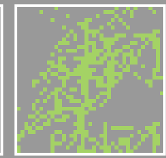



Sugar-Ethanol Bioelectricity in the Electricity Matrix

Nivalde José de Castro

Roberto Brandão

Guilherme de A. Dantas

Bioelectricity related to the production of sugar and ethanol has exceptional potential to play a strategic role in the expansion of the national electrical power system. This is because it is highly complementary to hydroelectricity, allows for distribution close to centers of consumption, and offers significant socio-economic and environmental benefits.

Bioelectricity produced from bagasse complements hydropower because it provides electricity during the driest months of the year. In 2008, the country's potential hydraulic energy (ENA in Portuguese) was between 80 to 90 GW av from January to March, falling to between 30 to 40 GW av in the period June to November, while sugarcane crushing in the Center-South region was above 80% of its maximum value in the period May through September. It is important to note that the potential for annual production of bioelectricity is almost 15,000 MW av by the end of the decade, representing approximately 15% of Brazilian national demand.

New hydropower dams increase the need for this complementarity, given the significant reduction in their reservoir capacity as a result of physical and environmental restrictions. With the construction of new dams in the North of Brazil (including Belo Monte), the ENA will be close to 120 GW av from January to April, but will not exceed 40 GW av between July and October.

This complementary characteristic of bioelectricity and hydroelectricity can play a strategic role in helping the country maintain a clean and renewable energy matrix, avoiding the need to use

fossil fuel powered thermoelectric stations as a backup. Estimates from the National Electricity System Operator (ONS in Portuguese) indicate that every GW av of bioelectricity injected into the National Interconnected System (SIN in Portuguese) can economize 4% of the reservoirs in the Southeast/Center-South electricity sub-system during the dry season.

The A-3 and A-5 auctions for new energy (open to projects of all sources) held in 2007 and 2008 used criteria and rules that favored oil-fired thermoelectrics, which have high costs of generation. Of the thermoelectric plants contracted, 98.9% were powered by fossil fuels (63% by oil) and just 1.1% by bagasse.

Sugarcane bioelectricity offers environmental benefits (reduction in the emission of greenhouse gases), economic benefits (job creation), and the guarantee of electrical energy supply (with decentralization). However, this competitive advantage is not being given adequately value by the current rules for energy auctions.

We recommend contracting energy through specific actions for each source, or auctions that are specific for generation during the dry season, and the formulation of a specific industrial policy that can create better conditions for power plants to connect to the grid and sell energy.

1. Introduction

The Brazilian electricity matrix is based predominantly on hydropower. This gives the country a privileged position vis-à-vis the rest of the world in matters of environmental sustainability. Most countries nowadays are seeking to increase the participation of renewable energy sources in their electricity matrixes in order to expand their energy supply while reducing their greenhouse gas emissions.

However, Brazil's unique matrix should not prevent the country from investing in alternative and renewable energy sources like sugarcane bioelectricity. An adequate understanding of the dynamics of introducing renewable and alternative energy sources into the national energy matrix requires an acknowledgment that the current model, based on hydropower plants with large reservoirs, is coming to an end. Limiting factors are physical questions and the attitude of environmental authorities, who will only license new hydroelectricity power plants that have small reservoirs. This means that diversification of national generating capacity is both necessary and inevitable within the growth of the Brazilian electricity system through the next few decades, with particular emphasis on energy sources that complement hydropower.

Given this process of evolution, it is important to analyze which alternative energy resources should be prioritized in the coming years.

One strategic option for Brazil's energy future is contracting energy sources that are complementary to hydropower, and that simultaneously contribute to maintaining Brazil's clean energy matrix. Sugarcane bioelectricity is outstanding among such sources, mainly thanks to the following characteristics:

I Costs competitiveness
II Seasonal complementarity in relation to the rainfall pattern
III Maturity of the sugar and ethanol industry
IV Contribution to reduction of GHG emissions
V Proximity to demand centers

The goal of this paper is to analyze and demonstrate the importance of sugarcane bioelectricity for maintaining the key characteristics of the electricity matrix, ensuring: reliable supply; national economic competitiveness, and environmental sustainability. Sugarcane bioelectricity offers the advantages inherent in a renewable energy source, generated through an efficient co-generation process, using as its primary energy source residual biomass from ethanol and sugar production. On the other hand, bioelectricity offers additional advantages for Brazil, such as the creation of income and employment in rural areas, stimulus for the capital goods industry, and a positive impact on the trade balance – the import coefficient is close to zero, avoiding not only the importation of equipment, but also of fuel.

