in the sugarcane sector and the scientific advances concerning environmental aspects.

Macedo et al. (2008) presented an analysis of the average conditions in the Brazilian Center-South Region for the 2005/2006 season, based on a sample of 44 mills monitored in the CTC (Centro de Tecnologia Canavieira) benchmarking control. The study was later expanded, paying special attention to the estimation of direct Land Use Change emissions, while considering the technological changes in the cane expansion projected for 2020 (Macedo and Seabra, 2008).

In 2009, the technical parameters were updated under the project Estudo de Sustentabilidade da produção de etanol de cana-de-açúcar, funded by CGEE. The CTC's database has been used once again, covering parameters for sugarcane production and processing for the 2008/2009 season. As CTC has increased the number of mills participating in its survey since 2005, for some parameters the sample on this occasion consisted of 168 mills. An in-depth analysis of critical parameters (e.g., diesel consumption) was conducted with the support of CTC specialists to ensure the consistency of the information.

The updated database was later used by Seabra et al. (2011) to assess the life cycle energy use and GHG emissions related to cane sugar and bioethanol, considering bagasse and electricity surpluses as co-products. The study evaluated the overall balance for the Brazilian Center-South Region, adopting different methods to evaluate sugar and bioethanol production separately. A well-to-wheels approach was adopted for bioethanol evaluation, and a field-to-gate approach for sugar.

In addition to fossil fuels utilization, emissions from cane trash burning and from the field due to fertilizers/limestone application and crop/industry residues returned to soil were included. The GREET 1.8c.0 model, adapted with the recent production parameters of the Brazilian Center-South Region, was employed as an auxiliary tool for the analysis.

To evaluate the environmental burdens associated with each of the main sugarcane products, a virtual subdivision method was applied, based on the mass balance with regards to the total recoverable sugars (ATR) associated to each sugar derived product of the mill, i.e. the ATR mix. The overall ATR balance of the Brazilian Center-South Region in 2008 was used in the subdivision method proposed.

Special attention was paid to the variation of some parameters among producing units based on data collected by industry. The consequent uncertainties in bioethanol life cycle emissions were assessed through a Monte Carlo analysis based on assigned distribution of probability curves for eleven selected parameters and informed by partial statistical data available from industry for distribution generation. Projections were also made for 2020 with scenario parameters based on best in current class technologies and technological improvements commercially available today.

The role of co-products

The main products of the Brazilian sugarcane industry are sugar (for the food market), anhydrous bioethanol, which is used as fuel (blended with gasoline), and hydrous bioethanol, which is used as neat fuel (in dedicated engines and flex-fuel vehicles (FFV) and also destined for a small non-energy market. There are more than 400 registered sugarcane mills in Brazil (MAPA, 2009) which can be classified into three different groups: sugar mills, for sugar production only; sugar mills with adjacent distilleries, which produce sugar and bioethanol; and autonomous distilleries for bioethanol production only. Sugarcane mills with adjacent refineries comprise about 60% of the total, autonomous distilleries make up about 37%, and the remaining are sugar mills only.

The main co-products of bioethanol and sugar production are bagasse and electricity. Nowadays, energy generation in most sugarcane mills is based on 'pure' cogeneration cycles (at pressures of 22 bar), which are able to meet the whole energy demand of the mills and still produce small bagasse and electricity surpluses (0-10 kWh/t cane). Even though an established bagasse market does not exist in Brazil, many industries acquire surplus bagasse to use as fuel, thus avoiding the use of fuel oil. Such practice, however, has been progressively reduced, as there is an increasing trend of using bagasse for electricity generation in cane mills. About 100 mills currently export electricity to the grid today, and this number is increasing.

At the end of the 1990s, with the change in the Brazilian energy sector regulation, the mills' power sections started generating surplus electricity for sale. A strong modernization process started, involving the acquisition of high pressure boilers, combined with process improvements to reduce energy demand (Seabra, 2008). As a consequence, the electricity surplus commercialized by the mills has increased, and has the potential to produce in the near future electricity levels ten times greater than those currently generated, considering the use of trash as additional fuel to bagasse.

Environmental emissions may be assigned to co-products and main products in many different ways. The most suitable way depends on the specific co-product for each case. The emissions' assignment may require different methodologies: the displacement method, physical causalities, the market value, or a specific reference scenario for the biomass/processes under consideration.

When bioenergy is the main product, the displacement method is usually selected, as recommended by the ISO standards (ISO, 2006) for LCA methodology. Usually, it takes into account the service offered by the co-product and how that service would have been delivered (the net emissions) in the absence of the co-product. These net emissions are credited to the biomass product chain for providing the co-product.

In this analysis, sugar and bioethanol pathways were created, with surplus electricity and bagasse as co-products. These co-products are used as suppliers of commercial energy, and they correspond to a relatively small value today. The displacement method was then adopted as the reference case in Seabra et al. (2011). For bagasse, authors considered the substitution of bagasse-fired boilers for fuel-oil-fired boilers, which is the most common application in Brazil (Macedo et al., 2004).

For electricity, the challenge is to estimate the amount of additional net GHG emissions that would have been produced by the Brazilian power system to provide the same energy in the absence of the surplus electricity supplied by sugarcane processing. To do so, the characteristics of the Brazilian power system need to be investigated. It consists of 80% hydropower generation (in an average hydrology year), and the remaining 20% is mostly from thermal power (EPE, 2009), to complement the national interconnected system (SIN) demand, to assist in eventual (localized) transmission restrictions, and to supply the isolated systems (SI). Wind energy also plays a (small) role, and distributed energy systems (renewable, cogeneration) are part of the system as well.

Projections for the expansion of the generation system indicate that from 2008 to 2017 the installed capacities for hydroelectricity will decrease from 81.9% to 70.9%, with a substantial increase in fuel oil based power (0.9 to 5.7%) (MME/EPE, 2009). This trend, in part, will decrease the environmental impact of large hydro power projects. Environmental restrictions to the flooding of large areas for use as water reservoirs for the new hydroelectric power stations has led to a much larger seasonal variation in power availability in the last years. New hydroelectricity units have (relatively) much smaller water-storage capacity in the dams (Chip, 2009; Silva, 2009). This has strongly limited the capacity for multiannual regulation of the large reservoirs in Brazil, demanding increased installation and dispatch of thermal power to help the supply system throughout the dry season.

The dispatch order in Brazil is: (i) hydroelectric; (ii) wind; (iii) nuclear; (iv) imports from other subsystems (ordered by ascending costs); and (v) thermal power (ordered by ascending costs). The bagasse-based generation units are classified as ‘inflexible thermal-based systems’, in the sense that they are always dispatched. They are in the lowest range of unit variable cost for the thermal systems (MME/EPE, 2009). The National Electric System Operator (ONS) considers that the energy they supply to the grid allows for the reduction of other thermal power plants’ use, with higher costs, which would have been dispatched for security reasons.

Surplus energy is produced by the sugar mills in the dry season, thus reducing the need for thermal power complementation. Since the bagasse-based surplus energy will remain at a level lower than 10% of the total electricity needs, in this decade, it is essentially reducing the use of fuels in the Operating Margin (OM). Hence, the emissions avoided by the bagasse-derived electricity today are well represented by the emission factor for the OM.

Various methodologies have been used in its evaluation (simple or adjusted OM; dispatch data analysis; average OM) (UNFCCC, 2004), but the use of the dispatch data is the most recommended one. The emission factor may then be calculated as the weighted average of the emission factors for the power generation units supplying 10% of total dispatched energy at the lowest priority dispatch (calculated each hour).

Considering the predominant use of natural gas thermal plants in the Brazilian OM generation mix (Figure 1), Seabra et al. (2011) adopted the natural gas emission factors for electricity credits evaluation in the reference scenario. The study also presented results for alternative allocation methods.

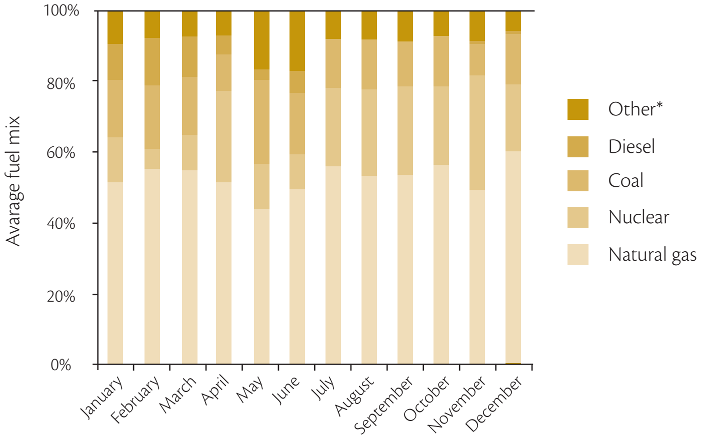


Figure 1. Average fuel mix for electricity generation in Brazilian SIN Operating Margin in 2008 (Based on MCT). *Includes hydro, wind, fuel oil, and gas coke. (SEABRA ET AL., 2011)

Energy use and GHG emissions

For the reference case (Table 1), fossil energy use and GHG emissions related to sugar production were evaluated as 721 kJ/kg and 234 g CO_2eq/kg, respectively. For the bioethanol life cycle, these values were 80 kJ/MJ and 21.3 g CO_2eq/MJ.

Table 1 – Fossil energy use and GHG emissions related to sugarcane products (2008)[a]

	Sugar		Bioethanol	
	Fossil energy use (kJ/kg)	GHG emissions (g CO2eq/kg)	Fossil energy use (kJ/MJ)	GHG emissions (g CO2eq/MJ)
Sugarcane farming	1109	85	88	6.8
Trash burning		48		3.8
Field emissions[b]		85		6.7
Agr. inputs production	508	48	40	3.8
Sugarcane transportation	237	18	19	1.4
Sugarcane processing	37	31	4	2.6
Bioethanol T&D[c]			22	1.8
Tailpipe emissions				0.8
Credits				
Electricity[d]	-754	-46	-60	-3.7
Bagasse[e]	-416	-35	-33	-2.7
Total	721	234	80	21.3

[a] From Seabra et al. (2011).

[b] Includes emissions from the soil due to fertilizers, residues and limestone application.

[c] Road transportation was considered using heavy-duty trucks and a total transportation distance (including distribution) of approximately 340 km.

[d] 10.7 kWh/t cane displacing NG thermoelectricity generation.

e. 3.3% of surplus bagasse displacing oil fueled boilers. 10% bagasse loss in handling and storage was assumed.

Considering the average conditions in 2008 in the Center-South Region, the use of anhydrous bioethanol in Brazil is able to mitigate around 80% of gasoline GHG emissions, but the uncertainties (due to differences among producing units) must be highlighted (Figure 2). The results of the Monte Carlo analysis show that the 90% confidence interval (i.e., between the 5th percentile and the 95th percentile) for anhydrous bioethanol emissions in the current conditions is 12 g CO2eq/MJ to 35 g CO2eq/MJ.

The reference case and the median values do not coincide, essentially because of the uncertainty distribution assumed for the N2O emission factor. The reference cases resulted from the average parameters; as the mean resulting from the triangular distribution is greater than the IPCC default value (used for the reference cases), higher emissions are verified in the uncertainty analysis. It is worth mentioning that for the Brazilian conditions, the averages verified for the N2O emission factor are even lower than the default value recommended by IPCC (ALVES ET AL, 2010).

Uncertainties related to variation of parameters over time also exist (mostly due to varying climatic conditions). Variations in cane quality and productivity, for instance, may impact emission averages in different ways from year to year. Nevertheless, a clear trend can be identified for the next decade, when the 90% confidence interval of bioethanol emissions is expected to be -10 g CO2eq/MJ to 14 g CO2eq/MJ. Due to the complete elimination of cane trash burning, rational use of residues in agriculture and, mainly, high levels of electricity exports, bioethanol net emissions could be close to zero on average by 2020.

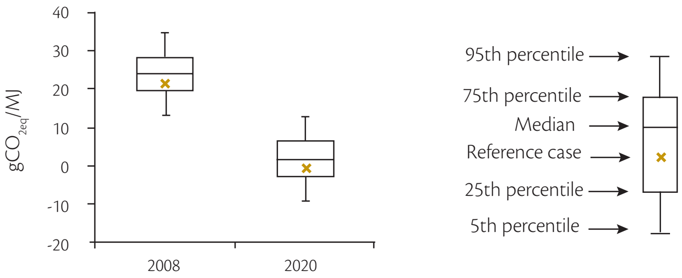


Figure 2. Box plot of the Monte Carlo uncertainty analysis results for bioethanol life cycle emissions. (SEABRA ET AL., 2011)

Potential emissions derived from Land Use Change due to sugarcane expansion are not included in the numbers presented above. For the direct LUC effects, the data for the specific Land Use Change for sugarcane expansion in the last decade indicate that less than 1% occurred over native vegetation areas (with higher C stocks) and the overall effect may actually be an increase in the C stocks of soil. For the expansion that occurred during the 2002-2008 period, LUC emissions have been estimated at -118 kg CO2eq/m3 bioethanol (MACEDO AND SEABRA, 2008). As the growth scenarios for 2020 indicate the need for relatively small areas compared to the availability, the trend is the use of more pasture lands and less crop areas in the expansion. So very little impact (if any) on LUC emissions are expected. As for the iLUC effects, there is no scientific consensus on a methodology to evaluate these emissions; besides, the large area availability in Brazil and the intensification of cattle raising systems, combined with current legislation, indicates that the iLUC effects could also be very small (NASSAR ET AL., 2009). Other sections of this book provide more in-depth analyses about LUC emissions for sugarcane.

Significant impacts may also be expected from the soil carbon stock change due to alterations in cane cultivation management. Galdos et al. (2009) paid special attention to the effects of trash management on carbon dynamics of the sugarcane crop, concluding that carbon stocks are higher in the unburned treatment. De Figueiredo and La Sacala Jr. (2011) estimated that the conversion from burned to unburned harvesting could save from 310.7 (not considering soil carbon sequestration) to 1484.0 kg CO2eq/ha.y (considering soil carbon sequestration). Galdos et al. (2010) also included the effects of the black carbon emissions. According to the study, GHG emissions in the unburned system are around 750 kg Ceq/ha.y, compared to almost 2400 kg Ceq/ha.y in the burned harvesting, taking into account the black carbon emissions. Additionally, soil carbon stocks could increase by 1500 kg Ceq/ha.y due to the shift from burned to unburned harvesting. All these results, therefore, indicate that the unburned system could considerably reduce the net GHG emissions of bioethanol production.

Advanced options for the future

The primary use of bagasse today is as an energy source in the mill's CHP systems to provide the energy requirements of sugar and bioethanol processes. Some electricity surplus is also currently produced, and this option has a great potential for expansion as mills adopt modern, commercial, high pressure cogeneration systems. For the near future, the biochemical conversion of ligno-cellulosic materials to bioethanol could be the main alternative technology. However, to play a significant role in the sugarcane sector, biochemical conversion technology must be not only a cost-effective alternative, but also competitive with the already commercial steam-Rankine systems for electricity generation from bagasse.

Studies (BOTHA AND VON BLOTTNITZ, 2006; LASER ET AL., 2009) have shown that conclusions about the comparative advantages of these alternatives are dependent on technology assumptions and regions of application. Seabra and Macedo (2011) compared the technical-economic performance and the environmental benefits (ability to mitigate GHG emissions) of power generation and bioethanol production from sugarcane residual biomass in Brazil, considering conversion plants adjacent to a mill (Figure 3). For power generation (Electricity option) a commercial Rankine-cycle system was considered, while the bioethanol production (Bioethanol option) was based on a projected enzymatic saccharification and co-fermentation system (which is expected to be commercially available in the near future).

The system performances were estimated using simulation models. In the Electricity option, the total electricity surplus of the biorefinery (mill + adjacent plant) was estimated at 130 kWh/t cane. Alternatively, the adjacent biochemical conversion plant would lead to an additional bioethanol production of about 33 L per tonne of cane, while restricting the total electricity surplus to 50 kWh/t cane.

