EVALUATION OF EXTERNALITIES IN SUGARCANE-ORIGIN COGENERATION PROCESS IN BRAZIL

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ABSTRACT: Proalcool, the Brazilian Alcohol Program, is the largest program of commercial biomass utilisation for energy production in the world, with well-known environmental benefits, reduction on import expenditures and creation of jobs in rural areas, among others. Besides the utilisation of alcohol as automotive fuel replacing gasoline, there is also the use of sugarcane bagasse for electricity cogeneration; in São Paulo, there are alcohol plants already selling electricity surplus to local utilities. Higher efficiencies in cogeneration processes are possible with conventional technologies already commercially available in Brazil nowadays. More advanced technologies (gasifier/gas turbine systems) shall be available in a near future but special policies will be needed to make it economically feasible. One of the possibilities under discussion is the incorporation of externalities in the electric sector energy planning. Therefore, this paper evaluates the externalities in sugarcane-based electricity, considering the life cycle of the cogeneration process, both in agricultural and industrial phases. Because cogeneration process has two products (steam and electricity), the partition of the costs has been based on the exergy concept, which is considered the most adequate method to compare rigorously these two products. The results are compared to other studies evaluating the externalities from wood-based and natural gas-based electricity.

1. INTRODUCTION

Only in recent years the Brazilian energy sector has included some environmental costs (mitigation costs mainly) in the energy planning but only for the large hydroelectric power plants. However the real figures for this kind of costs are much higher than the assumed ones[1]. These aspects are still more important by now with the large thermoelectric power plants proposed by the Ministry of Mining and Energy (19 GW from natural gas, coal and other fossil fuels) [2]. This new scenario obliges the revision of the Brazilian environmental legislation because until now there are not regulations limiting NO_x emissions from stationary sources (only for SO_2 and particulate), which are specially significant in natural gas-fired gas-turbine to be used in the new power plants.

In this context, the incorporation of externalities (as environmental costs) in the economic analysis of electricity generation is an important mechanism to compare fossil fuels and biomass-origin electricity. Therefore, this paper evaluates emissions from electricity cogeneration process from sugarcane-origin (direct and indirect fuel consumption), both from agricultural and industrial phases, and compares the obtained results with those from natural gas combined cycle.

2. SUGARCANE-ORIGIN ELECTRICITY GENERATION IN BRAZIL

2.1 The Brazilian Alcohol Program

Proalcool, the Brazilian Alcohol Program, presents the well-known environmental benefits, reduction on import expenditures and creation of jobs in rural areas, among other advantages. Social aspects are especially significant; current jobs in sugar-alcohol sector are one million direct jobs in rural area, more 300,000 industrial jobs in private industrial units and sugarcane growers. São Paulo State is responsible for 50% of these jobs. Moreover, to create a job in sugar/alcohol industry is much cheaper than in other industrial sectors.

Brazilian sugarcane production was 300 million (metric) tones in the 1999/00-harvesting season. Sugar and alcohol production was 19 million tones and 12.7 billion litters respectively. In São Paulo State, cane production was 194 million tones, corresponding to 13 million tones of sugar and 8.5 billion litters of alcohol. All these figures show the important role played by São Paulo State in this agribusiness sector.

In the past alcohol prices were not competitive when compared to gasoline prices and there were subsidies to support the difference. Two years ago Federal Government has liberated fuel prices and excluded alcohol subsidies, extinguishing also the centralised distribution system and creating a direct contact among alcohol producers and distributors. The free market for fuels, after so many years of strict regulations and crossed subsidies, conducted to an instable situation that is by now searching its own way. By now despite the free market, the Alcohol Program is being reactivated because of environmental and social role. Among several policies being discussed is the implementation of a large-scale cogeneration program for Brazilian sugar/alcohol sector. Revenues from electricity sales could allow further reductions on alcohol production costs and there are also its positive environmental impacts due to its biomass-origin.