This study is divided into two parts. The first is dedicated to an analysis of the transition currently underway in the Brazilian energy matrix, and the growing need to develop energy sources that are complementary to hydroelectric power, while the second part looks at bioelectricity as a complementary and competitive source for the Brazilian energy matrix, while also presenting a brief study of its environmental sustainability. Finally, we present conclusions that in general terms demonstrate bioelectricity's high degree of competitiveness, provided that current criteria for contracting energy are reviewed, as are the externalities of bioelectricity in comparison to other energy sources.

2. Transformation of the Brazilian generation matrix

Hydroelectric power plants constitute more than 80% of Brazil's energy generating capacity[i]. In terms of effective generation, around 90% of the Brazilian electricity supply comes from hydropower plants, as shown in **Table 1**. Brazil is second only to Norway in terms of hydropower participation within total capacity, as shown in **Table 2**.

The preponderance of hydropower in the Brazilian energy matrix ensures the supply of electricity at competitive prices[ii] and with reduced levels of carbon emissions[iii]. However, it is important to understand how the

Participation of hydropower in total generation – Brazil *In %* **Table 1**

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Percentage (%)	94.11	89.65	90.97	92.14	88.63	92.45	91.81	92.78	88.61

Source: site of ONS (National Electricity System Operator); operational history.

Participation of hydropower in total installed generating capacity – selected countries *In 2006* **Table 2**

Countries	Participation percentage (%)
Norway	98.5
Brazil	83.2
Venezuela	72
Canada	58
Sweden	43.1
Russia	17.6
India	15.3
China	15.2
Japan	8.7
USA	7.4
Rest of the World	14.3
World Mean	16.4

Source: IEA (2008).

Brazilian electricity generating sector manages to supply such a high percentage of total demand even though it is subject to irregular precipitation and seasonal variation of the rivers. Graph 1 shows the seasonal behavior of average river flows. We can see that potential hydraulic energy (ENA)[iv] exceeded 89,000 MW av in February, compared with an average of 30,000 MW av in September[v]. Another relevant fact is the comparison between the average ENA and the load. During the dry season, between May and November, the ENA is around 38,000 MW av while the load of the National Interconnected System (SIN) is around 51,000 MW av (2008 data).

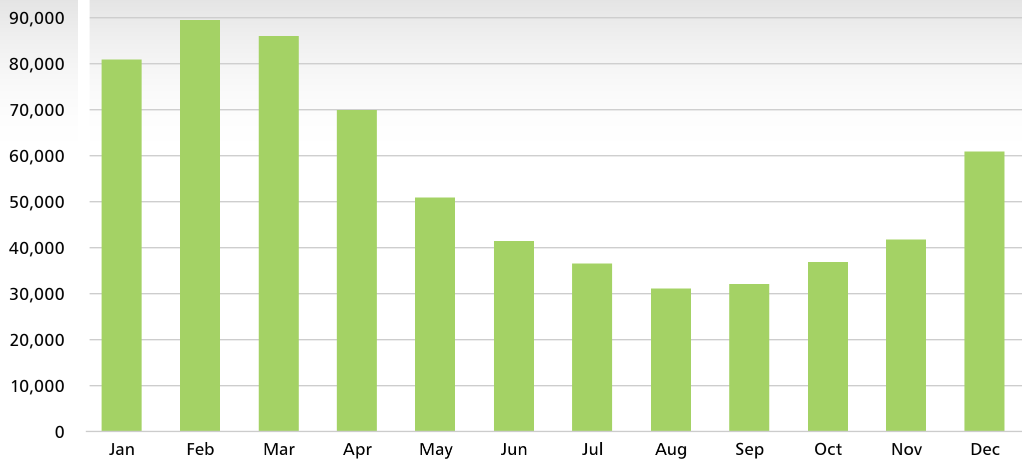
Up until now, it has only been possible to exploit Brazil's great hydropower potential with the construction of dams that have large reservoirs. The uncertainties related to seasonal river flows have been reduced by storing water during the wet season for its eventual use during the dry season. The potential energy of water in the reservoirs (called Stored Energy or SE) allows for the constant generation of energy throughout the year, or even for a few years.

Although Brazil has so far developed only 30% of its total hydroelectric potential[vi], the current model based on power plants with large reservoirs is drawing to an end. Installed hydroelectric capacity will grow in the coming years with small increases in the energy storage capacity of the system. This will reduce the ability to regularize energy supply during the year, as shown in **Graph 2**.