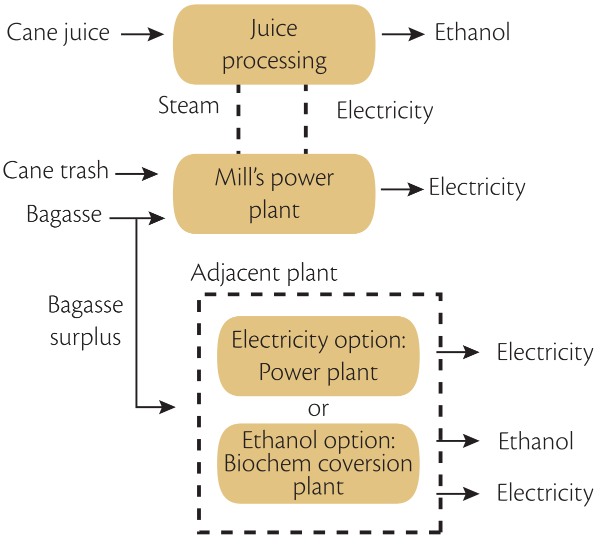


Figure 3. Sugarcane biorefinery: mill + adjacent plant.

The GREET 1.8c.0 model was used to evaluate GHG emissions in the sugarcane products life cycle considering projected 2020 scenarios. Since sugarcane production parameters were assumed to be the same for both technology routes, the total GHG emissions turned out to be similar, as presented in Table 2. Small differences are observed in the sugarcane processing – in the Electricity option, greater direct emissions are verified, derived from bagasse combustion, while the Bioethanol option presents greater emissions associated to chemicals production. For the Bioethanol option, emissions from bioethanol transportation and distribution and fuel combustion (tail pipe emissions) are naturally greater than for the Electricity option, due to the higher bioethanol yield per tonne of cane. Despite the additional emission sources, the Bioethanol option is able to mitigate more GHG emissions.

Though mitigated emissions by the displacement of NG thermo-electricity are significant (even for the Bioethanol option), the benefits of bioethanol substitution for gasoline determine the preference for the liquid fuel production. Nevertheless, power generation is preferred if more carbon intensive fuels (coal, for instance) are considered for the marginal electricity generation, as illustrated in Figure 4. It is worth mentioning that these results are sensitive to the products yields, and differences in the assumed process efficiencies may change the final results.

Table 2 – GHG emissions balance for the sugarcane biorefinery (kg CO2eq/t cane)

Parameter	2008	2020 Electricity option	2020 Bioethanol option
Total emissions	47.8	40.0	42.3
Avoided emissions	-196.4	-281.8	-310.2
Gasoline displacement	-185.4	-205.1	-280.5
Marginal elect. displacement	-6.3	-76.6	-29.7
Fuel oil displacement	-4.7	0.0	0.0
Net avoided emissions	-148.6	-241.8	-267.9

Compared to the current situation, both alternative scenarios represent a significant increase of the mitigation potential, especially because of higher efficiencies projected for the cane conversion step. As more cane derived products are available (bioethanol and electricity), more fossil products could then be displaced. The numbers presented here indicate that additional production of bioethanol through the biochemical route could lead to higher mitigation potential, but it must be noted that towards the next the decade other advanced options for cane biomass utilization may also reach a commercial level, possibly with even better environmental performances. Today, only the steam co-generation cycles are commercially available. Even though promising performances are projected at this point, significant developments are still needed before we can enjoy the benefits of advanced, cost competitive alternatives on a large scale.

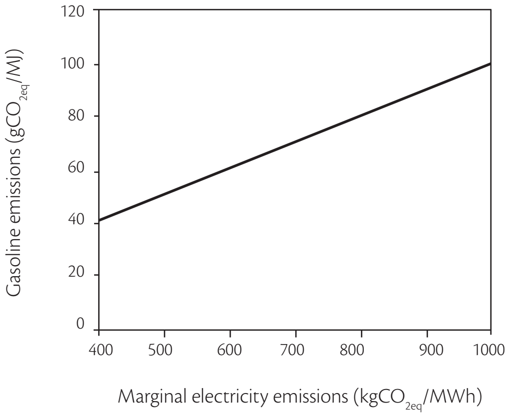


Figure 4. Life cycle emissions for gasoline and marginal electricity (to yield equal net mitigated emissions). (SEABRA AND MACEDO, 2011)

References

ALVES, B.J.R.; JANTALIA, C.P.; MADARI, B.E.; MACHADO, P.L.O.A.; FRANCHINI, J.C.; SANTOS HP ET AL. Emissões de óxido nitroso de solos pelo uso de fertilizantes nitrogenados em áreas agrícolas. Seropédica, RJ: Embrapa, Junho, 2010. (Comunicado técnico 126).

CHIPP H. Desafios para operação em um sistema com maior participação térmica. Operador Nacional do Sistema Elétrico (ONS). In: FÓRUM Matriz energética e segurança do sistema elétrico nacional. Rio de Janeiro, Agosto 2009.

DE FIGUEIREDO, E.B.; LA SCALA, N. Greenhouse gas balance due to the conversion of sugarcane areas from burned to green harvest in Brazil. Agriculture, Ecosystems & Environment. v. 141, n. 1-2, p. 77-85, 2011.

EMPRESA DE PESQUISA ENERGÉTICA - EPE. Balanço Energético Nacional 2009: Ano base 2008. Rio de janeiro, RJ, 2009.

_____. Balanço Energético Nacional 2010: Ano base 2009. Rio de janeiro, RJ. 2010.

GALDOS, M.V.; CERRI, C.C.; CERRI, C.E.P. Soil carbon stocks under burned and unburned sugarcane in Brazil. Geoderma, v.153, p.347-352, 2009.

GALDOS, M.V.; CERRI, C.C.; LAL, R.; BERNOUX, M.; FEIGL, B.; CERRI, C.E.P. Net greenhouse gas fluxes in Brazilian ethanol production systems. GCB Bioenergy v. 2, p.37-44, 2010.

ARGONNE NATIONAL LABORATORY. GREET - The greenhouse gases, regulated emissions, and energy use in transportation model. Version 1.8c.0. S.l.:2009.

ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

MACEDO, I.C. Greenhouse gas emission and energy balances in bio-ethanol production and utilization in Brazil. Biomass Bioenergy, v.14, n. 1, p. 77-81, 1998.

MACEDO, I.C.; LEAL, M.R.L.V.; SILVA, J.E.A.R. Balanço das emissões de gases de efeito estufa na produção e no uso do etanol no Brasil. São Paulo: Secretaria do Meio Ambiente, Governo de São Paulo. Abril 2004.

MACEDO, I.C.; SEABRA, J.E.A.; SILVA, J.E.A.R. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: the 2005/2006 averages and a prediction for 2020. Biomass Bioenergy v. 32, p.582-595, 2008.

MACEDO, I.C.; SEABRA, J.E.A. Mitigation of GHG emissions using sugarcane bioethanol. In: ZUURBIER, P.; VAN DE VOOREN, J. (eds) Sugarcane ethanol: contributions to climate change mitigation and the environment. Wageningen, the Netherlands: Wageningen Academic Publishers, 2008.

MACEDO, I.C. The sugar cane agro-industry and its contribution to reducing CO2 emissions in Brazil. Biomass and Bioenergy v. 3, n. 2, p. 77-80, 1992.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento - MAPA. Anuário estatístico da agroenergia. Brasília: Mapa/ACS. 2009.

____. Plano decenal de expansão de energia 2008/2017. Rio de Janeiro, RJ: EPE, 2009.

NASSAR, A.M.; HARFUCH, L.; MOREIRA, M.M.R.; BACHION, L.C.; ANTONIAZZI, L.B. Impacts on land use and GHG emissions from a shock on Brazilian sugarcane ethanol exports to the united states using the Brazilian land use model (BLUM). Report to the U.S. Environmental Protection Agency regarding the Proposed Changes to the Renewable Fuel Standard Program. Institute for International Trade Negotiations (ICONE), September 2009.

NOGUEIRA, L.A.H. Análise da utilização de energia na produção de álcool de cana-de-açúcar. Thesis (PhD), Unicamp 1987.

SEABRA, J.E.A.; MACEDO, I.C. Comparative analysis for power generation and ethanol production from sugarcane residual biomass in Brazil. Energy Policy v. 39, p.421-428 2011.

SEABRA, J.E.A.; MACEDO, I.C.; CHUM, H.L.; FARONI, C.E.; SARTO, C.A. Life cycle assessment of Brazilian sugarcane products: GHG emissions and energy use. Biofuels, Bioproducts & Biorefinig v. 5, p. 519-532, 2011.

SEABRA, J.E.A. Avaliação técnico-econômica de opções para o aproveitamento integral da biomassa de cana no Brasil. Tese (Doutorado). Campinas, Faculdade de Engenharia Mecânica, Unicamp. 2008.

SILVA, E. Análise dos leilões de energia elétrica. Assoc. Bras. de Geradoras Termoelétricas. Agosto 2009.

SILVA, J.G.; SERRA, G.E.; MOREIRA, J.R.; GONÇALVES, J.C.; GOLDEMBERG, J. Energy balance for ethyl alcohol production from crops. Science v. 201, n. 4359, p. 903-906, 1978.

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE - UNFCCC. Clean development mechanism (CDM): Approved baseline methodology AM0015: Bagasse-based cogeneration connected to an electricity grid. Version 01 (2004).

Chapter 14

Fossil energy use and greenhouse gases emission in the integrated production of bioethanol and biodiesel

Joaquim Eugênio A. Seabra
Simone Pereira Souza

Introduction

Global biofuels supply reached 0.7 mb/day in 2007, an impressive 37% increase since 2006. But the recent surge in biofuels production is not expected to continue in the short term. Concerns about the effects on food prices from diverting crops to biofuels, questions about the magnitude of greenhouse gases (GHG) emissions savings associated with switching to biofuels and doubts about their environmental sustainability have caused many to rethink biofuels blending targets (IEA, 2009). Despite the recent downturn, global use of biofuels is projected to recover in the long term, reaching 2.7 mb/d by 2030 in the IEA's Reference Scenario (IEA, 2009).

A considerable share of this growth is expected to come from second-generation technologies, which would enable the consolidation of biorefineries. In a broad sense, a biorefinery can be defined as an integrated complex which is able to produce different products (fuels, chemicals and power) from different biomass feedstocks (ONDREY, 2006), in a scenario that could also involve a reduced commitment of land for bioenergy purposes.

Today we can say that the already established sugarcane mills in Brazil are important pacesetters for future biorefineries, using sugarcane biomass for the production of bioethanol, sugar, power and other products. But the potential for improvement is still enormous. In addition to the better use of lignocellulosic material, a more efficient use of land aimed at the integration of bioenergy systems deserves attention as well. One example of such integration has been tested at a commercial scale in Brazil, exploring the integrated production of bioethanol and biodiesel (OLIVERIO ET AL., 2006).

The synergies from this integration are verified not only in the agricultural and industrial spheres, but also in the administrative and commercial contexts (MDIC, 2006). In the agricultural sector, oilseeds production in crop rotation with sugarcane is a well known practice that helps to break sugarcane diseases and pest cycles and contributes to the recovery of soil fertility. Additionally, the common use of agricultural and industrial infrastructure allows for the splitting of costs, the optimized use of industrial facilities and minimization of investments, as well as the possibility of using biodiesel as fuel in machinery and trucks. In the administrative and commercial fields, the use of the same business structure and the diversification of products bring important strategic advantages, and biodiesel commercialization can also take advantage of the experience acquired through bioethanol fuel.

The objective of this study was to investigate the environmental benefits of this type of integration by assessing their impact on fossil energy use and GHG emissions associated with bioethanol production. A hypothetical production system was analyzed, assuming that soybeans would be grown in the sugarcane reforming areas. The oil extracted from the soybeans would be the feedstock for the biodiesel to be produced in a conversion plant adjacent to the sugarcane mill. The biodiesel produced would partially displace diesel fuel (B5) for sugarcane cultivation.

Liquid biofuels in Brazil

Bioethanol

Bioethanol (or bioethanol) has a long history in Brazil. Production started back in the 1930's, when a 5% blend with gasoline was compulsory. But only in the 1970's, during the oil crisis, was the national bioethanol program (Pro-álcool) launched, and production was boosted (Figures1 and 2).

The technology to produce bioethanol from the cane's sugars is well-known and advanced. In Brazil, it is based on the fermentation of either cane juice or molasses, or a mixture of both. Most of the mills in Brazil (figure 3) are sugar mills with adjacent distilleries, but the number of autonomous distilleries has increased with the new greenfield projects.

In the last 30 years a progressive technology evolution has been verified in both agricultural and industrial areas, leading to important cost reductions (Figure 4). Today, sugarcane bioethanol is cost-competitive with fossil fuels, without any need for subsidies, and further improvement is foreseen in the near future. The technology advances in bioethanol production have also impacted environmental performance. Under the present conditions, for each fossil energy unit that is required in the bioethanol production chain, around nine units of renewable energy are produced. With respect to GHG emissions, bioethanol is able to mitigate about 80% of the emissions when compared to gasoline (MACEDO AND SEABRA, 2008).

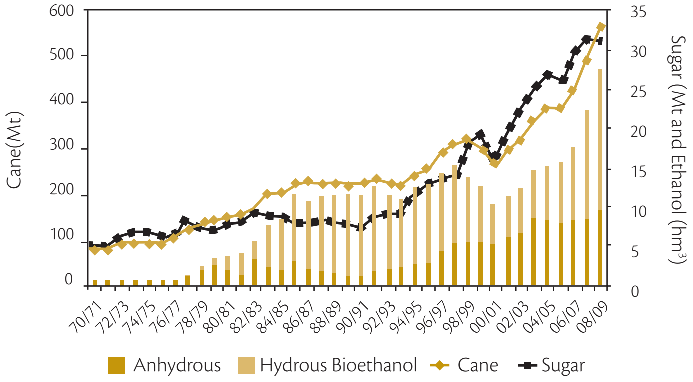


Figure 1. Historical trends in the production of sugarcane, sugar, anhydrous and hydrous bioethanol in Brazil (based on MAPA, 2009).

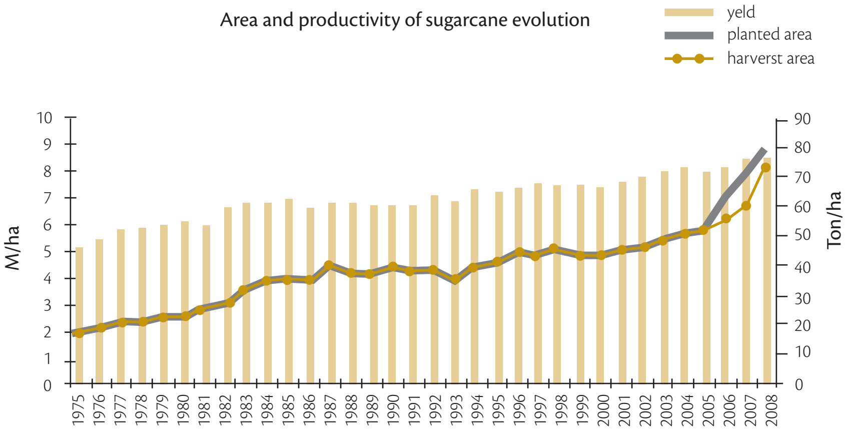


Figure 2. Evolution of the Brazilian production area and productivity of sugarcane for all purposes (MAPA, 2009).

