BIOENERGY REPLACING FOSSIL SOURCES OF ELECTRIC POWER

SUBSTITUIÇÃO DE FONTES FÓSSEIS DE ELETRICIDADE POR BIOENERGIA

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ABSTRACT: The purpose of this article when it discusses the potential to replace the generation of electric power from coal with sugarcane bagasse, straw, and tips is to study the possibility of reducing the current emission of greenhouse gas (GHG) in the Brazilian electric power matrix. Recognized as one of the cleanest electric power matrices, the Brazilian electric power matrix still depends on fossil fuels for electric power generation, such as coal, fuel oil, diesel oil, and natural gas. Neither the amount of investment and fiscal incentives offered by the Brazilian government nor the current legislation (federal, state, and municipalities) is enough to reduce the GHG emission by electric power matrix as expected. A historic series of 20 sugarcane vintages are used to estimate the opportunity to deliver electric power by the sugar-energy industry to the Interconnect Brazilian Grid. The environmental implications of not using this potential opportunity to generate clean electric power by sugar-energy mills were the GHG emission of 17.35 MtCO2 by electric power thermoelectric burning coal in 2016. Government incentives and current legislation should be improved to change this scenario of electric power generation.
Keywords: Renewable energy sources; Fossil electric power sources; Brazilian electric power matrix; sugar-energy mills; sugar cane bagasse, straw, and tips;

RESUMO: O objetivo deste artigo ao discutir o potencial para substituir a geração de energia elétrica a carvão por bagaço, palha e pontas da cana de açúcar é estudar a possibilidade de redução das emissões atuais de gases de efeito estufa (GEE) da matriz brasileira de energia elétrica. Sendo uma das matrizes mais limpas de do mundo, a matriz de energia elétrica brasileira ainda depende de combustíveis fósseis, tais como carvão, óleo combustível, óleo diesel e gás natural. O incentivo e o investimento oferecido pelo governo e bem como a legislação brasileira atual (federal, estadual e municipal) ainda não são suficientes para reduzir, como esperado, a emissão de gases de efeito estufa pela matriz de energia elétrica. Com série histórica de 20 safras de cana de açúcar é estimada a oportunidade do setor sucroenergético brasileiro para fornecer energia elétrica limpa ao Sistema Interligado Nacional (SIN). As implicações ambientais negativas da não realização desta oportunidade potencial para gerar energia elétrica limpa e renovável pelas usinas de cana de açúcar foi a emissão de gases de efeito estufa de 17.35 MtCO2 pela geração das termelétricas a carvão em 2016. Para a matriz de energia elétrica ficar mais limpa e renovável é necessária ação governamental.

Palavras-chave: fontes renováveis de energia elétrica; matriz elétrica brasileira; usinas de cana de açúcar; bagaço, palha e pontas da cana de açúcar; fontes fósseis de energia elétrica.

INTRODUCTION

Despite being one of the cleanest in the world, the Brazilian electric power matrix is still dependent on fossil sources. Coal and oil are fossil sources that still have essential electricity generation to meet Brazilian demand. The use of coal in power generation has been reduced in the Brazilian electric matrix composition. However, the rate of reduction is still too slow. Power plants that burn coal and oil products that used to be complementary sources are dispatched nowadays by the National Electric System Operator (ONS) as a primary source- together with hydroelectric plants -for the generation of electric power.

According to the Energy Research Company (EPE, 2018), the generation of electric power in 2017 showed a slight reduction in the use of fossil sources compared with 2016 figures. The participation of coal and oil products in power generation reached 5.34%, while the electric power generation with biomass sources reached 9.10% in 2017. Table 1 shows the composition of the electric power matrix by authorities in 2016 and 2017.