There are both physical and environmental restrictions on the construction of new reservoirs. Physical limitations lie mainly in the fact that the majority of potential hydropower sites in the Brazilian altiplano have now been developed, and remaining sites lie mainly in the flatter North region. It is difficult to build hydropower stations with substantial regulatory reservoirs in a region where the topography is predominantly smooth. It would be possible to flood large areas, but given the gentle slopes even large reservoirs would afford only modest energy storage. There are also environmental restrictions. Brazilian environmental legislation has become much tougher since the introduction of the new Constitution in 1988, and

Graph 1 • **Potential hydraulic energy**

Historic average; includes SIN subsystems (2008 configuration) in thousands of MW average



Source: ONS website (www.ons.org.br). Data assembled by GESEL/IE/UFRJ from the operation's historic databank in 2008.

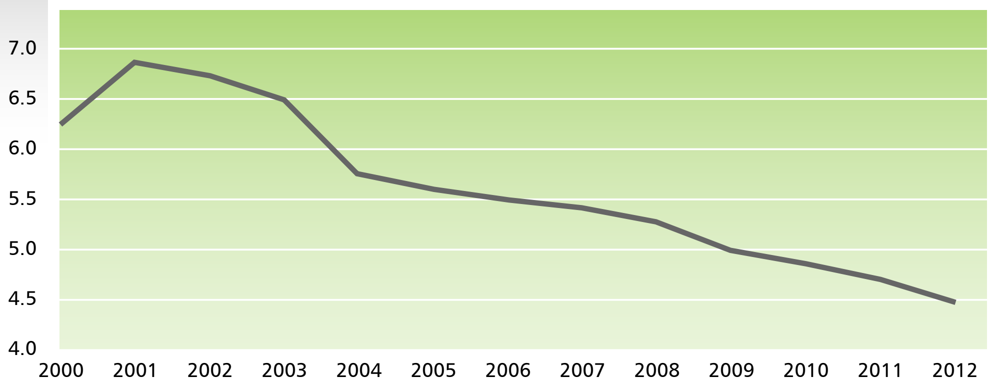
environmental authorities limit the construction of new reservoirs and even expansion of the country's hydroelectric capacity.

Given the physical and environmental restrictions mentioned above, the new hydropower plants now being built or planned have essentially run-of-river characteristics, without significant storage reservoirs. The sites on the Madeira River that recently went to tender are representative of this trend: the new reservoirs will occupy an area only slightly larger than is normally flooded during the rainy season. Belo Monte and the stations on the Tapajós and Teles-Pires rivers will follow the same general pattern. The inevitable consequence will be less ability to regulate the river flow and reduced hydropower generation.

The decreased ability to regularize the power supply by using large reservoirs will lead to growing difficulty in meeting energy demand from hydropower sources alone during the dry season. This allows us to conclude that the Brazilian electricity sector faces the challenge of complementing the existing hydropower plants with generators that operate efficiently during the dry season. Contracts for generation that complements hydropower capacity have given preference to thermoelectric plants burning fossil fuels, which in most cases have poor technical and economic efficiency. These power plants have low fixed costs, but high variable costs of generation. The logic of contracting power from such plants is to provide a backup for the hydropower capacity, because expectations are that they have a low probability of being dispatched. However, with the reduced ability of reservoirs to maintain constant power supply, these thermoelectric power plants will be dispatched more frequently than the original prediction, above all during the dry season. When the thermoelectric generators cease to play the role of simple back-up during moments of lower rainfall, their operational cost with lower technical and economic efficiency will prove to be excessive.

The Brazilian power sector therefore requires new generating stations that will complement the hydro stations with the technical and economic profile to supply base load during the dry season. Among the alternatives to complement hydropower generation, sugarcane bioelectricity is the most efficient.

Graph 2 **Change in reservoir capability to regularize generation** *Maximum stored energy/load*



Source: Chipp, Hermes. Operational procedures to ensure SIN energy supply. Presentation at GESEL-IE-UFRJ, Rio de Janeiro, July 9th, 2008.

3. Characteristics and benefits of sugarcane bioelectricity

Guaranteeing security of supply coupled with environmental sustainability will require investment in alternative and renewable sources as well as efficient processes of generation. Bioelectricity fits this premise because it is generated from biomass left over from sugar and ethanol production. Because it uses waste as its primary energy source, bioelectricity is, by definition, a renewable, efficient and sustainable source of energy. It is energy produced via co-generation, a process that ensures a significant degree of efficiency[vii]. Moreover, most of it is produced in São Paulo and neighboring states, which is the country's main region for electricity demand. This constitutes another plus in terms of economic and electricity efficiency, by reducing transmission costs and losses.