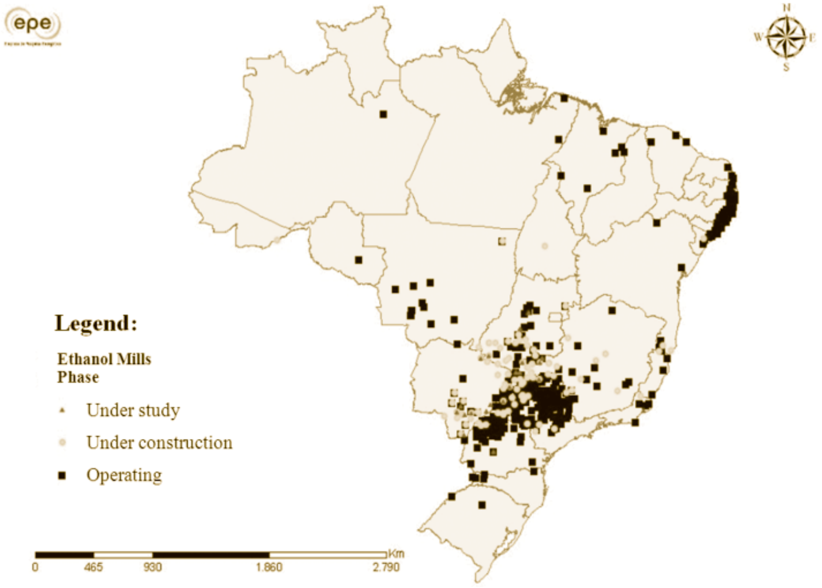


Figure 3. Sugarcane units in Brazil (EPE, 2008).

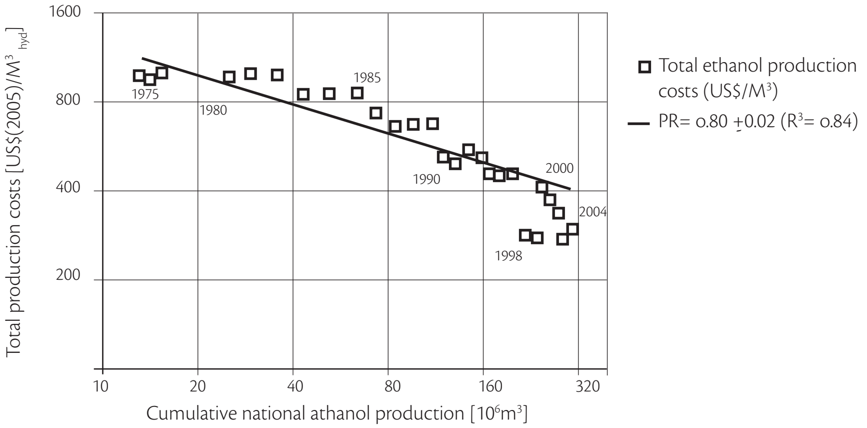


Figure 4. Evolution of hydrous bioethanol production costs between 1975 and 2004 (VAN DEN WALL BAKE, 2009).

Biodiesel

The first references to the use of vegetable oils as fuel in Brazil date back to the 1920s. In 1980 Resolution No. 7 from the Conselho Nacional de Energia (CNE) established the national program for the production of vegetable oils for energy purposes (Proóleo). Among other objectives, the Program intended to replace diesel with vegetable oils in a blend of up to 30% in volume, encourage technological research to promote the production of vegetable oils in different regions of the country and pursue the complete replacement of diesel with vegetable oils. Also in the early '80s, the department of industrial technology of the ministry of trade and industry (STI/MIC) developed and launched the national program for alternative renewable energy of vegetable origins, with some lines of action related to vegetable oil fuel, which led to the OVEG Program. Because of the subsequent fall in oil prices, these early initiatives of the government were unsuccessful (GARCEZ ET AL. 2009; BIODIESELBR, 2010).

With this background, and taking into account the strong European biodiesel program, the federal government launched the national program of biodiesel production and use (PNPB) in December 2004. Through law 11,097 of January 13, 2005, the Brazilian government established the mandatory addition of a minimum percentage of biodiesel to diesel oil sold to consumers nationwide. Since January 1, 2010, all diesel fuel sold in Brazil contains 5% biodiesel.

Biodiesel is comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. In Brazil, soybean is the main feedstock for biodiesel production, followed by tallow (Figure 5). Brazil is currently among the largest producers and consumers of biodiesel in the world, with an annual production of 1.6 billion liters (Figure 6).

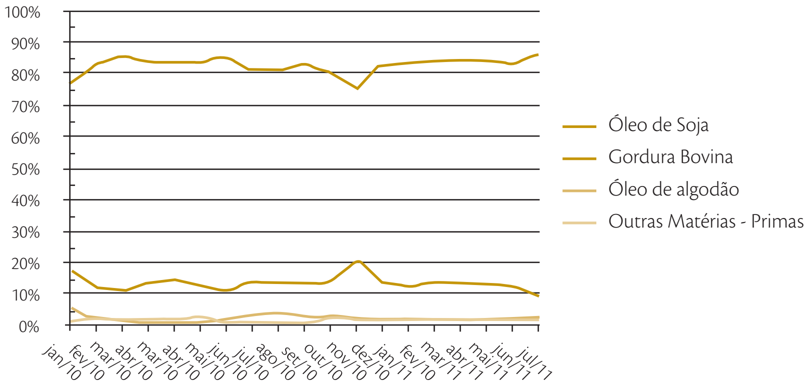


Figure 5. Main feedstocks for biodiesel production in Brazil (January/2009 to March/2010) (ANP, 2011).

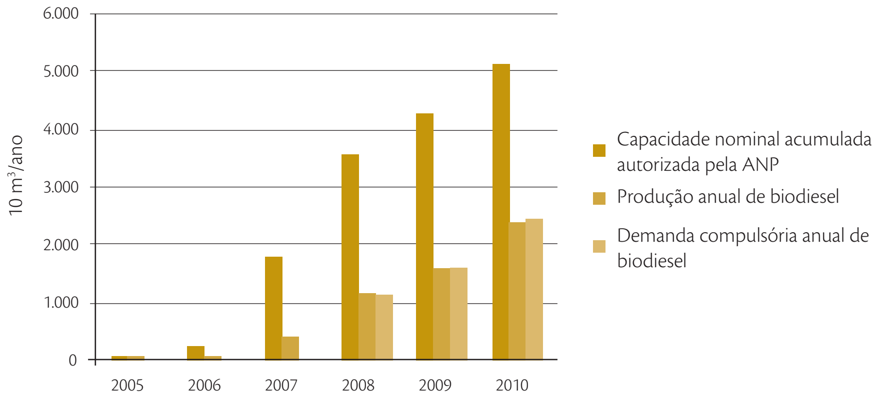


Figure 6. Historical trends in production, compulsory demand and nominal capacity authorized by ANP (ANP, 2011).

There are 67 biodiesel plants authorized by ANP to operate in the country (Figure 7), which corresponds to a total authorized capacity of 17,852.95 m3/day. Out of these 67 plants, 62 have authorization to commercialize the biodiesel produced, representing 17,165.25 m3/day (ANP, 2011). Biodiesel prices are established in auctions organized by ANP. The initial objective of the auctions was the establishment of the market, but they are still in practice in order to guarantee the percentage of blending required by law.

Despite its rapid growth, the sustainability of biodiesel production still needs to be demonstrated. Its cost is still far from being competitive with fossil diesel, and its social benefits are limited (HORTA NOGUEIRA, 2009). Regarding environmental aspects, benefits are verified (for some feedstocks) with respect to the energy balance and ability to mitigate GHG emissions, even though they are not as significant when compared to sugarcane bioethanol (Table 1).

Table 1 – Fossil energy consumption and GHG emission related to biodiesel production (HORTA NOGUEIRA, 2009)

Feedstock	Fossil energy consumption (MJ/kg biodiesel)	GHG emissions (g C/kg biodiesel)
Soybean	12.1	302.8
Castor	36.2	903.3
Palm oil	11.5	236.5
Animal Fat	6.0	139.5

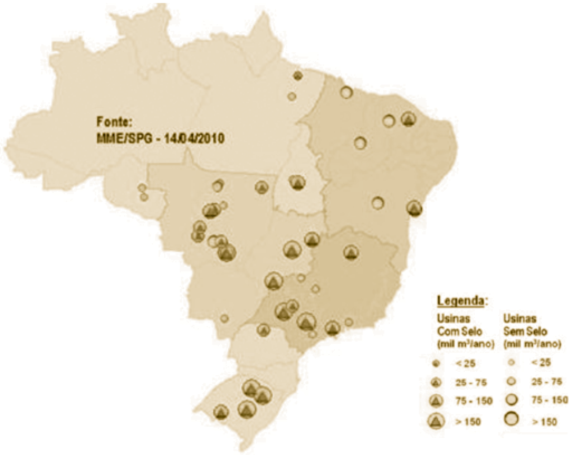


Figure 7. Biodiesel production units in Brazil (MME, 2010)

Methodology

Selected systems

In this study two cases were considered to assess the impact of biodiesel use on the emissions and energy balances of bioethanol:

- Reference Case: considers a conventional sugarcane production and processing system that uses only diesel (B5) as fuel in agricultural operations and transportation. Bioethanol and electricity are the final products.
- Integrated System: considers the integrated production of biodiesel, bioethanol and electricity. The biodiesel produced is used to partially replace the conventional diesel (B5) consumed in agricultural operations and sugarcane transport. For this replacement, it was assumed that 1 MJ of biodiesel (B100) would be able to displace 1 MJ of diesel (B5).

Figure 8 schematically represents the Integrated System considered, in which the soybeans would be grown in the cane reforming areas. Therefore, no additional area would be required for the biodiesel production. In this study it was assumed that 15% of the total sugarcane area would be reformed annually, and soybeans would be grown on 100% of this renovation area. Because of the biological nitrogen fixation (BNF) promoted by the soybean cultivation, it was assumed that the mineral nitrogen fertilization of plant-cane would not be necessary.

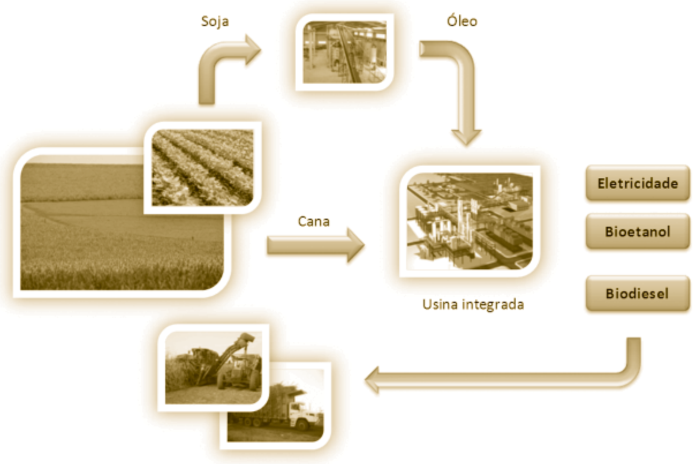


Figure 8. Integrated system considered in this study.

Oliverio et al. (2006) indicate three stages in the evolution of the integration between biodiesel and bioethanol production processes. The (hypothetical) integrated system studied here comprises the first stage of this evolution, which involves only a partial industrial integration. In this already commercially available system, soybeans are harvested and transported to an oil extraction and treatment unit. Through the Façon barter system (OLIVERIO ET AL., 2006), the co-produced meal is exchanged for oil, enabling a total oil "yield" of more than 430 kg/t grain. The oil produced is then transported to the plant for conversion to biodiesel.

The biodiesel production plant is adjacent to a distillery, which supplies the entire demand for utilities. Thus, bagasse is the only fuel used in the industrial complex. The final products of such an industrial complex are bioethanol, biodiesel and a small surplus of electricity. The impacts of the adjacent production of biodiesel on the bioethanol yield, total fuel consumption and electricity surplus were neglected in this analysis. This assumption is accepted because of the relative scales involved.

Biodiesel production is limited to the oil derived from soybeans grown in the sugarcane reforming area (although the availability of oil is higher because of the Façon system). However, larger adjacent plants should be considered in commercial systems, which should also be able to process other feedstocks into biodiesel. This is the case of the 50,000 t/year unit currently in operation in Brazil (OLIVERIO *et al.*, 2006), which is adjacent to a 2.2 Mt cane/year sugarcane mill. In 2006, this particular mill produced about 152,000 m3 of bioethanol and 50,000 tons of sugar. It is worth noting that the impact of the biodiesel plant in the plant's energy demand is minimal.

Table 2 presents the data considered for soybean production, transportation, oil extraction and oil treatment. Data on the agricultural stage of soybean production refer to the averages of the 2007/2008 and 2008/2009 seasons verified for three municipalities in the Mato Grosso state, representing a total area of 6300 ha (CAPAZ, 2009). For sugarcane, averages are taken from the CTC Report (CGEE, 2009) corresponding to the 2008/2009 season in the Center-South region. The industrial parameters (Table 3) are based on statistics provided from private organizations (ABIOVE, CTC, UNICA) and equipment manufacturers (MOURAD, 2008; CGEE, 2009; OLIVERIO *et al.*, 2006).

Table 2 – Parameters for soybean production, transportation, extraction and oil treatment.

Parameters	Units	Value
Farming[a]		
Percentage of sugarcane reforming area	%	100%
Yield	kg/ha	3150
Agricultural inputs		
N	kg/ha	1
P_2O_5	kg/ha	77.5
K_2O	kg/ha	84.4
$CaCO_3$	kg/ha	[b]
Herbicide	kg/ha	1.7
Insecticide	kg/ha	1.04
Fungicide	kg/ha	0.66
Seeds	kg/ha	50.83
Diesel consumption	L/t grain	11.5
Grain transportation[a]		
Average distance[c] (one way)	km	100
Load capacity	t	10
Fuel consumption	km/L	2.5
Oil extraction[d]		
Oil yield		
Additional oil yield (Façon)[e]	kg/t grain	180

Parameters	Units	Value
Hexane consumption	kg/t grain	1.1
Electricity consumption	kWh/t grain	37
Firewood consumption	kg/t grain	67
Oil transportationf		
Average distancec (one way)	km	100
Load capacity	t	22.7
Fuel consumption	km/L	2.1

[a] Capaz (2009).

[b] The consumption of limestone was attributed to sugarcane.

[c] Arbitrary values.

[d] Estimated from Capaz (2009).

[e] Olivério et al. (2006).

[f] Estimated from the GREET model.

Table 3 – Parameters for bioethanol and biodiesel production.

Parameters	Units	Value
Bioethanol production [a]		
Yield [b]	L/t sugarcane	85
Surplus Electricity [c]	kWh/t sugarcane	10.7
Bagasse consumption	kg/t sugarcane	264
Chemicals inputs [d]		
Lime	g/t sugarcane	880
Sulfuric Acid	g/L bioethanol	7.37
Caustic Soda	g/L bioethanol	2.12
Antibiotic	g/m3 bioethanol	9.285
Biodiesel production [e]		
Biodiesel yield	kg/t oil	1046
Glycerin yield (85%)[c]	kg/t biodiesel	117
Utilities		

Parameters	Units	Value
Electricity	kWh/t biodiesel	15
Steam	kg/t biodiesel	300
Water cooling	Mcal/t biodiesel	145
Air	Nm3/t biodiesel	6
Chemicals inputs		
Bioethanol	kg/t biodiesel	154
Sodium Methylate (30%)	kg/t biodiesel	33.4
Citric Acid	kg/t biodiesel	0.65
Hydrochloric acid (36%)	kg/t biodiesel	9.5
Caustic Soda (50%)	kg/t biodiesel	1.5
Sulfuric Acid	kg/t biodiesel	0.2

[a] CGEE (2009).

[b] Average of UNICA members in 2009.

[c] Coproducts.

[d] Main inputs.

[e] Ethyl route (Olivério et al.,2006).

Evaluation of fossil energy use and GHG emissions

This study evaluated the use of fossil energy and GHG emissions in the bioethanol production chain, from sugarcane cultivation to bioethanol processing (a cradle-to-gate analysis). Two levels of energy flows were considered in energy balance and GHG emissions: the direct consumption of fuels and electricity; and the additional energy required to produce the chemical inputs (fertilizers, limestone, sulfuric acid, lubricants, etc.).