2.2 Cogeneration in sugar/alcohol sector

Cogeneration in all Brazilian sugar/alcohol plants is from sugar-cane bagasse[1]. Because bagasse production

[1]Bagasse is a by product from sugar cane crushing process

is quite high[2], surplus not burned in boilers is sold to other industries. Almost all plants burn it in an inefficient way, using 21 bar-boilers and backpressure steam turbines, with very low efficiency. Energy production is enough to supply the needs of production process (500 kg of low-pressure process steam per tone of crushed cane and around 25 kWh/tc of mechanical/electric energy). Most Brazilian plants are self-sufficient and, in São Paulo State around 10% of them sell electricity surplus to local utilities.

Higher efficiencies in cogeneration process are possible with conventional technologies commercially available in Brazil, with an estimated potential of up to 4 GW.

Electricity surplus is currently available only during harvesting season and this is an advantage for local utilities because that is the dry season for hydroelectricity. To generate electricity off-season, it means, all over the year, it would be necessary to harvest green cane, through mechanical harvesting processes. In this case, top and leaves of sugarcane[3] would be stored and used for electricity generation off-season. This process is under implementation in São Paulo State by some industries and cooperatives (Copersucar[4]), but some technological and social[5] difficulties still exist.

Until now, prices offered by local utilities are considered not attractive by producers (around US$ 23/MWh in 1999, for long term contracts and US$6,5/MWh for short-term contracts). The purchase of this energy by the utilities is not mandatory and special discounts (up to 100%) on wheeling tariffs are available only for electricity from small dams.

In February, 2000, due to forecasts of high risk of deficit in electricity supply, special policies were established by Federal Government to implement large natural-gas power plants, like special tariffs for natural gas, the warranty of a power purchase agreement (PPA) and the financial support of Federal investment agencies to the investors. However these policies do not yet include biomass-origin electricity.

3. EVALUATION OF EXTERNALITIES – METHODOLOGY

3.1 Methodology used for pollutant emissions evaluation

The methodology utilised to evaluate the externalities in sugarcane-origin cogeneration includes agricultural and industrial phases (direct and indirect fuel consumption). Industrial phase includes only the cogeneration process. In agricultural phase, it is considered the harvesting of green cane, which is the better environmental option for sugarcane harvesting. So, in this phase, emissions are due to diesel oil consumption in the fields, as well as indirect fossil fuel consumption in the equipment.

Because cogeneration process has two products (steam and mechanical[6]/electric energy), the cost partition is based on exergy concept [3],[4],[9]. This is considered the most adequate method to compare rigorously these two products, according to the Second Law of Thermodynamics.

Obtained results are compared to externalities for a wood-fired integrated gasifier/gas turbine system [5] and for a natural gas-based combined cycle in Brazil.

3.2 Fossil fuel consumption and emission factors

The (direct and indirect) fossil fuel consumption is assumed from Copersucar studies[6]. Specific emissions from bagasse-origin cogeneration are evaluated for the following possibilities:

- Considering only the emissions from bagasse-fired boilers (final use)
- Considering all emissions: from boilers[7] and fossil fuel[8] (direct and indirect) emissions[9] .

Table 1 shows the main figures assumed for the exergy balance in cogeneration process. For the electricity surplus generation the following possibilities are considered:

- Steam turbine systems surplus: 30 and 60 kW/tc (during harvesting season), 100 kWh/tc (CEST, during season and off-season) [4]
- BIG/GT systems surplus: 300 kWh/tc [10]

Table 1: Energy and exergy consumption (average) in sugar/alcohol process:

Steam turbine systems	
Specific steam consumption [a]	500–400kg/tc [b]
Specific steam exergy [a]	88-71 kJ/kg [b]
Electric/mechanical energy consumption	25 kWh/tc [b]
BIG/GT [c]	
Specific steam consumption [a]	332 kg/tc [d]
Specific steam exergy	59 kWh/tc [e]
Electric/mechanical energy consumption	23 kWh/tc [f]

Sources: As mentioned below.

Notes: a. Steam @ 2.5 bar, 155° C (specific exergy: 635 kJex[10]/kg of steam); b. [4] for a large-size Brazilian plant; lower consumption for CEST systems[11]; c. Biomass integrated gasifier/gas turbine system; d. [10]; e. Same steam conditions as in steam cycle; f. [10].