However, these benefits have not been adequately and correctly priced in at Brazil's auctions for new energy. Auction results indicate bioelectricity's apparent lack of competitiveness in comparison to other sources of energy. The supposed lack of competitiveness is the result of unfavorable auction methodology, which does not correctly value the benefits that bioelectricity offers to the Brazilian electricity system thanks to its natural complementation of the hydropower generation system.

Sugarcane bioelectricity is an energy source that contributes to the security of Brazilian electricity supply by diversifying the matrix and above all by complementing hydropower production, besides being environmentally sustainable. Unlike other forms of thermal energy production, bioelectricity is carbon neutral. This is a highly desirable characteristic that has not been properly valued at auctions.

3.1 Potential and costs of bioelectricity

According to Corrêa Neto and Ramón (2002), the sugar-energy sector is traditionally self-sufficient in terms of energy, meeting 98% of its energy demand by burning sugarcane bagasse. Co-generation provides the thermal, mechanical and electrical energy needed for the production of ethanol and sugar. However, this self-sufficiency has traditionally been ensured via inefficient production processes that yield just enough energy to supply the mill itself.

According to Dantas (2008), the decision to adopt low-efficiency cogeneration technologies was aimed at maximizing bagasse incineration, given the difficulties of storing the product and the low market value of raw bagasse. There was also no commercial interest in investing in more efficient power plants that would be able to export surplus energy to the grid.

Until the early 1990s, the Brazilian energy sector was organized in vertically integrated monopolies with centralized energy production. Regulations did not permit entities other than the concessionaires to sell energy. This arrangement lasted until the mid 1990s, when independent energy producers were allowed. This created a legal structure that allowed sugar and ethanol plants to "export" electricity to the grid, so creating the scenario for investment in efficient co-generation plants, aiming to sell surplus energy.

Although the sugarcane sector has long had the technical potential to sell its surplus energy, it is only recently that this has become possible from a commercial point of view. It is thus important to look at how bioelectricity can contribute to the Brazilian energy supply in the coming decades.

Bioelectricity generation potential is a function of the sugarcane harvest, because the amount of harvested sugarcane will determine the amount of residual biomass available for bioelectricity generation. The potential also depends on the technology used, which determines the efficiency of the conversion of biomass into electrical energy.

Following the ethanol industry boom, lead by the Proálcool program in the 1980s, and the cycle of sugar expansion in the 1990s, the last few years have seen a new growth phase for the sugar and ethanol industry. Prospects now point to further increases in the supply of sugar and ethanol in coming years. Estimates indicate Brazilian sugarcane production will increase from the current 550 million tonnes to exceed one billion tonnes of crushed sugarcane per harvest within 10 years. In addition to the expansion of sugarcane production, another fact will increase the amount of biomass available as an input for energy generation: the end of pre-harvest burning[viii] will allow sugarcane straw to be used as a primary energy source alongside bagasse.

With respect to cogeneration technology, sugar and ethanol plants have traditionally used counter-pressure cycles that ensured only the energy self-sufficiency of the plants themselves. Even within this configuration, however, some modifications, principally the use of high-pressure cauldrons, make it possible to achieve considerable energy efficiency, generating around 40 kWh per tonne of processed sugarcane (Corrêa Neto and Ramón, 2002).

New greenfield projects are currently adopting extraction-condensation technology, which allows for production of significant energy surpluses at low costs. This technology can generate up to 96 kWh per tonne of processed sugarcane, of which an average of 80 kWh can be exported. These numbers take into account only bagasse use, but with the incineration of straw not burned in the plantation (with the end of manual harvesting), it is possible to reach up to 200 kWh per tonne of processed sugarcane (Kitayama, 2008). The cost of investment in this technology is around R$3,000 per installed kW. Table 3 shows data for the short, medium and long term potential for bioelectricity generation, assuming all sugar and ethanol plants adopt the best technology.

The estimates of bioelectricity potential are based on extraction-condensation technology that has already been fully mastered and is economically viable. However, the development of biomass gasification technology – which has already been mastered in the technical sense but is not yet commercially viable – could represent a major leap forward in the potential for bioelectricity generation. This technology is capable of producing up to 270 kWh of surplus energy per tonne of processed cane.