All energy flows were calculated in terms of primary energy, taking into account the energy inputs required over the whole life cycle stages of fuels and electricity. These background data were mostly based on parameters given by the GREET1.8c.0 model. For the B5 diesel, emission factors resulted from the weighted average (by volume) between fossil diesel (GREET1.8c.0) and soybean biodiesel (HORTA NOGUEIRA, 2009). For the B100 biodiesel produced in the integrated system, specific parameters were determined in this study.

Energy consumptions for the soybean production and firewood were based on Mourad (2008), which were used to estimate the GHG emissions. For the industrial chemical inputs, specific energy consumption and emissions were based on aggregated information provided by the national chemical industry association (ABIQUIM, 2008). Parameters for hexane were obtained from Cunha (2008).

In addition to the emissions from fuel use, emissions from sugarcane trash burning, application of nitrogen fertilizers and limestone and the residues that are returned to the soil (cane trash, filter cake, vinasse, ash) were quantified. For soybeans, the N2O emissions from above and below ground residues were estimated according to IPCC tier 1 method (2006). As for sugarcane, emissions from below ground residues were not considered here, but they will be included in future analyses as specific data for sugarcane crop become available. Direct N_2O emissions resulting from biological nitrogen fixation promoted by soybean cultivation were not considered due to the lack of evidence indicating significant emissions from this process (IPCC, 2006).

Energy and emission credits from coproducts were evaluated considering that the electricity surplus would displace the natural gas thermoelectricity, as discussed in CGEE (2009). In the case of glycerin (coproduct of biodiesel), a mass-based allocation method was used to separate the emissions related to oil production. Even though oil accounts for less than 20% of the mass of the soybean grain, emissions from soybean production were not allocated to the meal, since it is exchanged for oil in the Façon system (which can already be seen as an allocation criterion).

Results

In the Reference Case, the diesel consumption in agricultural activities and sugarcane transport is about 2/3 of the total consumption of fossil fuels for bioethanol production (Figure 9). Due to soil emissions and trash burning, the contribution of the use of diesel is much lower for GHG emissions, accounting for less than 30% of the total. This makes the displacement of fossil diesel especially interesting for the bioethanol's energy balance, although significant emission reductions can be observed (Figures 9 and 10). Because of soybean cultivation in the reforming areas, a small benefit is also verified from the assumed elimination of N-mineral fertilization of the plant-cane.

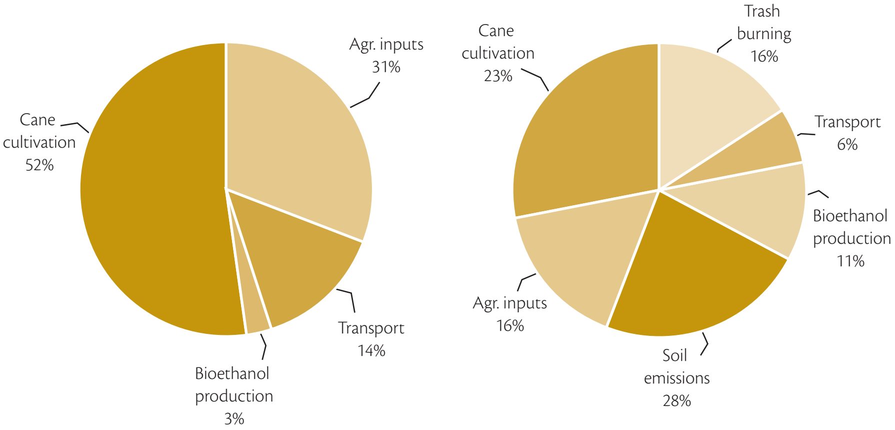


Figure 9. Breakdown of fossil energy use and GHG emissions for the reference case.

In the Integrated System, the biodiesel produced at the adjacent plant would be sufficient to replace about 70% of the diesel used in the production and transportation of sugarcane. Such substitution makes the consumption of fossil energy drop from 69 kJ/MJ of bioethanol (Reference Case) to only 4 kJ/MJ (Figure 10). In this system, the sugarcane cultivation and transportation stages represent only 1/3 of the energy consumption, leaving the production of agricultural inputs as the main contributor. As for GHG emissions, the impact of the substitution is less significant. GHG emissions in the Reference Case were evaluated as 18.9 g CO_2eq/MJ, while in the Integrated System they would be 13.7 g CO_2eq/MJ (Figure 11).

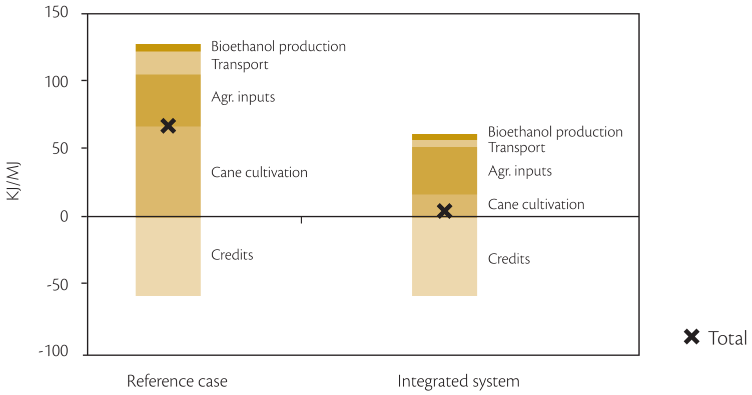


Figure 10. Fossil energy consumption in the sugarcane bioethanol production chain.

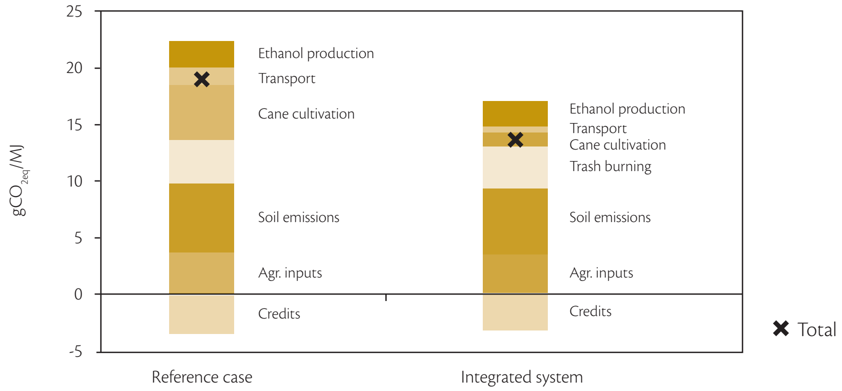


Figure 11. GHG emission in the sugarcane bioethanol production chain.

It is important to note that the profiles of energy consumption and emissions vary from mill to mill. The Reference Case adopted here represents the average situation in the Center-South region during the 2008/2009 season, but significant variations can be verified. In general, the trend for the next few years is the complete elimination of trash burning accompanied by increasing diesel consumption due to mechanization. The electricity surplus will also increase significantly, leading to emission credits that might even offset all emissions from the bioethanol production. Regardless, the integrated production of biodiesel is an important strategy, not only to further reduce emissions, but also to contribute to the independence from fossil fuels in the bioethanol production chain. However, the limitations of soy oil production should also be investigated, considering the constraints related to land availability and suitable conditions for cultivation.

Under the conditions assumed in this study, the fossil energy consumed in order to produce one tonne of biodiesel was estimated at approximately 4 GJ, while GHG emissions would be close to 410 kg CO_2eq. The soybean cultivation and transportation would represent the main energy consumers. In terms of emissions, the oil extraction may represent the main source, in the case of fuel oil being used as an energy source instead of firewood. In addition to the better use of land, the use of bagasse as fuel for biodiesel production also represents a major advantage of the integrated system, allowing for considerably lower fossil energy consumption and emissions compared to conventional systems. Mourad (2008), for example, estimates a total fossil fuel consumption of approximately 11.7 GJ/t biodiesel using soybeans as feedstock in a conventional system, while Horta Nogueira (2009) reports values of 12.1 GJ/t and 1110 kg CO_2 eq/t for fossil fuel consumption and emissions, respectively.

It is important to note that even higher performances could be achieved through the gradual advance of processes integration, eventually enabling both oil extraction and processing within the mill. Other feedstocks could also be used, based either on vegetal oils or animal fat. This flexibility would provide strategic advantages to the biorefinery and enable the exploration for environmentally attractive alternatives.

Conclusions

The diversification of feedstocks and the integration of different production systems can bring significant contributions to the sustainability of biofuel production. In Brazil, the integration of bioethanol and biodiesel has already been explored at a commercial scale, involving the cultivation of soybeans in cane reforming areas. In addition to the synergies verified in the agricultural, industrial and administrative areas, significant environmental benefits can also be observed through this type of integration.

It was verified in this work that the integrated production of bioethanol and biodiesel can reduce GHG emissions and, especially, fossil energy use in the bioethanol production chain. Compared to the Reference Case, the integrated system evaluated here would enable a drop from 69 to 4 kJ/MJ bioethanol for the consumption of fossil fuels, while emissions could be reduced from 18.9 to 13.7 g CO_2eq/MJ of bioethanol.

This integrated production is an important option for the independence from fossil fuels in the bioethanol production chain, without requiring the occupation of additional areas. Moreover, in larger scale systems, which would use feedstocks from other systems, the biodiesel surplus would also depend on the important environmental advantage of using bagasse as an energy source in the conversion step. All these options are environmentally attractive, but the socio-economic aspects must also be analyzed in order to have a comprehensive picture of the sustainability of these systems.

References

ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA QUÍMICA – ABIQUIM. Indústria química reduziu emissões de gás carbônico e consumo de água. Comunicação Abiquim, São Paulo, 18 de junho. 2008.

AGÊNCIA NACIONAL DO PETRÓLEO – ANP. Boletim mensal de biodiesel – Agosto de 2010. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis. Superintendência de Refino e Processamento de Gás Natural – SRP. (2011).

BIODIESELBR. Disponível em: <www.biodieselbr.com>. Acesso em: mai 2010.

CAPAZ, R.S. Estudo do desempenho energético da produção de biocombustíveis: aspectos metodológicos e estudo de caso. Dissertação (Mestrado). Itajubá, Universidade Federal de Itajubá. 121p. 2009.

CENTRO DE GESTÃO DE ESTUDOS ESTRATÉGICOS – CGEE. Estudo de sustentabilidade da produção de etanol de cana-de-açúcar. Relatório Técnico Final. 2009.

CUNHA, J.T. Inventário do ciclo de vida do Bodiesel de sebo bovino e de soja e de óleo diesel de petróleo para o uso em ônibus urbanos na cidade de São Paulo/SP. Dissertação (Mestrado). São Paulo, Instituto de Pesquisas tecnológicas do Estado de São Paulo (IPT). 132p. 2008.

EMPRESA DE PESQUISA ENERGÉTICA.- EPE Perspectivas para o etanol no Brasil. Cadernos de Energia EPE. Ministério de Minas e Energia. 2008.

GARCEZ, C.A.G.; VIANNA, J.N.S. Brazilian Biodiesel Policy: Social and environmental considerations of sustainability. Energy v. 34, p. 645-654. 2009.

HORTA NOGUEIRA, L.A. Does biodiesel make sense? In: INTERNATIONAL CONFERENCE on Efficiency, Cost, Optimization Simulation and Environmental Impact of Energy Systems (ECOS 2009). September, Foz do Iguaçu, Brazil. 2009.

INTERNATIONAL ENERGY AGENCY – IEA. World energy outlook 2009. Paris. 2009.

IPCC. Guidelines for national greenhouse gas inventorie. Eggleston H.S.; Buendia L.; Miwa K.; Ngara T.; Tanabe K. (eds). National Greenhouse Gas Inventories Programme. IGES, Japan. 2006.

MACEDO, I.C.; SEABRA, J.E.A. Mitigation of GHG emissions using sugarcane bioethanol. In: ZUURBIER, P.; VAN DE VOOREN, J. (eds). Sugarcane ethanol: Contributions to climate change mitigation and the environment. The Netherlands: Wageningen Academic Publishers, p. 95-111. 2008.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento.- MAPA. Anuário estatístico da agroenergia. Brasília, DF: Secretaria de Produção e Agroenergia. 2009.

BRASIL. MINISTÉRIO DE MINAS E ENERGIA. – MME. Boletim mensal dos combustíveis renováveis. nº 27 – Mar/2010. Secretaria de Petróleo, Gás Natural e Combustíveis Renováveis. Departamento de Combustíveis Renováveis. 2010.

MOURAD, A.L. Avaliação da produção de biodiesel a partir da soja em sua cadeia produtiva. Tese (Doutorado). Campinas, Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas. 125 p. 2008.

OLIVÉRIO, J.L.; BARREIRA, S.T.; RANGEL, S.C.P. Integrated biodiesel production in Barralcool sugar and alcohol mill. International Sugar Journal, v. 108, n. 1287. 2006.

ONDREY, G. The path to biorefineries. Chemical Engineering, v.113, Iss. 4; p. 27, 3 p. New York: Apr 2006.

VAN DEN WALL BAKE, J.D.; JUNGINGER, M.; FAAIJ, A.; POOT, T.; WALTER, A. Explaining the experience curve: Cost reductions of Brazilian ethanol from sugarcane. Biomass and Bioenergy v. 33, p. 644-658. 2009.

Chapter 15

Contribution of sugarcane bioenergy to the Brazilian energy matrix

Arnaldo Walter

Introduction

In this chapter the contribution of sugarcane bioenergy to the Brazilian energy matrix is assessed. The text is divided into two parts, the first being devoted to an overview of historic facts and to the current contribution of sugarcane, while the second part deals with the perspectives leading up to 2030. The first part is based on data from 1970 to 2010, presented by the Brazilian Energy Balance (EPE-MME, 2011), and the second part is based on official forecasts for the years 2020 and 2030 (EPE, 2011; EPE, 2007).

The evolution of the Brazilian energy matrix

Few countries with the same development level as Brazil have an energy matrix where renewable energy sources have such an important role. In 2010, considering the Total Primary Energy Supply (TPES), the contribution of renewable energy sources was 47.5%, and this share has been kept almost constant over the last five years. Sugarcane products have been the main renewable energy source since 2007, and in 2010 represented 19.3% of the TPES (bioethanol and bagasse are the secondary energy sources). Figure 1 shows the evolution of the TPES in Brazil from 1970 to 2010, and highlights the contribution of renewable energy.

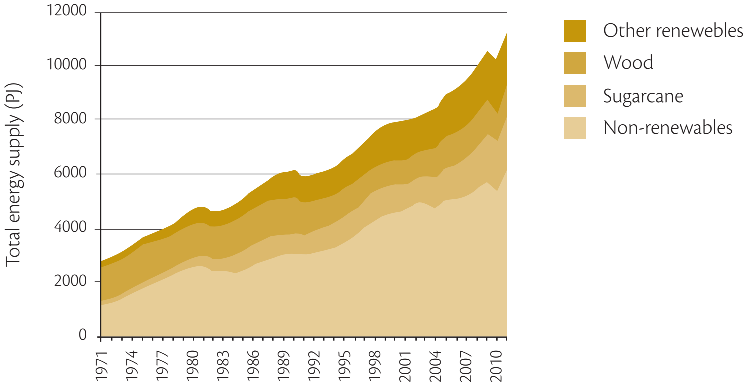


Figure 1. Evolution of total primary energy supply in Brazil – 1970-2010.

Source: EPE-MME (2011).

Over roughly three decades, Brazil greatly reduced its external oil dependency and currently, in general, has a self-sufficient oil supply. On the other hand, Brazil depends a lot on high quality coal (coke and coal for metallurgic purposes), mainly consumed in the iron and steel industry. During the 1980s this dependency was partially reduced when specific policies fostered the use of charcoal for displacing coke[1]. The external dependency on natural gas is more recent and started with imports from Bolivia in the 1990s; concerning natural gas supply, there is an effort to enlarge the domestic supply but the results so far are modest. And finally, the external dependency regarding electricity is mostly due to the imports from Paraguay, which is co-owner of the Itaipu dam. Figure 2 shows the evolution of the external dependency of oil, natural gas, coal and electricity over 40 years.