4. RESULTS

Tables 2 and 3 compare the results obtained here to the existing results [5] for a 30 MW-BIG/GT using wood (direct and indirect fossil consumption, 42% of conversion efficiency) and to natural gas emissions

[2] Bagasse correspond to 30% of harvested sugar cane, 50% wet.

[3] Corresponding to more than 30% of harvested cane.

[4] Cooperative of Sugar/alcohol Producers in São Paulo State

[5] Due to the high number of jobs in this sector

[6] Mechanical energy is consumed in the sugarcane steam turbine-driven mills.

[7] Bagasse-fired boilers particulate emissions assumed from boilers under surveillance of CETESB, the environmental authority of São Paulo State: 0.6 kg/tone of bagasse(tb). Other emissions[7]: CO 0.0126 kg/tb; NO_x 0.6548 kg/tb; CO_2 emissions null due to the biomass carbon balance; no SO_2 .

[8] Diesel oil emissions: particulate 0.104 t/TJ, CO_2 80 t/TJ, SO_2 0.09 t/TJ, NO_x 0.99 t/TJ, CH_4 0.22 t/TJ, CO 0.99 t/TJ [5]. LHV for diesel oil assumed equal to 42252 kJ/kg [8]

[9] Global fossil fuel consumption in bagasse cogeneration systems: 4.15 liters of diesel oil-equivalent per tc (150 MJ/tC) [6]

[10] Exergy based

[11] CEST – condensing extraction steam turbine system

evaluated for a 50% efficiency-combined cycle (only direct emissions from the natural gas burning).

These results show, as expected, that more efficient systems present lower specific emission. Comparing the direct emissions from bagasse-fired systems (Table 2) with those from natural gas, we conclude that CH_4, NO_x and CO emissions are lower in bagasse systems, even from the low-efficiency ones; only particulate emissions are higher from bagasse systems when compared to natural gas ones.

When including indirect fossil fuel consumption (Table 3), emissions from biomass low-efficiency systems are higher but we must remember that the emissions from NGCC showed here are only direct emissions from the NG burning. However, even considering all (direct and indirect) emissions from fossil fuel, emissions from BIG/GT systems are still lower than those (direct) emissions from NGCC.

If, in a very preliminary evaluation, we assume figures[12] for specific (environmental) costs among the several ones available in literature, bagasse-based electricity generation costs[13] can be as low as US$ 1.09 per MWh generated, for bagasse-BIG/GT, against US$ 8.85 per MWh for NGCC[14], not including carbon emissions. When these emissions are included, biomass advantages become still higher. Even considering all fossil fuel consumption in biomass cycle for electricity generation, carbon emissions (CO_2 equivalent) from low efficiency bagasse-fired systems corresponds to around 20% of (direct) carbon emissions from natural gas combined cycle, as shown above. Considering the discussion regarding carbon emissions in the Kyoto Protocol, the advantages of sugarcane bagasse cogeneration become evident for Brazilian situation.

5. CONCLUSION

Several studies have already been developed regarding externalities in Brazilian sugarcane sector [11],[12]. Nowadays this subject becomes more important due to the changes in Brazilian Energy Matrix.

Assuming that the large thermoelectric power plants will be built as forecasted, Brazilian Energy Matrix will present a higher participation of fossil fuels for electricity generation. Brazilian installed power is nowadays around 65 GW, 95% of it from hydro power plants. Emissions from thermoelectric generation were, in 1997, less than 4 million tones of carbon [2]. The 17 GW from natural gas combined cycle together with the 1.8 GW from coal-fired plants will be responsible for the emission of more 16 million tones of carbon together. Therefore carbon emissions will be multiplied by a factor of 5.

In fact, average emissions from electricity generation will still be low (48 kg C/kWh) due to the high participation of hydroelectricity [12]. However, considering the huge potential of sugarcane bagasse origin electricity, the incorporation of biomass in the electric sector planning could collaborate to reduce carbon emissions significantly. Replacing NGCC by sugarcane-electricity produced by only 45% of São Paulo State sugar/alcohol plants[15], carbon emissions avoided can reach 2.9 million of tC/year, considering 4 GW with BIG/GT.