Dantas and Castro (2008) state that the development of cellulosic ethanol could negatively impact the future supply of bioelectricity, because it may offer an alternate economic use for biomass. However, based on recent projections for the ethanol and electricity markets, the authors have assumed that investments in cogeneration will not be reduced. Rather, they are likely to be increased, especially if specific policies are adopted, for example auctions for new energy separated by source. The 2008 auction for Reserve Energy is an example.

However, because the potential for bioelectricity generation is calculated in relation to the total harvest, it is important to analyze the situation of existing sugar and ethanol plants, which need to be retrofitted to generate electricity more efficiently. These plants must replace part of their equipment to adopt more modern cogeneration technologies. It is a question of replacing functioning equipment, which may have a considerable remaining service life and that already ensures energy self-sufficiency for the plant. Realizing the generating potential of these plants therefore requires an auction price cap higher than that applied to greenfield projects. According to Castro (2008) and based on pre-crisis economic parameters in September 2008, while new projects are viable selling energy an average price of R$155/MWh, retrofitted projects need an average price of R$180/MWh to be viable. It should be noted that the sugar-energy sector has a heterogeneous production structure and these values may have a high standard deviation, especially when factoring in the costs of connection to the electricity grid, which is the responsibility of the bioelectricity entrepreneur.

3.2 Bioelectricity complementing the Brazilian electricity system, and externalities

The mere fact of incorporating bioelectricity into the system on a scale compatible with its potential would contribute to increasing the security of Brazilian electricity supply by virtue of diversifying the energy matrix. However, the most favorable characteristic of sugarcane bioelectricity for the Brazilian electricity system security is its complementary quality in relation to rainfall patterns in the Center-South region, where 70% of Brazilian reservoir capacity is concentrated. The sugar-energy harvest takes place between April and November, coinciding with the dry season in the Center-South region. Graph 3 compares the sugarcane crushing pattern with natural hydropower energy flow, demonstrating the complementarity of bioelectricity and hydropower.

Because sugarcane bioelectricity generation is concentrated during the dry season, it constitutes an energy source of great relevance to complement the installed hydropower base. It is effectively a "winter energy". According to the ONS, every 1,000 MW av of bioelectricity injected into the interconnected system during the dry season is equivalent to a 4% saving of reservoirs in the Center-South subsystem.

Table 3 **Estimates of sugarcane bioelectricity potential***

Harvest	Sugarcane (in millions of tonnes)	Generation potential (in MW av)
2012/13	696	9,642
2015/16	829	11,484
2020/21	1038	14,379

* These estimates assume the use of extraction-condensation technology, with the use of 75% of available bagasse and 50% of available straw.
Source: Prepared by Gesel/IE/UFRJ from UNICA data.

3.3 Economic viability

Despite all the acknowledged benefits of incorporating bioelectricity in the electricity matrix, there are doubts and arguments about its viability and economic competitiveness. The main argument is that if bioelectricity were competitive, it would already be sold in the new energy auctions. However, the methodology used at auctions for contacting new energy does not necessarily select the best generation projects, as discussed by Castro et al (2009a).

Table 4 presents information that demonstrates the need for a more detailed analysis regarding the apparent lack of competitiveness of bioelectricity.

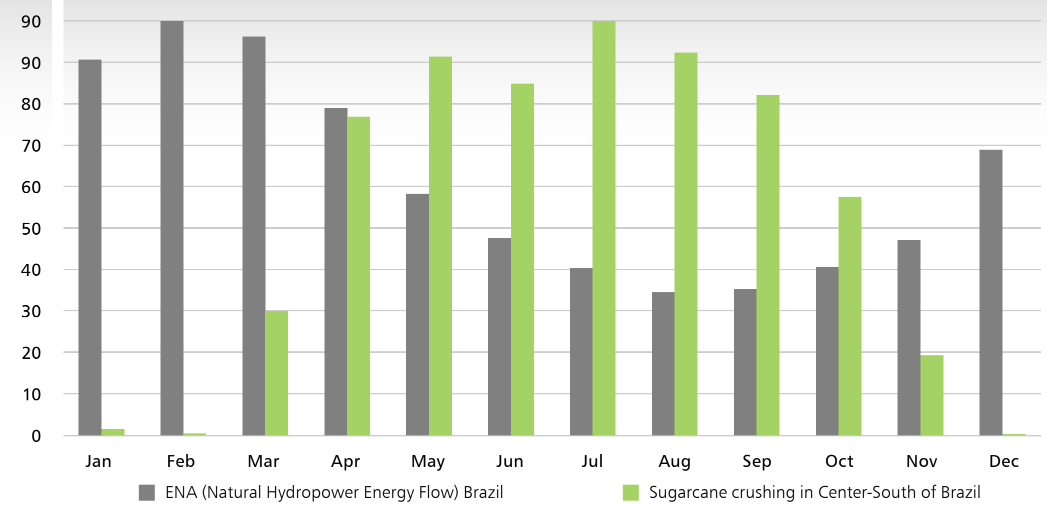
This table shows that 71.1% of contracted thermoelectric power had variable cost greater than R$200 in July of 2009, to which must be added to the fixed costs of the generating station. Given this data, it is fair to question whether a biomass generator with a fixed generation cost of R$155 per MWh or even R$180 for a retrofitted mill really constitutes a threat to the rates structure.