Figure 3 shows details of the final biomass energy consumption in Brazil. Wood consumption was reduced from the mid 1980s to the late 1990s, mainly because of lower consumption in households; it has been more or less constant over the last 10 years. The bulk of wood consumption is in the residential and industrial sectors (about 28% each sector). Recently, sugarcane bagasse represented about 50% of the final biomass consumption and is mainly used as fuel in the mills in which sugar and bioethanol are produced. Charcoal is mainly used in the industrial sector (87% of the energy consumption in 2010), especially in the pig-iron and steel industry. "Others" in Figure 3 corresponds to different agricultural and industrial residues, black liquor being among them.

---

[1] But the imports of coal and coke rose again as long as international prices were reduced.

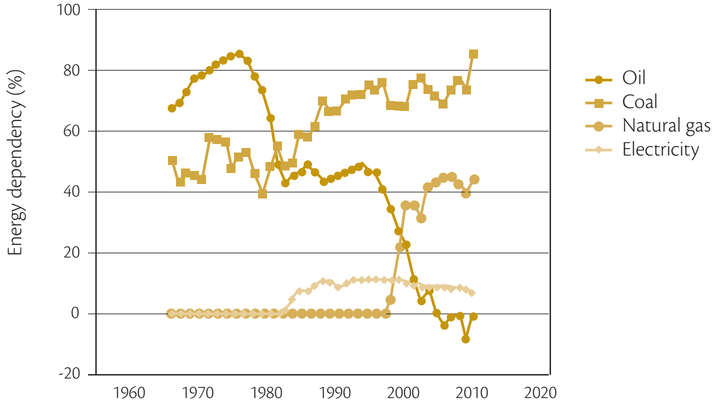


Figure 2. Evolution of the external dependency of energy sources – 1970-2010.

Source: EPE-MME (2011).

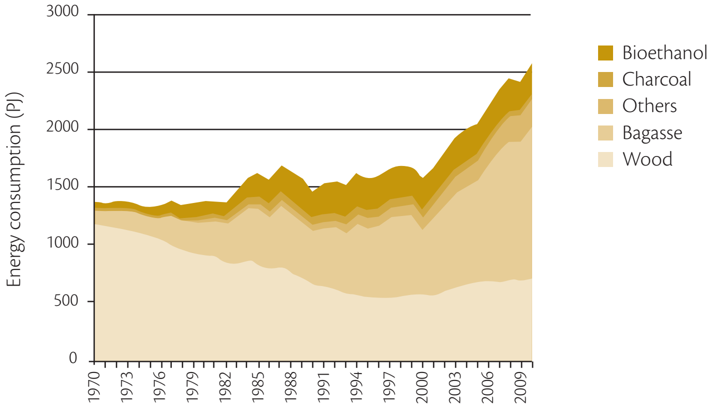


Figure 3. Final consumption of biomass – 1970-2010.

Source: EPE-MME (2011).

The evolution of energy consumption in the transport sector is shown in Figure 4. Large scale fuel bioethanol consumption started in 1976 (anhydrous bioethanol is blended with gasoline and since 1979 hydrated bioethanol has been used as neat fuel). In 2010 bioethanol consumption was attributed to 17% of the energy consumption in the transport sector and to 38% of the energy consumption due to light vehicles (in the same year it was equivalent to almost 70% of gasoline consumption, energy basis).

In Figure 4, "Others" corresponds to mainly kerosene (used by aircrafts) and natural gas (used by light vehicles; in 2010 its consumption was equivalent to almost 10% of gasoline consumption, energy basis). Figure 5 shows the profile of energy consumption in the transport sector, in 2010.

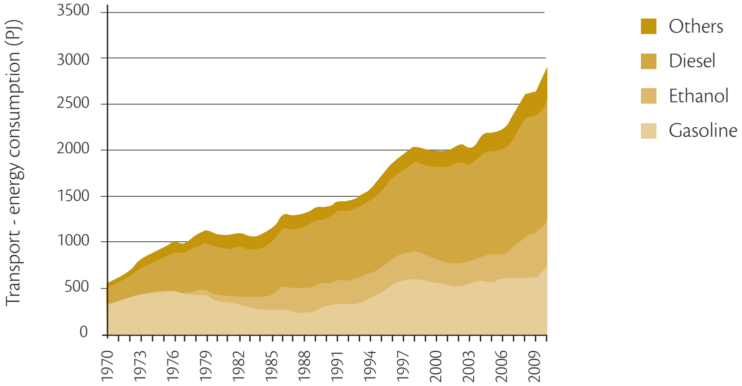


Figure 4. Energy consumption in the transport sector – 1970-2010.

Source: EPE-MME (2011).

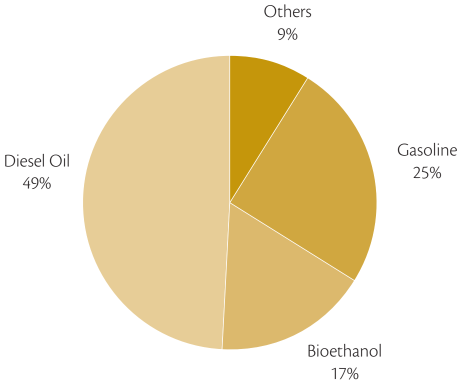


Figure 5. Profile of the energy consumption in the transport sector, in 2010.

Source: EPE-MME (2011).

In Brazil, the bulk of electricity generation is based on hydro power plants (see Fig. 6). Most of the estimated hydroelectric potential is still untapped (about 70% of the total), but it is mainly located in the North Region (112 GW out 261 GW), in (or close to) the Amazon region and far from most populated areas. As a consequence, this potential will be barely fostered to a large extent. The current tendency is the construction of hydro power plants with smaller capacities, in order to reduce flooded areas, and this implies the necessity of complementary capacity (so far, mostly thermal plants) for electricity supply during the dry period.

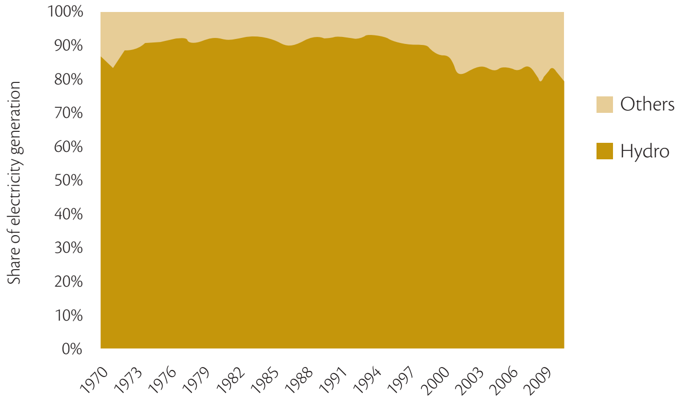


Figure 6. Share of hydro electricity generation and the set of complimentary sources – 1970-2010.

Source: EPE-MME (2011).

Figure 7 shows the profile of electricity generation in 2010 (the contribution of hydro – 79% - was the smallest during the period of 1970-2010). These results correspond to domestic generation and do not take into account the generation by Paraguay's share of Itaipu power plant, which is mostly bought by Brazil.

Figure 8 shows the contributions of other sources (i.e., besides hydro) for electricity generation in Brazil, from 1990 to 2010. The growing contribution of other sources since the mid 1990s is clear, as well as a more diversified profile since 2001. The first tendency can be partially explained by the constraints of investing in large hydro power plants. On the other hand, after 2001-2002, when a shortage of electricity supply impacted most of the country, new thermal power plants were built and regulatory rules were changed for improving the system's reliability. In recent years, a significant amount of wind power plants and biomass cogeneration (mostly using sugarcane residues) were installed, contributing 0.5% and 3.6% of total generation in 2010, respectively. In Figure 8, "Others" corresponds to electricity production from coke gas, other residues and wind.

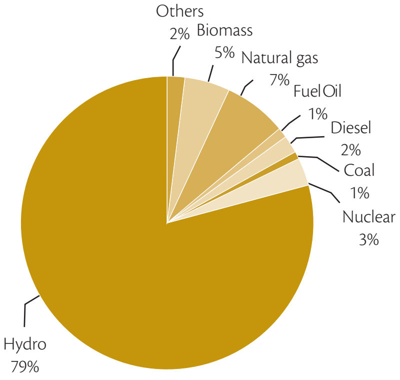


Figure 7. Profile of electricity generation in Brazil in 2010.

Source: EPE-MME (2011).

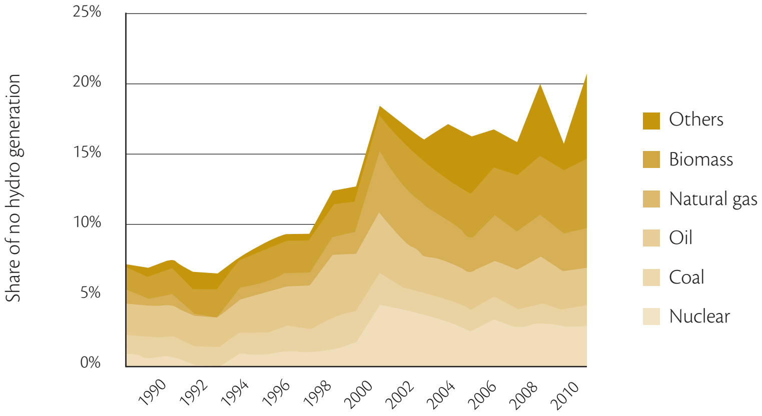


Figure 8. Electricity generation – share of other sources – 1990-2010

Source: EPE-MME (2011).

Regarding the installed capacity of electricity production, by the end of 2011 hydro power plants contributed almost 70% of the total (excluding 50% of Itaipu's capacity). At that time, about 7.5% of the installed capacity corresponded to thermal power units based on biomass: i.e., almost 9 GW, being 7.3 GW from sugarcane based cogeneration units, and 1.2 GW from black-liquor based cogeneration units (Table 1).

Table 1 – Profile of the installed capacity of electricity generation – December 2011

	Capacity (MW)	Share (%)	Number of plants
Hydro – large-scale	78,706	66.9	180
Hydro – small-scale	3,874	3.3	418
Thermal- conventional	32,857	26.7	1,513
Nuclear	2,007	1.7	2
Wind	1,561	1.2	72
Solar	0	0.0	6
Total	119,227		2,561

Source: ANEEL (2012)

Perspectives regarding the energy matrix

The perspectives presented in this section correspond to the results of two official studies developed by EPE (Energy Research Company, in Portugal), one considering 2019 (EPE, 2010) and the second considering 2030 (EPE, 2007) as time horizons. The results of both studies do not match accordingly, as some premises are different. An effort has been made here to summarize the studies and to present their results in a coherent way.

The so-called 10-year Energy Plan (EPE, 2010) presents results considering a more optimistic scenario, which could be considered a Business-as-Usual (BAU) scenario. A crucial hypothesis is that the average growth rate of GDP would be 5.1%. The results regarding the domestic energy supply indicate an annual average growth of 5.4% and that the contribution of renewable energy could be even higher than today (EPE, 2010). Main results are presented in Table 2.

Some results of the National Energy Plan 2030 (EPE, 2007) are also presented in Table 2 in order to make comparisons possible. In this case the average growth rate of GDP would be 4.1% during the 2005-2030 period (reference scenario) and the domestic energy supply would grow by 3.7% per year, on average. The share of renewable energy in the energy matrix would be kept very high (at least 45%) and, in particular, the contribution of sugarcane would be more important than in recent years.

Table 2 – Predicted energy matrix in 2019 and 2030 – average annual growth rates regarding 2010

	2010[1]	2019[2]	Annual growth rate (%)	2030[3]	Annual growth rate (%)
Domestic energy supply (Mtoe)	268.8	429.9	5.4	555.8	3.7
Oil and its products (%)	37.6	31.0	3.1	29.0	2.4
Natural gas (%)	10.3	12.2	7.4	16.0	6.0
Coal and coke (%)	5.2	7.4	9.6	7.0	5.3
Uranium (%)	1.4	1.5	6.2	3.0	7.7
Hydro and electricity (%)	14.0	12.7	4.2	14.0	3.7
Sugarcane products (%)	17.8	21.5	7.6	18.0	3.8
Wood and charcoal (%)	9.7	9.9	5.6	6.0	1.2
Other renewable (%)	4.0	3.7	4.4	7.0	6.6
Share of renewable (%)	45.5	47.8		45.0	

Sources: 1 (EPE-MME, 2011); 2 (EPE, 2010); 3 (EPE, 2007)

In both studies, the hypothesis that leads to a greater consumption of natural gas is due to its increasing use in industries (partially displacing wood and fuel oil) and in refineries (due to a larger installed capacity), while in the case of coal and coke the results are due to a greater production of iron and steel. The larger output of siderurgies also explains the growth of charcoal consumption in industries (the main reason for the growing tendency regarding wood and charcoal).

The 10-year Energy Plan (EPE, 2010) is optimistic regarding the results of electricity efficiency that would grow from about 2.7 TWh in 2010 – equivalent to 0.6% of the final consumption that year – to 23.3 TWh in 2019, or 3.2% of the predicted final consumption. The hypotheses also reflect a strong confidence that cogeneration would grow remarkably in industries, more than doubling the electricity generation by 2019.

According to the 10-year Energy Plan, the installed electricity capacity would reach 167.1 GW (EPE, 2010) (compared with 119.2 GW by the end of 2011 – see Table 1) and could reach 217 GW in 2030 (EPE, 2007). Table 3 shows the predicted installed capacity in 2019 and in 2030.

Table 3 – Predicted profile of the installed capacity of electricity generation in 2019 and 2030, based on different studies (GW)

Technology/energy source	20101	20191	2019/2020	20202	20302
Hydro – large-scale	83.2	116.7	1.01	116.1	156.3
Hydro – small-scale	4.0	7.0	2.12	3.3	8.3
Nuclear	2.0	3.4	0.79	4.3	7.3
Natural gas	8.9	11.5	0.82	14.0	21.0
Coal	1.8	3.2	1.07	3.0	6.0
Oil products	5.8	10.7	1.95	5.5	5.5
Biomass	5.4	8.5	2.66	3.2	7.9
Wind	1.4	6.0	2.61	2.3	4.7
Total	112.5	167.1	1.10	151.7	217.0

Sources: 1 (EPE, 2010), 2 (EPE, 2007)

The important role held by large hydroelectric power plants within the electricity matrix in the predicted scenarios for 2019 and 2030 reflects the vision of the Brazilian government, which is to foster the use of the remaining potential as much as possible. The total potential is estimated at 261 GW and about 35% has been used or is close to being used (hydro power plants are currently under construction); the tapped potential could reach 45% and 60% in 2019 and 2030, respectively.

An important issue, as previously mentioned, is that more than 40% of the total potential is located in the North region (112 GW), and the bulk of the remaining potential is in the legal Amazon area. The recent problems encountered in keeping the construction of four large new hydroelectric power plants in that region is clear evidence that it will be costly and difficult to take advantage of the remaining potential, as predicted.

As it has not been possible to build new hydroelectric power plants with large reservoirs, thermo power plants have been necessary to assure system reliability. A premise of the planning process is to diversify the electricity matrix in Brazil, and different energy sources and technologies have been considered. As can be seen in Table 3, the results of the 10-year Energy Plan (EPE, 2010) indicate important changes regarding the predictions presented in the 2030 study (see column 2019/2020 in the table): (a) a significant reduction of nuclear and thermo power plants fuelled by natural gas and (b) an increase of other renewable energy sources (small hydro, wind and biomass) and – surprisingly – thermo power plants fuelled by oil products.