Power generation sources- GWh	2016	2017
Hydroelectric	380,911	370,906
Natural gas	56,485	60,593
Biomass	49,236	49,385
Oil products	12,103	12,733
Nuclear	15,864	15,739
Steam coal	17,001	16,257
Solar photovoltaic	85	832
Other (includes wind power)	13,723	14,146
Total	547,424	542,608

Table 1 – participation of electric power generation sources in Brazil (EPE, 2018)

Sugarcane plays a strategic role in the Brazilian economy. The Brazilian Government supported research and development investment, causing a relevant upgrade in the traditional sugarcane industry. In addition to the production of sugar and ethanol, a new business opportunity arose with the burning of bagasse, straw, tips, and sugarcane wastes to generate the electricity surplus in the mills in operation, defined as bioelectricity cogeneration (Vasconcelos and Carpio, 2017).

The surplus of electricity (supply) from the sugar-ethanol industry became available to the National Interconnected System (SIN). Even the industry's name changed from the sugar-ethanol industry to the sugar-energy industry. The chain of the Brazilian sugar-energy industry sells US$ 43.6 billion in end products representing about 2% of the Brazilian GDP (Vasconcelos and Carpio, 2017; Novacana, 2015). This value is equivalent to the economic output of countries like Paraguay, North Korea, Afghanistan, Jamaica, and Estonia.

The mills and the agents involved in the economic activity around sugar, ethanol, and bioelectricity production from sugarcane generate a gross revenue higher than US$ 100 billion per crop (VASCONCELOS and CARPIO, 2017; Novacana, 2015). These figures confirm the relevance of the sugar-energy industry to the Brazilian economy (MORAES et al., 2016).

The Chamber of Electric Energy Commercialization (CCEE) reported that in July 2016, cogeneration from sugarcane biomass achieved its historical record, with up to 8.1% of the Brazilian electricity consumption generated by the sugar-energy industry.

The sugarcane harvest occurs in the Southeast/Midwest regions from April to November. This is the period when drought occurs, impairing the water replacement in the reservoirs of the hydroelectric power plants in this region. The central hydroelectric power plants with reservoirs are located in these regions. About 70% of the hydroelectric power plant reservoirs are concentrated in the Southeast/Midwest regions (VASCONCELOS and CARPIO, 2015).

Due to the shortage of rain that occurred in the Southeast/Midwest regions of Brazil during 2001/2002, the hydroelectric power plant reservoirs had the water level reduced to critical levels, which led to electricity rationing (VASCONCELOS and CARPIO, 2015). Government actions since then increased the share of thermal electricity generation using coal, oil, and natural gas in the Brazilian electricity mix.

Another period with low rainfall happened during 2014 in the regions where hydroelectric power plants with reservoirs are located (VASCONCELOS and CARPIO, 2015). In this new period of rainfall shortage (2014/2015), Brazil's major hydroelectric water reservoirs reached critical levels. Thus, the National System Operator (ONS) authorized the thermoelectric generation plants to maintain the supply and meet the demand for electricity throughout the period in an uninterrupted way (VASCONCELOS and CARPIO, 2015).

According to the ONS, each 1,000 average MWh of bioelectricity delivered to the SIN during the dry season means savings of 4% of the water from the reservoirs of the Southeast/Midwest subsystem (VASCONCELOS and CARPIO, 2017; CASTRO et al., 2010).

Since 2004, sugarcane biomass has increased its participation as input for bioelectricity generation. According to the Brazilian Energy Research Company (EPE, 2015), the national policies promoted the diversification of electricity generation.

The Brazilian Electricity Regulatory Agency (ANEEL) announced that there was 7.9 GW of installed capacity for the cogeneration of electricity by the sugar-energy industry at the beginning of 2014. In May 2015, this capacity expanded to 9 GW.

EPE (2015) reported that 177 mills with sugar-energy production units provided a surplus of electricity to the SIN. Since the total sugar-ethanol mills reach 355 production units (ÚNICA, 2016), there is still growth potential in the bioelectricity supply (VASCONCELOS and CARPIO, 2017).