It is important to note that, to obtain the cost of these generating stations that are dispatched in order of merit, one cannot simply add the fixed and variable costs, because these stations were contracted as back-up, with estimated dispatch for a small number of hours per year. It is because of this methodology – low fixed cost, high variable cost and infrequent dispatch – that these plants appear competitive at auctions. However, in a hydroelectric system with declining regulatory capacity, where complementary generation

Graph 3

Complementarity of hydroelectricity and the sugar-energy sector

As a % of the month with the greatest supply



Source: ONS (www.ons.org.br) website and UNICA. Data prepared from 2008 operational history (ENA) and sugarcane crushing in the 2007/2008 harvest in the Center-South of Brazil.

will be increasingly necessary (especially during the dry season), these power plants are not the best option. They will prove to be much more expensive for the system than sugarcane bioelectricity thermal plants that operate inflexibly with no variable costs.

3.4 Environmental sustainability: GHG emissions

The Brazilian energy matrix, and particularly the electricity matrix, has unique characteristics in terms of reduced environmental impact, especially with regard to emission of greenhouse gases (GHG). However, this cannot be used as an argument for contracting dirty and polluting energy sources.

The energy sector has the greatest responsibility for global greenhouse gas emissions, with 48.8% of the worldwide total. **Table 5** compares the Brazilian emissions profile with that of other countries, illustrating the differences. It can be seen that most Brazilian emissions come under the heading of "Land use, land-use change and forestry (LULUCF)", which includes burning. Emissions from the Brazilian energy sector account for only 8.8% of the country's total.

Because bioelectricity is a renewable source of energy, it is neutral in GHG emissions. This is a marked contrast to the significant emissions of thermal energy generation with fossil fuels, as shown in **Table 6**.

Based on an estimated potential total of 14,379 MW av of bioelectricity for export in the 2020/21 harvest, we can calculate the equivalent generation of 125,960 GWh. Production of this same energy by coal-fired power plants would create total emissions of 100.7 million tonnes of CO_2. Were this generation from oil-

Table 4 **Variable unit cost (VUC) of thermal generation in the National Interconnected System (SIN)**

In 2009

VUC (R$/MWH)	Available power (MWa)	% Total
up to 100	1,536	6.80%
100 to 150	3,655	1.30%
150 to 200	1,313	5.80%
200 to 250	6,386	28.40%
250 to 300	2,723	12.10%
300 to 400	3,561	15.90%
400 to 600	1,643	7.30%
more than 600	1,637	7.30%
Total	22,454	100%

Source: ONS, PMO of July 2009.

fired stations, emissions would be 69.3 million tonnes of CO_2. Even with combined-cycle natural gas plants, emissions would be 50.4 million tonnes of CO_2. We can therefore clearly see the importance of bioelectricity for maintaining a matrix with reduced carbon intensity, and so contributing to climate change mitigation.

3.5 Source of distributed generation and additional benefits of bioelectricity

Bioelectricity counts as a source of distributed generation by virtue of being located in the Center-South region, close to the country's principal demand centers. This proximity reduces the need for expansion of transmission, which constitutes both an environmental benefit (reduction of losses in the transmission system) and an economic benefit (less need for investment in the expansion of the transmission system). Bioelectricity can even be injected directly into the distribution network, without any need to reinforce the very high tension basic grid. We can thus see that bioelectricity is compatible with the new technological paradigm of the electricity sector, which places great emphasis on the exploitation of niches for distributed generation.