It is important to mention that even the 10-year Energy Plan (EPE, 2010) is conservative regarding the future contribution of biomass for electricity generation. Firstly, it is worth mentioning that the installed capacity in 2019 was estimated at 8.5 GW, while the capacity by the end of 2011 had already reached 9 GW, and secondly, the capacity of electricity production with sugarcane residues could be 3 to 4 times larger than the 7.3 GW already installed (ANEEL, 2012), using available technology and with no further expansion of sugarcane production.

In Brazil, a controversial issue is related to the impacts of the recent discoveries of large petroleum reserves on the production of liquid biofuels, and mainly on bioethanol production. It can be understood that the results presented by EPE in its studies reflect the policies of the Brazilian government in this respect, along with the plans of PETROBRAS, the Brazilian state-controlled oil company. Here, only the results of the 10-year Energy Plan are presented (EPE, 2010), as the previous 2030 Energy Plan (EPE, 2007) – prepared when the discoveries of large oil reserves were not yet a reality – does not match the most recent study.

Table 4 summarizes the main figures of oil and oil products in Brazil for 2010 and those predicted for 2019. The results for 2019 are those presented by the 10-year Energy Plan (EPE, 2010) that used 2009 as the reference year; these results correspond to a more aggressive scenario regarding oil refinery vis-à-vis the figures known for the time being as “business-as-usual”.

As can be concluded from data presented in Table 4, Brazil could become a net exporter of both crude oil (about 2,200 bpd) and oil products (230 bpd, over half being gasoline) in 2019. The results correspond to a scenario in which the capacity of oil refineries would rise to match the demand of the main oil products, resulting in a surplus of motor gasoline due to the increased production of bioethanol (see below). These results seem to be realistic with some constrained investment capacity and within a very short time frame, despite the fact that it would be more rational to refine more crude oil and export oil products.

Table 4 – Production, consumption and trade flows of oil and oil products (bpd – barrel per day)

	20091	20102	20191
Oil production	2,000	2,060	5,100
Oil refined	1,783	1,787	
Refinery capacity	1,980	2,093	3,328
Net exports of crude oil	151	293	2,200
Gasoline production	355	399	385
Gasoline consumption	325	393	260
Net imports of gasoline	30	4	125
Diesel production	730	714	1.410
Diesel consumption	785	838	1.375
Net imports/exports of diesel3	(55)	(129)	35

Sources: 1 (EPE, 2010), 2 (EPE-MME, 2011)

Note: 3 number between paranthesis corresponds to imports

The predicted production of biofuels in 2019 (EPE, 2010) corresponds to the results of a BAU scenario in which it is considered that the mandate for a B5 blend (5% biodiesel blended with mineral diesel, volume basis) would be kept, and that the domestic demand of hydrated bioethanol – due to the success of flex-fuel vehicles – would drive bioethanol production.

In the case of biodiesel, the production required would reach 4.2 billion litres (BL) in 2019, enough for assuring B5 blends all over the country; the production in 2010 was slightly higher than 2.5 BL. In the 2030 Energy Plan (EPE, 2007) a trend of growing biodiesel-diesel blends was considered, reaching a B11 figure in 2030. The study by EPE (2010) only considers the production of first generation biodiesel, and is conservative regarding the feedstock: the bulk of production would be based on soy oil (78%, compared with the current figure of 85%) and a continuously growing production based on animal fat (reaching 16% in 2019, compared to 10% in 2010-2011). The predicted B5 blends would contribute to reducing mineral diesel imports, as shown in Table 4.

On the other hand, the scenario regarding bioethanol can be considered optimistic, taking into account the drawbacks of bioethanol production in 2009-2011 due to the constraints on sugarcane production. In the 10-year Energy Plan (EPE, 2010) it is predicted that bioethanol production should reach 64 BL by 2019, being 52.4 BL for the domestic market (as hydrated and anhydrous bioethanol), 9.9 BL for exports, and the remaining production (1.7 BL) for other uses including, for instance, the production of plastics. Table 5 presents a summary of the results for 2019, figures for the reference year considered (2010) and actual results for 2010.

Table 5 – Production and consumption of bioethanol, production and harvested area of sugarcane

Parameter	2010 (reference)1	2010 (actual)2	20191
Total bioethanol production (BL)	33.7	28.0	64.0
Domestic consumption as fuel (BL)	29.0	23.3	52.4
Exports of fuel bioethanol (BL)	3.4	1.9	9.9
Other uses of bioethanol (BL)	1.3	2.5	1.7
Production of sugarcane (Mt)3	415	336.75	784
Harvested area (estimated) (Mha)4	4.97	4.325	8.22
Average productivity (L/ha)	6,781	6,481	7,786

Sources: 1 (MME-EPE, 2011), 2 (EPE, 2010), 3 (CONAB, 2011)

Notes: 3 estimated sugarcane area for bioethanol production; 4 estimated average productivity dividing total bioethanol production per harvested area of sugarcane

It can be seen from Table 5 that the results reached in 2010 are reasonably different to those predicted by EPE (2010), mainly concerning total bioethanol production, domestic consumption as fuel and sugarcane harvested for bioethanol production. In fact, the recent drawbacks in sugarcane production (since 2009), combined with the high prices of sugar in the international market, impacted bioethanol production and reduced its competitiveness vis-à-vis gasoline.

As 2011 was an even worse year regarding sugarcane and bioethanol production, it can be predicted that the estimated figures for 2019 can only be achieved with a great effort, achieving annual average growth rates of more than 10% for both sugarcane and bioethanol production (for comparison, it should be noted that in 2000-2008 the annual average growth rate was 10.4% for sugarcane, and 12.7% for bioethanol).

Also, regarding the estimates for 2019, it should be said that the demand of bioethanol for other uses seems to be low, as the actual consumption in 2010 was much higher than that predicted for 2019. In terms of bioethanol exports, the goal of almost 10 BL in 2019 can be regarded as attainable, considering Brazil exported more than 5 BL in 2008, along with the new trade regime in the US (since early 2012), but it can also be considered a challenge due to the loss of competitiveness regarding production overseas.

Final remarks

The importance of renewable energy sources in the Brazilian energy matrix has been remarkable, and it is predicted that this aspect will not change much in the years to come. In fact, there are clear efforts to keep its contribution between 45-50% of the TPES.

As far as electricity generation is concerned, the aim is to take advantage of the hydroelectric potential that still remains, despite the high costs and pressures (in Brazil and abroad) for reducing the impacted area in the Amazon region. Actually, it would be possible to significantly increase the generation capacity combining hydro power plants of low storage capacity (i.e., lower flooded area) with wind energy and/or power plants from residual biomass (e.g., sugarcane residues).

Due to the recent discoveries of large oil reservoirs some concerns have been raised regarding the future production of biofuels. Prospective studies indicate that oil production will increase in Brazil, as well as the production of oil products, but it is possible, and desirable, to export oil and oil products and keep the production of bioethanol from sugarcane. Bioethanol produced from sugarcane in Brazil is the cheapest biofuel produced worldwide – and feasible as long as international oil prices are higher than 50 US$/barrel – and its contribution to reducing greenhouse gas emissions is remarkable. Its production can increase remarkably, for instance, without important impacts on land availability, food supply or biodiversity, and these results can be even better with the advent of bioethanol production through hydrolysis of cellulosic residues of sugarcane. The challenge is coordinating the efforts made for increasing the production of conventional bioethanol and developing technology for enlarging productivity, diversifying production and improving sustainability.

In a general sense, Brazil has huge potential for producing modern bioenergy (e.g., as biofuels, electricity and heat) and biomaterials, and so far sugarcane is the best input available. In this respect, in the future, sugarcane can achieve a greater importance than is indicated by the figures presented in this chapter.

References

AGENCIA NATIONAL DE ENERGIA ELETRICA – ANEEL. 2012. Available at: <www.aneel.gov.br>.

COMPANHIA NACIONAL DE ABASTECIMENTO – CONAB. Acompanhamento da safra Brasileira 2010/2011. Brasília: Ministério da Agricultura, Pecuária e Abastecimento. 2011.

EMPRESA DE PESQUISA ENERGETICA – EPE. Balanço Energético 2011. Brasília: Ministério de Minas e Energia, 2011.

____. Plano decenal de expansão de energia 2019. Brasília: Ministério de Minas e Energia, 2011.

____, Plano Nacional de Energia 2030. Brasília: Ministério de Minas e Energia, 2007.

Chapter 16

Contribution of sugarcane bioenergy to the Country's greenhouse gas emission reduction

Manoel Regis LimaVerde Leal
Joaquim Eugênio A. Seabra
Luis Augusto B. Cortez

Introduction

Throughout this book several alternatives to improve the sustainability of Brazilian sugarcane bioethanol have been presented and discussed, covering the most important issues. These issues have been grouped into four themes:

- Agro-industrial technological paths
- Production systems, environment and land use
- Certification, indicators and impacts
- Energy and greenhouse gas balances

The main international legislations covering the qualification of biofuels (Renewable Fuel Standard – RFS2 in USA, Low Carbon Fuel Standard – LCFS in California and the Renewable Energy Directive in the EU) and the most important biofuel certification programs are unanimous to indicate the greenhouse gas (GHG) abatement potential of biofuels as a key parameter and the first step in the qualification system. This is easy to understand since biofuels are considered as one of the mitigation alternatives for GHG emissions from the transport sector, responsible today for 14% of global emissions, and from the energy sector, that accounts for 25% of global GHG emissions (WRI, 2009).

To understand the role of sugarcane energy in reducing GHG emissions in Brazil it is important to know the context in which this primary energy source is set, and what its participation is in the National Energy Matrix (NEM). Brazil has traditionally relied on renewable energy to satisfy its needs, and in the past 50 years the renewable energy profile has changed from mainly wood to a combination of hydro, sugarcane and wood sources, with a minor (but growing) contribution from other sources such as wind energy. Today, renewable energy represents 45.4% of the Total Primary Energy Supply (TPES) and sugarcane is the main renewable energy source since 2007, with 17.7% of the 2010 TPES (EPE, 2011), second only to oil. The country is nearly self sufficient in oil, thanks to bioethanol, but imports coal and natural gas (NG). Wood energy has evolved from traditional biomass types to more modern forms of biomass energy use, such as charcoal used in the steel and iron industry displacing mineral coal (imported), with residential use limited to around 28% of the total wood fuel.

The transport sector fuel pool was satisfied in 2010, on an energy basis, by 49% Diesel, 25% gasoline, 17% bioethanol and 9% others (NG and kerosene/jet fuel); today, bioethanol production is struggling to recover from the pre-2008 crisis performance after dropping around 17.2% from 2010/2011 to 2011/2012 (CONAB, 2011) due to a reduction in sugarcane production as a consequence of bad weather and inadequate agricultural management (reduced fertilizers and herbicides use and bellow optimum cane field renewal since 2008/2009).

Hydro power dominates the electric energy sector providing around 80% of the total electricity produced in the country. Nuclear (3%), NG (6%), biomass (6%), coal (1%) and other sources (4%) complete the electricity generation (EPE, 2011); wind power presents only a small contribution (0.4%), but it is growing at a very fast pace. The government decision to diversify the power sector since the 2001/2002 power shortage due to droughts and the constraints to build large hydro plants in the Amazon will put a cap on this type of electricity generation.

With such a renewable energy contribution to the National Energy Matrix one should expect very low GHG emissions in Brazil. However, the contribution of deforestation (Land Use Change/Forests sector) amounts to 75% of all CO2 emissions in the country (1994); the Energy and Industry sectors contribute 23% and 1.6%, respectively. The Brazilian National Climate Change Plan (PNMC, 2008) gives a very high priority to the reduction of deforestation, densification of cattle husbandry and integration of agriculture/forestry and maintenance of the renewable energy participation at the present high level.

This Chapter tries to summarize the main findings of the previous Chapters, highlighting the impacts of bioethanol and sugarcane in Brazilian national GHG emissions, accounting for and indicating some areas with high potential for improvements. It starts with an assessment of the GHG LCA for Brazilian sugarcane bioethanol production and use, considering average conditions for the Center-South region (around 87% of the cane production); it covers the situation of the industry and agriculture sectors at the mills, presents the main alternatives for future production integration (bioethanol, biodiesel, cattle) and reviews Land Use Change impacts of the recent sugarcane expansion.

The role of sugarcane in GHG emission reduction in Brazil

The introduction of bioethanol as a transport fuel in Brazil dates back almost a century and was motivated mainly by the need to create a new market for the surplus sugarcane produced in Brazil, as well as to reduce imports of gasoline. The real big boost in this process occurred in 1975 with the launching of the National Alcohol Program – Proalcool –with the same motivations as today, but back then with the pressing need to settle the balance of payments under pressure from the sharp increase in oil price since 1973 (when the country imported around 80% of its oil needs). In the past few years concerns about the global warming phenomena has brought attention to biofuels as alternatives to reduce GHG emissions in the transport sector, and sugarcane bioethanol has been demonstrated to be the best existing option for that. The opposition to biofuels has forced the producers and supporters to demonstrate the mitigation potential of the various biofuels, in a continuous process that is becoming more and more sophisticated, including the necessity to prove the sustainability of production and usage paths conforming to a long list of criteria and indicators. GHG mitigation potential is one of the key criteria in this process and, therefore, this chapter will try to show the present situation and the potential for future improvements of sugarcane production and processing for its main energy products, bioethanol and electricity, in mitigating the GHG emissions.

GHG life cycle analysis (LCA)

In Brazil, sugarcane represented 17.7% of the TPES in 2010, down from 18.2% in 2009 (EPE, 2011), and bioethanol made up 5.7% of the final energy consumption in 2010 . In Chapter 14 of this book, Seabra and Macedo developed a Life Cycle Analysis of sugarcane bioethanol, considering the most common production model in Brazil of sugar/bioethanol/electricity joint production and using data from up to 168 mills from the Center-South region for inputs and performance parameters. The energy and GHG balances for bioethanol, considering the path from field to pump, have shown that the agricultural area (cane production and transportation to the mill) accounts for around 97% of the fossil energy consumption and 90% of the GHG emission in this path. Soil and cane burning emissions totaled 47% of the agricultural emissions. Also, the surplus power and bagasse can produce significant credits to further improve these balances. Therefore, a lesson learned from this work is that to improve the bioethanol LCA for GHG emissions, the main points that deserve attention is the reduction, or the end, of cane burning, the reduction of fossil fuel use in agriculture (optimization of input uses, especially N fertilizer, diesel for cane transport and soil preparation for planting), the improvement of soil carbon stocks (use of conservationist practices such as no or minimum tillage, straw blanket on the ground and directing cane expansion to avoid high carbon stock areas), yield improvement in agriculture and an efficiency increase in the cane processing and other actions to reduce land use (the integration of sugarcane cropping with cattle husbandry can bring enormous economic and environmental benefits for both sectors) and maximum use of the cane residues (bagasse and straw) to generate surplus power and/or to produce second generation (2G) biofuels (gains in yield and co-product credits).

In an attempt to shed light on the frequently asked question of which alternative use of the sugarcane residues will prevail, electricity or 2G bioethanol, a simulation of these two alternatives, projected for 2020, was presented: electricity at 130 kWh/tonne of cane or the biorefinery at 33 additional liters of bioethanol/tonne of cane plus 50 kWh/tonne of cane surplus electricity. The biorefinery option resulted in higher GHG emission mitigation per tonne of harvested cane, even while considering that the surplus power would be displacing NG fueled power plants. It is important to point out that different assumptions, such as the National emission factor of the electric system, may lead to other conclusions and that, ultimately, the economic results may prevail in the final decision.

Industrial technology

In spite of the fact that it accounts for only around 3% of fossil energy use and 10% of GHG emissions of the production path, and that the technologies in use today are quite advanced, there is still room for improvements that will positively impact both the energy and GHG balances.