In the Regulated Contracting Environment (ACR) market, new electric power sellers that had participated in the bioelectricity generation auctions for the years 2014, 2015, and 2016 have also evolved positively, reaching the level of US$ 61.4/MWh in the LFA2015 auction (LFA: Alternative source energy auction only for wind electricity and bioelectricity). In April 2014, the cap price of electricity on the Deregulated Contracting Environment (ACL) reached US$ 234.86/MWh (VASCONCELOS and CARPIO, 2017; CCEE, 2015).

The generation of electric power with the burning of sugarcane bagasse, straw, and tips, by-products of the production process of sugar and ethanol, has the potential to replace the generation of electric power from coal and oil products.

1 HISTORIC PRODUCTION OF SUGARCANE AND THE POTENTIAL FOR ELECTRIC POWER GENERATION

The sugarcane vintage takes place between April and November in the Brazilian Southeast/Midwest regions, and mills in the Brazilian Northeast region have their vintage between November and April. Thus, considering the entire Brazilian territory, the sum of sugarcane regional vintage periods indicates that electric energy cogeneration could happen throughout the year (one part in the Southeast/Midwest regions and another in the Northeast region).

Depending on the sugarcane amount harvested during the vintage, some plants extend the milling period by up to two months. In this case, they produce additional bagasse, straw, and tips and may generate more electric power.

Mills in the Brazilian Northeast region have their vintage between November and April. Thus, considering the entire Brazilian territory, the sum of sugarcane regional vintage periods indicates that electric energy cogeneration could happen throughout the year (one part in the Southeast/Midwest regions and another in the Northeast region).

According to Vasconcelos and Carpio (2017) and RAÍZEN (2015), one ton of sugar cane milled generates on average 250 kg of bagasse and 204 kg of straw and tips. Research stated that 50% of the straws and tiprecommendationsould be left in the field to maintain it, control erosion, and keep moisture, temperature, and soil fertility (VASCONCELOS and CARPIO, 2017; VILLELA, MOREIRA e FREITAS, 2015).

Another point that should be considered is that, depending on the technology used in the manufacturing process of the boiler installed in the plant, straw and tips could be burned along the bagasse in many different proportions. Pellets, briquettes, wood chips, and sawdust can be burned along with bagasse (VASCONCELOS and CARPIO, 2017). The opportunity for electric power generation of 20 Brazilian crops of sugar cane is presented in Table 2.

	Vintage Year	Ton of sugarcane	Ton of Bagasse (1 ton sugarcane = 250 kg)	Ton straws/tips (1 ton sugarcane=204/2 kg)	Oportunity to deliver Electric Power. - BRAZIL		
					MW (1 ton bagasse +straws+tips = 0,1882 Mw)	MW internal own use (40%)	MW available for cogeneration (60%)
1	1997/98	302198516	75549629	2962731	14776026	5910410	8865616
2	1998/99	315640787	78910197	3094518	15433287	6173315	9259972
3	1999/00	310122784	77530696	3040419	15163484	6065394	9098090
4	2000/01	254921721	63730430	2499233	12464423	4985769	7478654
5	2001/02	292329141	73082285	2865972	14293462	5717385	8576077
6	2002/03	316121750	79030438	3099233	15456804	6182722	9274082
7	2003/04	357110883	89277721	3501087	17460972	6984389	10476583
8	2004/05	381447102	95361776	3739677	18650893	7460357	11190536
9	2005/06	382483002	95620751	3749833	18701544	7480618	11220926
10	2006/07	428816921	107204230	4204087	20967045	8386818	12580227
11	2007/08	485843192	121460798	4763169	23755351	9502140	14253210
12	2008/09	573738489	143434622	5624887	28053000	11221200	16831800
13	2009/10	603056367	150764092	5912317	29486500	11794600	17691900
14	2010/11	624501165	156125291	6122560	30535046	12214018	18321027
15	2011/12	560993780	140248445	5499939	27429846	10971938	16457908
16	2012/13	589237141	147309285	5776835	28810808	11524323	17286485
17	2013/14	658697545	164674386	6457819	32207081	12882832	19324249
18	2014/15	637714365	159428591	6252102	31181106	12472443	18708664
19	2015/16	666304044	166576011	6532393	32579002	13031601	19547401
20	2016/17	633879440	158469860	6214504	30993597	12397439	18596158

Table 2 – Electric power generation opportunity per crop.