Emission profiles of selected countries *In percentage, 2005 data* Table 5

Region/ Country	Energy	Transportation	Industrial processes	Agriculture	LULUCF	Waste	Total
World	48.8	11.8	3.4	13.8	18.6	3.6	100
Annex 1	63.3	18.6	3.6	8.2	-	6.2	100
Non- Annex 1	36.9	6.1	3.2	15.6	35.1	3	100
China	64.6	4.6	7.9	21.4	-1	2.5	100
India	52.3	6.8	3.5	34.8	-2.2	4.8	100
Indonesia	7.9	2	0.5	4	83.6	1.9	100
South Korea	68.8	17.5	9.2	2.8	0.2	1.6	100
Brazil	8.8	5.7	1.5	20.1	62	1.8	100
Mexico	50.5	16.6	3.5	8.2	15.8	5.3	100
South Africa	73.7	9.6	2.7	10.7	0.5	2.9	100

Source: Souza and Azevedo (2006).
* Land use, land-use change and forestry

GHG emissions by different sources *In kg per MWh* Table 6

Energy source	CO_2 emissions (in Kg per MWh)
Natural Gas (open cycle)	440
Natural Gas (combined cycle)	400
Oil	550
Coal	800
Hydroelectricity	25
Wind Power	28

Source: European Union (2007).

Furthermore, the Brazilian capital goods industry is ready to provide the necessary equipment for the construction of cogeneration plants. In this sense, investments in new, more efficient, cogeneration plants – notably retrofit conversions – do not require substantial importation of equipment, thus saving hard currency and providing a boost to the Brazilian industrial sector.

On the other hand, bioelectricity uses a nationally-produced primary energy source, as opposed to other types of generation that require imported fuel. In this sense not only there are foreign exchange savings, but also the price volatility of energy is reduced. This becomes clear in the contracts arising from the auctions for new energy: the cost of generation using oil, coal and natural gas is indexed to the international spot price of these energy inputs, while bioelectricity is indexed to the Broad Consumer Price Index (IPCA).

▶ 4. Conclusions

The Brazilian electricity matrix is going through a phase of transition, facing the increasing need to complement hydropower generation with other options to generate electricity efficiently during the dry season. Bioelectricity is an energy source that is intrinsically complementary to hydro generation, because the sugarcane harvest coincides with the dry season.

The cycle of expansion of the sugar-energy sector, together with the gradual end of burning sugarcane, ensures the necessary biomass for significant bioelectricity generation in the coming years. This justifies investments in technology that allows bioelectricity to be incorporated into the Brazilian electricity matrix.

The apparent lack of competitiveness of bioelectricity at auctions for new energy is the consequence of existing criteria for contracting energy, that do not correctly take into account all the benefits of bioelectricity for the Brazilian electricity system. In this sense, merely the reasons restricted to the "energy world" would be sufficient to justify the incorporation of bioelectricity into the Brazilian electricity matrix in a scale compatible with its potential. However, besides reasons of energy, there is the relevant fact that bioelectricity is a renewable energy source in a world that demands measures to reduce greenhouse gas emissions, and so mitigate climate change.

These reasons justify modifying the policy of contracting energy via auctions for the regulated market. Adoption of auctions by specific type of energy source, or auctions specifically for base-load generation during the dry season, would seem to be a more efficient alternative than auctions that are open to any type of project, and which have not been stimulating the efficient contracting of new projects. This guideline would be one of the most important components for a public bioelectricity policy.

Another point to be addressed via public policy is the creation of conditions for existing sugar and ethanol mills to be connected to the grid and sell energy. Sugar and ethanol mills are geographically dispersed; many are far away from sub-stations capable of receiving the energy produced. This means that access to the grid becomes an obstacle to the incorporation into the system of new bioelectricity generation ventures. The solution found for this problem around the time of the Reserve Energy Auction – the design of a collection grid to serve various projects in the same region – was certainly a step in the right direction. However, given that the financial commitment to build the collection grid had to be made before the auction, this was not an ideal alternative. Bearing in mind the competitiveness of bioelectricity, studies are recommended to reinforce the grid in regions where there is high production potential, even before confirming that mills in the region have been successful at energy auctions.

In summary, the following are important points for a public policy for the sugarcane bioelectricity sector: 1) give appropriate value to the seasonal complementarities of bioelectricity at auctions for new energy; 2) hold regular auctions restricted to this source, or at least to sources that are compatible with it; and 3) plan the expansion of transmission systems in a way that effectively allows for incorporation of bioelectricity into the generation matrix.