Chapter 6 shows that significant gains in efficiencies and yields were achieved in the 30 years following the start of the Proalcool (OLIVÉRIO, 2007 AND FINGUERUT, 2005): the average global distillery stoichiometric efficiency went from 66% to 86%, boiler thermal efficiency from 66% to 88% and the milling capacity of a six 78 inch units milling tandem increased from 5,500 to 14,000 tonnes of cane/day. This performance improvement has left little room for further gains as it is unlikely that the conventional technology global distillery efficiency will go above 90%. On the other hand, the efficiency of the conversion of total sugarcane primary energy in the field into useful energy (bioethanol and electricity), which today is in the order of 30% in the good mills, can be brought above the 50% level by reducing the process steam consumption from today's average of 500 kg/tonne of cane to 300 kg/tonne of cane (technology for this is already commercially available) to save more bagasse and recover some of the straw from the field; this extra fiber available at the mill site would be used to generate more surplus power for sale and/or to produce 2G biofuels. An increase in the size of the mills, an observed trend in the greenfield units and in the upgrading of the old mills (brownfield), is improving the economies of scale of these modernization options. The use of high pressure boilers and turbines (above 60 bar) became the standard in new installations since 2007, when BNDES (National Bank for Economic and Social Development) charged lower interest rates for equipment with pressure above the 60 bar level. The larger mills even prefer pressures at 100 bar or above, and the installation, or design of the plant for future installation, of condensing turbines in order to use all bagasse (and straw when available), extending power generation beyond the crushing season. UNICA foresees (2008) that by the 2015/2016 crushing season the share of electricity in the mill gross revenues will reach, on average, 16%, up from 1% in the 2005/2006 season. It is important to remember that prior to 1975 the mills used wood fuel to supplement bagasse and bought electricity from the grid to meet the mill demands, due to the use of boiler and steam generators with pressure in the range of 10 to 20 bar and a process steam consumption of 600 kg/tonne cane.

Agricultural technology

It is in the agricultural area where the main issues concerning the sustainability of sugarcane bioethanol can be observed: two thirds of the production costs, more than 90% of the LCA GHG emissions and fossil energy consumption, social impacts (land demand, jobs), environmental impacts (air, water and soil pollution) and impacts on biodiversity. With the focus on GHG emissions, previous chapters show that diesel consumption in agricultural operations and cane harvesting and transporting, fossil energy use in chemical inputs production (fertilizers, lime and herbicides), soil emissions and cane burning related emissions (non CO_2) are the main sources of these emissions. Sugarcane burning is being phased out and this is increasing the rate of mechanization of harvesting and planting. The present mechanization technology being used causes serious soil compaction problems and requires heavy soil preparation before planting a new cane field at the end of the five to seven years cycle (these operations consume a significant amount of energy and revolves the soil, exposing the soil organic matter to oxidation); the use of conservationist agricultural management such as no tillage or minimum tillage, so successful in the grain cropping, has no advanced in sugarcane, which is probably due to the heavy soil compaction that results from the present mechanization technology. The main reason is that the mechanization system for sugarcane is at a much lower technology level compared with the systems developed for grains, which represent a considerably larger market. There are alternatives to reduce the soil compaction and fuel consumption and they are being tried in Brazil and in other sugarcane producing countries (two row harvesting, increased wheel spacing, careful management of mechanical equipment operations). However, a radical change in the sugarcane mechanization will be required to adequately solve all problems associated with the present soil compaction. Due to the amount of sugarcane area in the world (23 Mha compared with 600 Mha of the four main grains), the investments required to develop new technology will be scarce in the traditional equipment supplier sector. Another problem with conventional cane mechanical harvesting is the high cane losses that are being treated at a very slow pace.

The straw blanket that remains in the field after green cane harvesting has several agronomic benefits, such as soil protection against erosion, reduction of soil temperature variation, protection against direct radiation, increased soil biological activity, better water infiltration and less run off, less water evaporation, weed control, increased soil organic matter (SOM) and nutrient recycling. Negative aspects include the increase of some pest populations, risk of accidental fires and increased difficulties in some agricultural operations. The impacts of the straw blanket in the sugarcane yields are not clear since the technical literature shows both good and bad results, and seems to depend on cane varieties, agricultural practices and local climate conditions. There are strong indications that some of the straw can be removed for energy use in the mill while still preserving the positive impacts in the field; more research is necessary to allow for the optimization of straw recovery and use (field and factory). It is quite clear that the use of straw for energy (surplus electricity and/or 2G bioethanol) is a very important point in the effort to increase the efficiency of recovery of the sugarcane primary energy, since straw represents approximately one third of the cane primary energy. In addition, by stopping straw burning there is a considerable reduction of GHG emissions in the form of methane and nitrous oxide; Macedo et al. (2008) estimate that this reduction is in the order of 30 kgCH4 and 0.80 kgN_2O per hectare (Chapter 13). The increase in SOM due to the straw deposition on the ground is another bonus of the green cane harvesting and has been estimated at 0.35 tC.ha-1.yr-1 under the prevailing conditions in the Center-South region (Chapter 3).

Another clear alternative to reduce fossil energy consumption and GHG emissions in the bioethanol LCA is to replace part of the diesel oil used in agricultural operations and cane transport (around 230 liters/ha) with renewable fuels such as biodiesel or bioethanol. The simulations in Chapter 3 have shown that GHG emissions could be reduced by up to 17% when B100 from tallow/palm oil is used, and by 9% when bioethanol replaces diesel. With the present trend of increasing mill sizes, to gain in economies of scale in investment and operating costs in the mills, it is expected that an increase in transportation costs and energy demand will take place, the latter aspect having a negative impact on GHG emissions. It is very important that this situation be evaluated in detail and the optimization of cane field layout (densification) and cane transport be pursued; the fuel consumption of a simple truck (15 t) and that of the more modern road train (58 t) are 0.030 and 0.016 L.t-1.km-1, respectively. The optimization of harvesting fronts, displacements and transport logistics, already practiced by the good mills, can present significant reductions in fuel use (and GHG emissions) and costs.

Integrated production of bioethanol and biodiesel

Diesel consumption in agricultural operations and sugarcane transportation represents around 2/3 of the total consumption of fossil fuels in the conventional bioethanol production chain, making it an excellent target for improvements in the energy balance and LCA GHG emissions. For this reason, in Chapter 14 an alternative to reduce diesel use is evaluated: the partial replacement of fossil diesel used in agriculture with biodiesel produced in the distillery, integrated with the bioethanol production, using the utilities available at the distillery and vegetable oil produced from soybeans cultivated in the cane renewal area. This cultivation of soybeans in the cane renewal areas, which represents approximately 15% of the total area used for sugarcane cropping, is an activity normally performed in several mills as a way to increase soil fertility by planting a nitrogen fixing crop (peanuts, sunflower and crotalaria are other alternatives). This integration of bioethanol and biodiesel production has several synergies: it reduces the investment cost of the biodiesel plant (it can use the utilities already produced in the distillery, such as steam and electricity), reduces operating costs and uses a feedstock normally produced in many mills. The Barralcool distillery in Mato Grosso state is a practical example of this integration and it uses the so called Façon barter where the soybeans produced by the distillery are processed in an independent oil extraction plant and the soy meal is traded as soy oil, resulting in 430 kg of oil/tonne of soybeans (considerably more than the 180 kg of oil/ tonne of soybeans obtained by the direct crushing of the grains). This business model is used in simulation of the alternative case in Chapter 14. Considering that 15% of the total sugarcane cropped area is used for soybean cultivation and the Façon barter is used between the distillery and the soybeans processor, around 70% of the diesel used in agricultural operations and sugarcane transport can be displaced by biodiesel and the fossil energy consumption drops from 69 kJ/MJ of bioethanol to 4 kJ/MJ of bioethanol and the GHG emissions are reduced from 18.9 g CO_2eq/MJ of bioethanol to 13.7 gCO2eq/MJ of bioethanol. This can be considered as significant improvements in these two areas.

Sugarcane cropping and cattle husbandry integration

The expansion of biofuels in general and bioethanol in particular is raising concerns about the potential negative impacts on food supply and prices. In a country with continental dimensions such as Brazil, this issue can be managed in many different ways: elaboration of the sugarcane Agroecological Zoning (AEZ) preserving the sensitive areas from sugarcane expansion, analysis of the possible scenarios of agriculture expansion considering the potential increase in bioethanol production (using econometric models calibrated with reliable historical data) and integrated sugarcane/cattle production. The Brazilian sugarcane Agroecological Zoning has been officially released in 2009 (EMBRAPA, 2009):

- preserving the Amazon and Pantanal biomes, including a buffer zone for the latter area formed by the Upper Paraguay River basin;
- preserving the sensitive areas for food production;
- avoiding land with slopes above 12%;
- considering only rainfed agriculture, there are 65 Mha of land for low impact sugarcane production.

The analysis of agricultural expansion scenarios was performed by ICONE – Institute for International Trade Negotiations and is detailed in Chapter 9. In 2010, the estimated areas for pasture and agriculture (annual and permanent crops) were 196 Mha and 68 Mha, respectively, indicating the enormous proportion of pasture in Brazil (23% of the total country land area), and it is being used in a very low intensity system (around one animal unit/ha). Since sugarcane is lately expanding mostly on pasture, it is important to analyze possible ways to integrate this crop with cattle raising, aiming to release pasture area for sugarcane production and maintaining or increasing meat production and profits.

To get a good perspective of the potential of this integration process a simulation using mathematical models for a scenario where a distillery with a crushing capacity of 2 million tonnes of cane/year is considered as a reference with the following assumptions:

- The sugarcane renewal area occupies 15% of the 28,000 ha cultivated with sugarcane; south of Goiás region as reference for parameters (land price, yields, etc.);
- Soybeans and corn, intended for cattle feed, is planted in 60% of the crop rotation area (cane renewal land);
- Around 10% of the total bagasse is made available for feed formulation, part hydrolyzed (steam explosion using steam from the distillery) and part in natura;
- Maximum pasture intensification of 1.2 animal units/ha.

Land used for cattle can be optimized based on the feed ingredients available at the distillery (bagasse, soybeans, corn). The Objective Function of this optimization process is the maximum Net Present Value of the cattle raising business, and for the 28,000 ha with sugarcane, the optimum intensified pasture area is 29,998 ha, which will produce 51.9% more meat than in the reference case of a more extensive cattle raising system of 56,998 ha (28,000ha + 29,998 ha of total used land). In other words, the integrated sugarcane/cattle system will provide 51.9% more meat than the same total area of 56,998 ha with extensive cattle raising.

Land Use Change (LUC) assessment

The GHG emissions derived from land use changes, both direct and indirect, have been known for some time, but the issue gained a new dimension in 2008 with the publication of the results of the studies made by Searchinger et al. (2008) and Fargione et al. (2008) that indicated very high values for these type of GHG emissions. Although the results were highly overestimated, as demonstrated by more precise methodologies and input data (EPA, 2010; IFPRI, 2010; EC, 2011), the studies had the merit of bringing attention to this controversial issue. The most important legislations dealing with biofuels qualification and certification and final use targets are the Renewable Fuel Standard (RFS2) in the USA, Low Carbon Fuel Standard (LCFS) in California and Renewable Energy Directive (RED) in the European Union (EU). All of them set minimum threshold limits for emission reduction to be met by the biofuels or transport energy including the LCA GHG emissions derived from land use changes (LUC), both direct (DLUC) and indirect (ILUC). However, methodologies to estimate the DLUC/ILUC and the impacts on GHG emissions LCA are controversial and still in the development stage, in spite of the progress made in the recent past; the input data normally are in a much more aggregated form, making it difficult to allocate the additional land demanded by biofuels expansion. Economic and biophysical models are normally used to calculate the DLUC/ILUC effects and all present limitations and uncertainties; for instance, the GTAP model used by California consider Brazil as a single region which is a very crude approximation to calculate the emissions derived from LUC.

Institute for International Trade Negotiations (ICONE) is developing a partial equilibrium model, with collaboration from CARD-FAPRI of the University of Iowa, called Brazilian Land Use Model (BLUM) (see Chapter XII). It is intended to be a standalone model able to run independently from international model data. Initially, Brazil is divided into six sub-regions and BLUM evaluates the competition among the 11 most land demanding agro activities; it uses land availability data from the Agricultural Land Use and Expansion Model – Brazil (AgLUE-BR) and evaluates the advances of agricultural production on native vegetation; the disaggregation of land competition matrices is being performed to improve the land allocation detailing by using 558 micro regions established by the Brazilian Institute of Geography and Statistic (IBGE). The resulting GHG emissions are determined through the emission factors associated with Land Use Change resulting from the expansion of sugarcane bioethanol obtained by using the best historical data.

A simulation of the sugarcane bioethanol expansion from 2005 to 2008 using BLUM indicated a sugarcane area increase of 2.4 Mha and a reduction of native vegetation of 191 000 ha, 181 000 ha due to indirect effect and 10 000 ha due to direct effect. The latter is a good indication that sugarcane does not advance directly on native vegetation in a significant way (only 0.4% of total sugarcane expansion area). The indirect effect (7.5%) must be observed with caution since the causes of deforestation are not clearly understood. In terms of LUC GHG emission, direct LUC resulted in 47 kt CO_2eq capture and the indirect LUC emitted 2.4 Mt CO_2 eq, and the total LUC marginal emission factor was 7.63 gCO_2 eq/MJ, which is a much lower figure than that normally found in the literature that used very simplified data and methodology.

Final comments

This short summary of the main areas concerning sugarcane bioethanol GHG emissions reduction potential demonstrates that, although this biofuel presents the best emission mitigation values among the existing 1G biofuels in use today, there are many alternatives to improve this mitigation performance even further. Some of these alternatives are already being implemented, such as cane burning phase out, agriculture yield increase, an increase in the energy recovery efficiency by improving cane processing and surplus power generation, sugarcane agroecological zoning (to avoid, among other things, planting in high carbon stock areas). Other alternatives may require adequate policies and R&D investments, such as biofuels replacing fossil fuels in sugarcane production, low impact agriculture mechanization and management (low soil compaction equipment, no till cropping, precision agriculture), integration of sugarcane cropping with cattle husbandry and directing the sugarcane expansion to minimize negative impacts (even inside the AEZ), full use of the sugarcane residues (bagasse, straw, vinasse and filter mud) and last but not least, development and introduction of high yield transgenic sugarcane varieties for commercial use. The 2G biofuels production integrated with the present 1G bioethanol production is very promising, but it will depend on many developments to succeed: to bring the 2G technologies to the commercial stage, to optimize the straw use and maximize bagasse surplus, and to reduce the economic scale size.

.References

COMPANHIA NACIONAL DE ABASTECIMENTO – CONAB. Cana-de-açúcar Safra 2011/2012 – Terceiro Levantamento. Dez. 2011.

EUROPEAN COMMISSION – EC. Report from the Commission on the indirect land-use change related to biofuels and bioliquids, COM(2010)811 final, Brussels, December 22, 2010.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Zoneamento agroecológico da cana-de-açúcar. Rio de Janeiro, RJ: 2009, 56p.

ENVIRONMENTAL PROTECTION AGENCY - EPA, US renewable fuel standard program (RFS2) Regulatory Impact Analysis, EPA-420-R-10-006, 1120p. 2010.

EMPRESA DE PESQUISA ENERGÉTICA – EPE. Energy research company Brazilian Energy Balance 2011, year 2010 Preliminary Results, Rio de Janeiro. 2011.

FINGUERUT, J. Simultaneous production of sugar and alcohol from sugarcane. In: INTERNATIONAL SOCIETY OF SUGAR CANE TECHNOLOGISTS (ISSCT) Congress, 25., Guatemala City, Guatemala, 2005. Proceedings… Guatemala City, 2005.

FARGIONE, J.; HILL, J.; TILLMAN, D.; POLASKY, S.; HAWTHORNE, P. Land clearing and the biofuel carbon debt, Science v. 319, p 1235-1238. 2008.

INTERNATIONAL FOOD POLICY INSTITUTE – IFPRI. Global trade and environmental impact study of the EU biofuels mandate. Final Report prepared by Perrihan Al-Riffai, Betina Dinamaran and David Laborde, March 2010, 125p.