Considering the power supply crisis that occurred in 2001/2002, a fact that has led to government actions to encourage cogeneration by mills and the time required to adjust or replace the boilers and to install generators, substations, and the necessary connection with the transmission/distribution to the grid, it was assumed that the opportunity of cogeneration could start on the 2004/2005 vintage.

Another critical point is that in Table 2 it was used the percentage of 60% of the electric power generated for delivery as cogeneration for each vintage. That is the percentage of electric power available during the vintage period. In the off-vintage period, there is no mill consumption of 40% of the electric power generated. As mill production lines stopped (usually for periodic technical maintenance), all electric power generated could be dispatched during this period. This off-time opportunity was not computed in this study.

2 BRAZILIAN ELECTRIC POWER SECTOR

As Vasconcelos and Carpio (2017) studied, the current model of the Brazilian electric power sector is regulated by law no. 10848/2004 and the decree no 5163/2004. In the model, there are two contrasting environments, as follows: the Regulated Contracting Environment (ACR) and the Free Contracting Environment (ACL).

ACR is the market where electric power purchasing and sale are negotiated between selling agents and distribution agents through bidding (auction). Contracts are signed between sellers, generating agents that offered electric power for the lowest price and won an auction, and electric power distribution companies, which are the buyers. These contracts are called Power Purchase Contracts in the Regulated Environment (CCEAR).

The second market, ACL, is where free negotiations between agents with a stake in a generation, marketing, export, and import with free consumer companies occur. The ACL negotiations are formalized by commercial contracts containing electric power volumes, prices, terms, and guarantees.

Generation and marketing agents can sell electric power in both environments. Rules and trading procedures defined by the Electric Energy Trading Council (CCEE) consist of the Normative Resolution n_o 109/2004. Contracts are registered in CCEE and form the source for their accounting and financial settlement.

Under the current rules, self-producers and cogeneration companies with an installed capacity below 50 MW can participate in CCEE operations as long as they are already interconnected with power distribution companies' facilities. Self-producers are not dispatched directly by the National System Operator (ONS) but through the power distribution companies.

Electric power self-producers and cogenerators may be CCEE agents or represented by another registered agent to market electric power in ACR and ACL markets. Compliance assurance of signed contracts made by their generation or other contracts already registered in CCEE.

To ensure the whole electric power supply delivery in their contracts, cogenerators should offer electric power "ballast" as a physical guarantee of the maximum electric power amount associated with the self-generation enterprise or third-party purchase agreements, which can also be used to meet the delivery expected in the sales contract.

In addition to the two contrasting environments, the Short Term Market accounts for and settles differences between the electric power produced and consumed and the effects measured volume.

Differences determined by CCEE are valued by the Differences Settlement Price (PLD). The short-term market is known as the "spot market" and "spot price," about international trends of the free market. PLD is calculated and published weekly for each load level and SIN submarket, based on the marginal cost of system operation (CMO), limited by a minimum and a maximum price. Oliveira 2008, and Hofsetz and Silva (2012) described the electric power markets in Brazil.

3 ENVIRONMENTAL IMPLICATIONS

Using bagasse has environmental benefits, such as carbon emission reduction – if compared with coal burning emissions –, deforestation reduction, and the absence of flooding and land flooding to build hydroelectric reservoirs. In addition, it does not interfere with tropical ecosystems (VASCONCELOS and CARPIO, 2017).

This is because bagasse is a sugarcane by-product generated during ethanol and sugar production. Sugarcane crops historically do not cause deforestation, as they occupy areas already deforested and degraded by cattle (old pastures opened in agricultural borders, especially in the Brazilian Midwest region (VASCONCELOS and CARPIO, 2017; VILLELA, MOREIRA e FREITAS, 2015).