5. Bibliography

- Aneel. *Atlas de Energia Elétrica do Brasil*. 3a. edição. Brasília, 2008.
- Castro, Nivalde José; Dantas, Guilherme de A.; Brandão, Roberto; Leite, André Luiz da Silva. *Bioeletricidade e a Indústria de Álcool e Açúcar: possibilidades e limites*. Synergia. Rio de Janeiro, 2008.
- Castro, Nivalde José; Brandão, Roberto; DANTAS, Guilherme de A.. *A seleção de projetos nos Leilões de Energia Nova e a questão do valor da energia*. Mimeo. Gesel/IE/UFRJ. Rio, August 2009a.
- Castro, Nivalde José; Brandão, Roberto; DANTAS, Guilherme de A.. *Problemas no cálculo das Garantias Físicas para os Leilões de Energia Nova*. Mimeo. Gesel/IE/UFRJ. Rio, September 2009b.
- Castro, Nivalde José; Brandão, Roberto; Dantas, Guilherme de A.. *Considerações sobre a Ampliação da Geração Complementar ao Parque Hídrico Brasileiro*. Texto de Discussão do Setor Elétrico n.o 15. Gesel/IE/UFRJ. Rio de Janeiro, January 2010.
- Castro, Nivalde José de; Bueno, Daniel. *Os Leilões de Energia Nova: vetores de crise ou de ajuste entre oferta e demanda?* Rio de Janeiro: IE-UFRJ, June 18, 2007.
- Corrêa Neto, V.; Ramón, D. *Análise de Opções Tecnológicas para Projetos de Cogeração no Setor Sucroalcooleiro*. Setap. Brasília, 2002.
- Dantas, Guilherme de A. *O Impacto dos Créditos de Carbono na Rentabilidade da Cogeração Sucroalcooleira Brasileira*. Master's Degree Thesis. ISEG/Universidade Técnica de Lisboa, 2008.
- Dantas, Guilherme de A.; Castro, Nivalde José de. *O Uso do Bagaço e da Palha: Bioeletricidade ou Etanol Celulósico?* In: I Workshop do Infosucro sobre Impactos Econômicos e Tecnológicos da Indústria Sucroalcoleira no Brasil. Rio de Janeiro, November 2008.
- Goldenberg, P.; Guerra, F. *Inovação na Geração de Energia Elétrica a Partir do Bagaço de Cana*. In: I Workshop do Infosucro sobre Impactos Econômicos e Tecnológicos da Indústria Sucroalcoleira no Brasil. Rio de Janeiro, November 2008.
- International Energy Agency. *Key World Energy Statistics*. Paris, 2008.
- Kitayama, Onorio. *Bioeletricidade: perspectives e desafios*. In: III Seminário Internacional do Setor de Energia Elétrica – Gesel/IE/UFRJ. Rio de Janeiro, 2008.
- Souza, Z. *Geração de Energia Elétrica Excedente no Setor Sucroalcooleiro*. Ph.D. Thesis. Departamento de Engenharia de Produção/Universidade Federal de São Carlos. São Carlos, 2003.
- Souza, Z; Azevedo, P. *Energia Elétrica Excedente no Setor Sucroalcooleiro: um estudo a partir de usinas paulistas*. Revista de Economia e Sociologia Rural. Brasília-DF, 2006.

Explanatory Notes

[i] Includes the Paraguayan half of Itaipu.
[ii] Competitiveness at the generation level, as shown in auctions for the Rio Madeira dams. Final electricity prices in Brazil are not low for a number of reasons that are beyond the scope of this paper.
[iii] CO_2 emissions by the Brazilian energy matrix per tonne equivalent of petroleum are 1.57, compared to 2.36 for the global energy matrix. Hydroelectricity and the large-scale use of ethanol are among the factors responsible for reducing carbon intensity in the Brazilian matrix.
[iv] Hydraulic energy in rivers, available for energy purposes.
[v] These numbers include only those rivers that already have hydropower stations.
[vi] Brazil hydropower generation potential is estimated at approximately 260 GW.
[vii] Cogeneration can be defined as the simultaneous production from the same primary energy source of thermal and mechanical energy that can be converted into electricity.
[viii] The Agro-Environmental Protocol in the State of São Paulo contemplates the end of sugarcane burning and manual harvesting in flat areas by 2014. Over 50% of the harvest is already mechanized. Therefore, even though part of the cane will be left on the soil to protect it, there will be a significant increase in the biomass available for energy use.