Also considering that Brazilian environmental legislation does not include emission factors for NO_x , these emissions will be increased by more than 200,000 tones of NO_x per year. This fact is also important because the Table 2 above shows that bagasse-fired boilers, even with no NO_x-cleaning systems, present lower emissions than gas turbine systems.

[12] (US$/kg): 0.88 for SO2, 6.42 for NOx, 0.132 for CH4, 0.902 for CO, 2.31 for particulate (control costs) [13]

[13] Including only direct emissions from bagasse

[14] Direct emissions from NG burning

[15] Plants crushing more than 2,000,000 tones of sugarcane per year considered the adequate size for cogeneration processes.

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Table 2: Pollutant emissions from sugarcane origin cogeneration compared with those from electricity generation from wood and natural gas considering only direct emissions from bagasse boilers and natural gas-fired gas turbines:

Fuel (a)	**SUGARCANE BAGASSE**				**Natural gas**
Conversion Technology (b)	**Steam turbine systems**			**BIG/GT**	**C.C.**
Conversion efficiency (c)	**30 kWh/tc**	**60 kWh/tc**	**100 kWh/tc**	**300 kWh/tc**	**50%**
Fossil fuel consumption (d)	**BC**	**BC**	**BC**	**BC**	**NGC**
SO_2 (kg/MWh)	0.00	0.00	0.00	0.00	0.00
NO_x (kg/MWh)	1.28	1.06	0.94	0.14	1.34
CH_4 (kg/MWh)	0.00	0.00	0.00	0.00	0.04
CO (kg/MWh)	0.02	0.02	0.02	0.18	0.23
Particulate (kg/MWh)	1.17	0.97	0.86	0.02	0.00
CO_2	0.00	0.00	0.00	0.00	403.34

Sources: [7]; [5]; authors' evaluation

Table 3: Pollutant emissions from sugarcane origin cogeneration compared with those from electricity generation from wood and natural gas considering direct and indirect emissions biomass systems:

Fuel (a)	**SUGARCANE BAGASSE**				**Wood**	**Natural gas**
Conversion Technology (b)	**Steam turbine systems**			**BIG/GT**	**BIG/GT**	**C.C.**
Conversion efficiency (c)	**30 kWh/tc**	**60 kWh/tc**	**100 kWh/tc**	**300 kWh/tc**	**42%**	**50%**
Fossil fuel consumption (d)	**BC/FF**	**BC/FF**	**BC/FF**	**BC/FF**	**BC/FF**	**NGC**
SO_2 (kg/MWh)	0.09	0.08	0.07	0.04	0.10	0.00
NO_x (kg/MWh)	2.32	1.92	1.70	0.53	0.49	1.34
CH_4 (kg/MWh)	0.23	0.19	0.17	0.09	0.06	0,04
CO (kg/MWh)	1.06	0.88	0.78	0.57	0.56	0.23
Particulate (kg/MWh)	1.28	1.06	0.94	0.06	0.06	0.00
CO_2	84.06	69.50	61.55	31.55	24.00	403.34

Sources: [7]; [5]; authors' evaluation

Notes for Tables 2 and 3:
(a) Sugarcane bagasse 50 % wet, 7440 kJ/kg (LHV); LHV for natural gas 8554 kJ/Nm^3 [8]; (b) Generation only during harvesting season (30 to 60 kWh/tc); generation during season and off-season (CEST, 100 kWh/tc), BIG/GT (bagasse-fired gasifier gas turbine system)[10]; (c) Conversion efficiencies for bagasse-fired systems as in (b); for wood-fired BIG/GT global efficiency is 42% [5]; for natural gas combined cycle (CC), efficiency is 50%; (d) Fossil fuel consumption: BC - (direct) emissions from biomass-fired systems; BC/FC – biomass and fossil fuel (direct and indirect) consumption in biomass-fired systems, NGC – direct emissions from natural gas consumption in C.C.; (e) Natural gas emissions[16] [7]; (f) [5]

[16] Natural gas emissions in gas turbine systems: CO_2 56.1 t/TJ (15.2 tC/TJ), CO 0.032 t/TJ, CH_4 0.0061 t/TJ, NO_x 0.187 t/TJ [7]