As a semi-perennial plant, which is an advantage in reducing the number of farm operations that expose the soil to storms and facilitate the loss of its fertile layer, sugarcane is a conservationist plant. According to Villela, Moreira, e Freitas (2015), studies show that the sugarcane crop is the least degrades the soil (soil loss by erosion) compared to other crops.

Galdos et al. (2013) detailed relevant technical aspects of waste management for sugarcane ethanol production. Regarding the retention capacity of rainfall water, an essential item in agriculture, even for soil protection, sugarcane is considered one of the most efficient crops, as it has losses lower than 5% (BNDES, 2008). It also does not interfere with food production, as sugarcane produces sugar.

Compared to traditional thermal power plants that use fossil fuels, electric energy generation by the sugarcane industry has other competitive advantages, such as small-sized generating units that allow the decentralization of generation centers and reduce transmission costs.

3.1 SUGARCANE FIELDS BURNING

According to Vasconcelos and Carpio (2017), sugarcane field burning was adopted all over Brazil to facilitate the sugarcane harvest by workers. This practice was necessary, as the entire crop used to be manual, and the sugarcane straw hindered the workers' harvest during cutting.

However, besides changing sugarcane yield in plants, burning also causes environmental pollution through the emission of greenhouse gas (GHG) and the health and life quality of the nearby town population. Moreover, burnt sugarcane must go through an extra cleaning process at the beginning of the sugarcane preparation process milled in the plant.

Lack of proper control and wind may cause the fire to reach neighboring properties of the sugarcane fields, destroying crops and industrial and private facilities, and generating thick smoke clouds that impair traffic on nearby roads and cause accidents. CONAMA issued resolutions No. 382/2006 and 436/2011 about maximum atmospheric pollutant emissions for stationary sources.

In March 2013, the Brazilian Supreme Federal Court (STF), through the Library Documentation/Coordination Department, published "Sugarcane Burnings - Bibliography, Legislation and Jurisprudence," whose aim was to publicize the existing doctrine on the subject in the Virtual Libraries Network (RVBI) in full-texts and specific pages published on the internet.

The São Paulo state government, where the most significant area planted with sugarcane is located, providing raw material for the highest concentration of sugar-ethanol industries in Brazil, was the pioneer in legislating sugarcane field burnings. In 2002, through state law no 11241, São Paulo defined a schedule with gradual plantation burning reductions, whose goal is to eliminate this practice incrementing mechanized agriculture areas by 2021 and to eliminate the practice from non-mechanized agriculture areas by 2031.

Other states that produce sugar and ethanol follow the form of São Paulo, such as Mato Grosso do Sul, Paraná, and others, including conditions from the Brazilian Northeast region.

In addition to the problem of sugarcane burnings, decrees and resolutions also establish criteria and procedures for the environmental adequacy of plants. Federal Decree no 6961/2009 approved sugarcane agro-ecological zoning in the country.

3.2 REVERSE LOGISTIC POLICIES OF WASTE AND AGRICULTURAL ZONING

Federal Decree no 7404/2010 regulates the National Policy on Solid Waste created by Federal Law no. 12305/2010. It sets standards for selective collection and recovery of solid waste from the productive sector for recycling or other environmentally suitable destination, such as biomass use (bagasse) to produce electric power (VASCONCELOS and CARPIO, 2017). Reducing the soil and water contamination by using bagasse to have electric power is an environmental action that increases the mill profits (VASCONCELOS and VASCONCELOS, 2017).

The state of Mato Grosso does Sul applies the Climate Risk Agricultural Zoning for sugarcane crops through decree no. 93/2011, according to Federal Decree no. 6961/2009.