OLIVÉRIO, J.L. As usinas de açúcar e álcool: o estado da arte da tecnologia. In: INTERNATIONAL CONGRESS OF AGROENERGY AND BIOFUELS, Teresina, PI, Brazil, June 2009.

PLANO NACIONAL SOBRE MUDANÇAS DO CLIMA – PNMC. Comitê Interministerial Sobre Mudança do Clima. dez. 2008, 132p.

MACEDO, I.C.; SEABRA, J.E.A.; SILVA, J.E.A.R. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: the 2005/2006 averages and a prediction for 2020. Biomass & Bioenergy v. 32, p. 582-595, 2008.

SEARCHINGER, T.; HEIMLICH, R.; HOUGHTON, R.A.; DONG, F.; ELOBEID, A.; FABIOSA, J.; TOKGOZ, S.; HEYES, D.; YU, T.H. Use of US croplands for biofuels increases greenhouse gases through emission from land use change, Science Express, February 7th, 2008.

UNICA, Outlook of Brazilian biofuels, 2008 Canadian Renewable Fuels Summit. 2008.

WORLD RESOURCES INSTITUTE – WRI. World greenhouse gas emissions in 2005, Working Paper by Tim Herzog, July 2009.

Part VI

Post-scriptum

Chapter 17

From the sugarcane ethanol sustainability that we have to the sugarcane ethanol sustainability that we should have

Luis Augusto B. Cortez

Introduction

There is much debate about what we understand about sustainability of biofuels. This debate is not always constructive for those concerned about establishing sustainable biofuels production. In practical terms, *what should we do concerning sustainability of fuels*? What are the important issues on which we should concentrate our efforts, and how can we improve the current situation?

We already know that there are scientists who are opposed to biofuels production, trying to find every possible reason to criticize any kind of biofuels, regardless of any advantages they may have. This first group of people is relatively small, but persistently and methodically publishes articles with the express purpose of confusing the general public and the scientific community. In their strategy we find that they mix positive examples with bad ones and they do not have the neutrality necessary to evaluate and separate issues. An example can be given to illustrate the problem: Why were some issues, such as N_2O, only discussed for biofuels production but not for agriculture in general, including food? Why were GHG mitigation issues only discussed for Brazilian sugarcane ethanol when the real possibility to become a net exporter of biofuels presented itself? Before 2002 practically nobody was really concerned about how Brazil was producing and using its ethanol, but when the country demonstrated its capacity to become a net exporter of biofuels, criticism started to build up in a more organized way.

There is another group of scientists devoted to understanding how biofuels can contribute to alleviate GHG emissions and at the same time fulfill other sustainability criteria such as those related to society, economy and the environment.

We will assume the standpoint of the second group of scientists, the ones with a more positive mind set, concerned with which is the best strategy to follow to make the "biofuels of tomorrow" from a sustainability perspective.

We can identify two possible approaches:

- A strategy or roadmap to improve existing sustainability indicators for biofuels production;
- Creation or development of a new concept for the production of biofuels that can fulfill the necessary requirements of sustainability.

The basic differences between these approaches is that the first can be accomplished in stages, improving existing technologies, while the second, more radical approach can be more disruptive, thinking out-of-the-box, proposing a more innovative production system.

The sustainability that we have for ethanol production in Brazil

brazilian sugarcane ethanol presents very impressive sustainability indicators. Among the most important we can list the following:

- **Low production cost** (around 50-70 cents/liter of ethanol). The ethanol learning curve (GOLDEMBERG, 2010) shows that the more ethanol is produced, the less it costs, at least until 2009. Production costs have been consistently reduced, mainly as a result of better farming practices including better management and new cane varieties;
- **Good overall productivity** (6,000-7,000 liters of ethanol/ha): It is been consistently improved since 1975, when it was around 3,500 liters of ethanol/ha. This was accomplished by increasing cane productivity yields (from 70 to 85 tc/ha.year) and also increasing industrial yield. It is important to mention that the higher the overall productivity, the less land is needed to produce biofuels;
- **Excellent renewable energy/fossil energy ratio** (8-9): This is an excellent ratio when compared with U.S. corn ethanol (1.4) and even European rapeseed biodiesel (3.0) or Malaysian palm oil biodiesel (5.0). This excellent ratio presented by sugarcane bioethanol

is credited to the bagasse present in sugarcane that helps to fuel the distillery, as opposed to other biofuels in which extra fossil fuel is often used;

- **Good GHG mitigation potential** (according to EPA, 1st G sugarcane ethanol presents a 62% potential reduction of GHG compared with gasoline, being considered an "advanced biofuel"): All other options to reduce liquid fuels can´t compete with 1st G sugarcane ethanol, which can be compared to the hybrid engine in its GHG mitigation potential. This figure (62%) includes ILUC of 15% considered by EPA as representative of Brazilian sugarcane ethanol.

Other parameters are considered important where biofuels sustainability is concerned:

- **Competition for land**: This introduces the discussion about Food vs. Biofuels, and related threats of biofuels expansion to food production. The LUC and ILUC discussion is part of this parameter;
- **Competition for Fertilizers and Water**: It is claimed that biofuels use considerable amounts of fertilizers and water, representing a threat to both food production and biodiversity;
- **Social conditions**: Conditions or quality of labor involved in biofuels production and related overall impact of biofuels in regional or national economies.

Significant efforts are being made by scientists throughout the world to discuss, estimate and measure the sustainability of biofuels, including sugarcane ethanol. It is internationally recognized that Brazilian sugarcane ethanol presents very good indicators compared with other biofuels. However, even Brazilian sugarcane ethanol receives criticisms, the most important ones being:

- **Indirect Land Use Change (ILUC)**: There are several studies to quantify ILUC caused by sugarcane ethanol in Brazil. There is no consensus on what is the most adequate methodology for ILUC quantification. Most scientists, including those from Brazil, agree that ILUC caused by sugarcane ethanol in Brazil can be estimated to reduce its GHG mitigation potential by around 15%;
- **N_2O emissions**: Some of the Nitrogen used as fertilizer will be released into the atmosphere. N_2O is recognized to have a considerable GHG potential, and therefore needs to be avoided;

Although the importance of these parameters is recognized, the trend is that most criticism is directed towards agricultural related issues. Also, when we analyze the reality of technology used in Brazil to produce sugarcane ethanol, particularly in agriculture, we can deduce that more effort is needed to change agriculture technology paradigms rather than generating more information about the problem.

In another words, more effort should be devoted to creating new science and technologies to transform present agriculture rather than continuously discussing the problems involved. This approach can also be called "applied sustainability" or "sustainable technologies". This new technology should be conceived to respond to identified problems.

For example, other important local issues can be considered very important for long term sustainability of sugarcane ethanol in Brazil, but these issues have not received attention in literature, probably because they are non-trade related issues:

- Non-optimized application of fertilizers, resulting in both excessive application, with high GHG, water contamination and higher costs; and insufficient application, causing fertilizer deficit with a lower cane yield;
- Problems introduced by mechanization: soil compaction caused by heavy harvesting machines with heavy loads, worsened with every operation;
- Soil erosion by water and wind;
- The need to improve social conditions of workers directly and indirectly related to sugarcane ethanol production;
- The need to improve macro scale planning, integrated with ecological sustainability, including preservation of biodiversity and other related issues such as air and water quality.

A detailed evolution of sustainability indicators (agriculture, industry, and energy) involved in sugarcane bioethanol production in Brazil is presented in CGEE (2009).

A new sustainable agriculture model for sugarcane bioethanol

low production costs, high overall productivity, high renewable energy/fossil energy ratio, and high GHG mitigation potential are essential attributes a biofuel needs when competing with fossil fuel. But what strategy should be addressed? Can the present incremental strategy lead to significant improvements or have current technologies, particularly in agriculture, achieved maturity and therefore we need new technologies if we really want to improve the aforementioned sustainability parameters and other local parameters, with a significant impact in the long term on soil, water and biodiversity.

Sugarcane agriculture as we know it today is an adaptation of secular practices developed mainly for sugar production in many countries, which is not exactly the best for Brazilian conditions. Current technology, both in agriculture and industry, was simply not conceived to meet the criteria imposed by biofuels as seen today.

For better discussing the New Agricultural Model for Sugarcane Bioethanol in Brazil we propose the following approach: firstly discuss the new technologies needed inside the sugarcane production boundaries, followed by a set of measures needed to plan the integration of sugarcane ethanol, particularly during its expansion, to optimize land use and maximize expected benefits.

The technologies involved in creating a new sustainable agriculture for sugarcane would include the introduction of:

- direct planting for sugarcane
- precision agriculture
- nitrogen fixation, crop rotation
- new management practices for logistics of planting and harvesting

These new agricultural models would present lower production costs, higher overall productivity, higher renewable energy/fossil energy ratio and higher GHG mitigation potential, but would imply completely changing sugarcane agriculture as we know it today.

Example: An example of a New Sustainable Agriculture Model for Sugarcane Ethanol in Brazil has been formulated by the CTBE Agriculture Program. The new model proposed by CTBE consists basically in introducing direct planting (no-tillage) technology and precision agriculture for fertilizer and seed application. To achieve these goals a new machine named ETC (Figure 1) is needed to reformulate new patterns to minimize soil compaction and improve logistics.

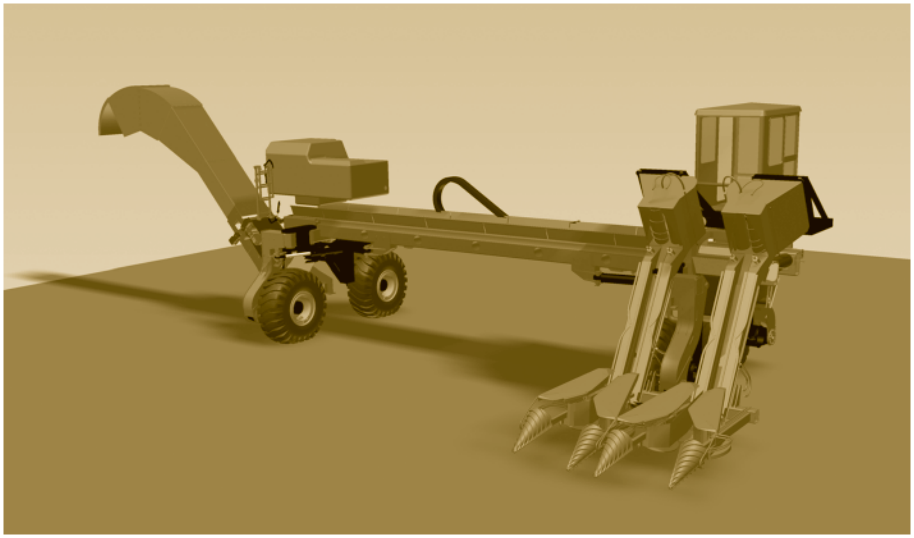


Figure 1. ETC developed by CTBE

The new model can be evaluated by the sustainability indicators for a given goal (200 billion liters/year) and the sustainability parameters.

- Cost Reduction: although the ETC is a piece of equipment that requires more capital, it will replace conventional machines, resulting in a reduction of about 20% in the cost per ton of cane;
- Higher productivity with expected land use: the new model is expected to increase cane productivity by 20%, mainly due to significantly less soil compaction. Mulching will result in less water stress which negatively impacts sugarcane, particularly between August and October in Central-South Brazil;
- GHG mitigation potential: the new model will have a significant impact on GHG mitigation, mainly because it will use less diesel in agricultural operations, less fertilizers, and will include the use of straw for mulching and electricity. GHG mitigation is expected to increase by 20%;
- Fertilizer use: It will be around 20% less due to direct planting
- Soil erosion is expected to decrease due to the introduction of mulching, increasing soil longevity;
- Water: availability of water for the plant is expected to increase due to mulching;
- What else to quantify the impact of the new proposed model?

Outside the boundaries defined by the sugarcane production systems, we have to acknowledge that land use in Brazil is vastly dominated by: the Amazon (450 Mha, or about 50%), pasture land (200 Mha, or about 25%), Agriculture Land (60 Mha, or about 8%), cities, roads, the Pantanal and other mountains. Sugarcane occupies nearly 9 Mha in Brazil, 1% of Brazilian territory, half (4.5 Mha) for sugar and the other half for ethanol production. However, it is acknowledged that sugarcane for ethanol is more likely to expand rapidly in Brazil than for sugar production, if Brazil realizes its goal of becoming a large exporter of ethanol.

Another important point is that sugarcane and other crops will most likely expand over pasture land. It has been like this in recent years and this trend will probably become a standard: the use of degraded pasture land for sugarcane in Central Brazil (see Figure 2 below, for sugarcane ecological zoning).

Figure 2. (a) Present location of sugar and ethanol distilleries in Brazil (b) Present-black and new distilleries-yellow in Central-South Brazil (c) Regions considered adequate for sugarcane expansion in Brazil according to the Brazilian Ministry of Agriculture (MAPA).

Therefore, a proposal is needed for a new production model for sugarcane expansion which would consider maintaining meat production or even increasing it, maintaining grain production and also promoting horticultural production as the sugarcane mill can provide enough inputs (energy, CO2 and fertilizers) for the more intense agriculture that is derived from modern sugarcane agriculture. There will be no room for sugarcane or other crop expansions in Brazil without a sound policy that makes rational planning of pasture land in the country, while preserving eco sanctuaries such as the Amazon and the Pantanal.

Finally, the impact on available water in a given watershed is an important key issue when analyzing local environmental impacts of sugarcane bioethanol production in Central-South Brazil. Locally the impact should be evaluated using the existing reference, which is defined by the present land use in a given watershed. The main question is this: what will be the impact on water availability of a given watershed that is been considered for large sugarcane cropping?

The impact on water availability should be measured or estimated considering present river water flow rates, water table levels which are affected by a change in overall evaporation (including evapotranspiration) and run-off. The impact should also be analyzed considering the Parana river watershed that is ultimately the most important basin used by Brazilian agriculture.

Conclusions

Bioethanol sustainability is an important issue that needs to be addressed using assessment tools and also technology changes, an "applied sustainability made with sustainable technologies". Most of the criticism involved in biofuels today focuses on the identified problems but not necessarily on how to solve them.

The solutions to sustainability issues are not confined to the system under analysis. We need to address the boundaries around the system many times to understand the whole problem. One example is the present land occupation around the globe and the agriculture related activities and production systems derived from it.

We have enough resources in the world to feed humanity and also to sustainably produce biofuels to alleviate poverty and mitigate GHG. Sustainable biofuels production can promote rural development and alleviate food shortage and poverty around the globe. However, we cannot misuse the existing resources on one side of the planet while being too rigorous on the other side. We suggest using from now on the same standard to measure all activities on our planet using sustainability as a method for understanding, using and creating a sustainable society for future generations.

.References

CENTRO DE GESTÃO DE ESTUDOS ESTRATÉGICOS – CGEE. Bioetanol combustível: uma oportunidade para o Brasil. Brasília, DF: 2009, 536p.

COPERSUCAR. A história do açúcar no mundo. a história do açúcar no Brasil. Academia do Açúcar e do Álcool. Disponível em: <www.copersucar.com.br>

CORTEZ, L.A.B. Integral approach in agriculture, challenges and opportunities. In: SOIL QUALITY AND NUTRIENT RECYCLING CTBE/BE-BASIC WORKSHOP, Campinas, August 19., 2011. Presented… Campinas, 2011.

GOLDEMBERG, J. Sugarcane bioethanol: R&D for productivity and sustainability. ISBN 978-85-212-0530-2, Coord: CORTEZ, L.A.B. Ed. Edgard Blucher, 2010, 992p.

ISBN 978-85-60755-47-9

cgee | Centro de Gestão e Estudos Estratégicos
Ciência, Tecnologia e Inovação

CNPEM
Centro Nacional de Pesquisa
em Energia e Materiais

CTBE

Ministério da
**Ciência, Tecnologia
e Inovação**