The affected areas are, as follows: the Amazon and Pantanal biomes and the Upper Paraguay River Basin; lands with declivity above 12%; lands with native or reforestation vegetation cover; remaining forests or protected areas; dunes, mangroves; scarps; rock outcrops; mining areas; urban areas; and indigenous lands (VASCONCELOS and CARPIO, 2017). Law nº 12305/2010, art. 13, II, b and ABNE 10004:2004 classify bagasse, straw, and tips as industrial waste (NUNES, MATOS and VASCONCELOS, 2019).

3.3 LICENSING FOR ELECTRIC POWER COGENERATION

Each of the Brazilian states has solutions regarding allowing license for electric power cogeneration by sugar-ethanol plants. As a sample, below was selected the state of Mato Grosso do Sul that has the following resolutions:

a. SEMA/IMAP nº 004/2004, from the State Environment Institute, citing environmental licensing standards for biomass plants with capacities lower than 30 MW of electric energy generation and for electric energy plants with a capacity exceeding 30 MW;
b. SEMAC nº 010/2007, for power cogeneration license granting;
c. SEMAC nº 020/2007, which unifies licensing procedures for installation, water collection, soil fertilization, gas station, and biomass plant.

4 RESULTS AND DISCUSSION

The sugarcane vintage takes place between April and November in the Brazilian Southeast/Midwest and Northeast regions between November and

April. Thus, considering the whole Brazilian territory, the sum of sugarcane regional vintage periods indicates that electric energy cogeneration could happen throughout the year.

As stated in Table 2, every one of the 20 vintages presented from 1997 to 2017 had the potential to offer at least 8.800 GWh of renewable electric power (bioenergy) to be dispatched by the ONS operator for the SIN. Just after the 2002/2003 electricity crisis, the 2003/2004 vintage had the potential to offer more than 10 GWh of renewable electric power. Since 2012 the potential of renewable electric energy has reached twice the possibility of 1997.

During this period, due to government decisions, neither enough investment was made to building new sugar-energy plants with the capacity of electric power cogeneration nor new projects to upgrade old sugar cane mills to install electric power cogeneration. Based on the current situation, sugar-energy mills' electric power cogeneration is still insufficient to replace thermoelectric coal plants.

Another critical factor is the emission of greenhouse gas (GHG). Table 3 presents the SIN GHG emissions of fossil sources utilization ($MtCO_2$) for electric power generation.

SIN GHG EMISSIONS - MtCO2					
Fossil fuel	2012	2013	2014	2015	2016
Diesel	2.92	3.06	7.11	7.73	3.41
Fuel Oil	2.32	8.01	13.16	10.82	4.29
Steam coal	8.58	15.68	19.28	19.89	17.35
Natural gas	15.13	26.08	31.45	30.52	20.30

Table 3 – SIN GHG emissions. Source: EPE, 2018.

Steam coal is the primary GHG generator of the Brazilian Electric Power Matrix. Although natural gas presents a more considerable GHG emission, as stated in Table 3, it is necessary to compare the electric power generated per source (Table 1). Natural gas plants delivered 56,485 GWh to SIN in 2016 with the corresponding GHG emission of 20.30 $MtCO_2$ (0.036 %), and Steam coal plants returned 17,001 GWh to SIN in 2016 with the related GHG emission of 17.35 $MtCO_2$ (0.102 %).

CONCLUSION

Based on historical sugarcane production, as stated in Table 2, there is an opportunity to increment the electric power cogeneration by sugarcane mills in the next few years. The increment of the cogeneration by sugar cane mills is viable to interrupt or at least strongly reduce the dispatch of thermoelectric coal plants by ONS.

An essential environmental benefit can be achieved by interrupting thermoelectric coal use. It reduces GHG emissions, resulting in the cleaning of the Brazilian electric matrix. With the increment of the burning of bagasse, straws, and tips in the mill's cogeneration processes, there will be a reduction in soil, water, and air pollution nearby sugar-energy mills.

Neither the amount of investment and fiscal incentives offered by the Brazilian government nor the current legislation (federal, state, and municipalities) is enough to reduce the GHG emission by electric power matrix as expected. Government incentives and current legislation should be improved to change this scenario of electric power generation.

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