ENERGY FROM SUGARCANE BAGASSE UNDER ELECTRICITY RATIONING IN BRAZIL: A COMPUTABLE GENERAL EQUILIBRIUM MODEL

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ABSTRACT

In the midst of the institutional reforms of the Brazilian sectors of generation, transmission, and distribution of electrical energy initiated in the 1990s, a serious electricity shortage crisis developed in 2001. As an alternative to blackout rationing, the government instituted an emergency plan aimed at reducing electricity consumption. From June 2001 to February 2002, Brazilians were compelled to curtail electricity use by 20%. Since then energy policy has been directed towards increasing thermoelectricity supply and promoting further gains in energy conservation. Two are the main issues addressed here. Firstly, we estimate the economic impacts of constraining the supply of electrical energy in Brazil. We investigate secondly the possible penetration of electricity generated from sugarcane bagasse. A computable general equilibrium (CGE) model is used. The traditional sector of electricity and the remaining of the economy are characterized by a stylized top-down representation as nested CES (constant elasticity of substitution) production functions. The electricity production from sugarcane bagasse is described through a bottom-up activity analysis, with a detailed representation of the required inputs based on engineering studies. The obtained model is used to study the effects of the reduction in electricity output by the preexisting sector on prices, production, and income. It is shown that the generation of electricity surpluses by the sugarcane agro-industrial system may ease the economic impacts on the gross domestic product (GDP) of an electrical energy shortage crisis.

KEY WORDS

Energy and environmental policy, general equilibrium modeling, impact and scenario analysis

INTRODUCTION

In the midst of the institutional reforms of the Brazilian sectors of generation, transmission, and distribution of electrical energy initiated in the 1990s, a serious electricity shortage crisis developed in 2001. Hydroelectricity represents approximately 90% of total electrical energy produced in Brazil. Water in reservoirs typically attains its maximum volume at the end of the rainy season, which extends from November to April. However, in May 2001 average water level for reservoirs in the southeast, central west, and northeast regions corresponded to about 30% of storage capacity. As an alternative to blackout rationing, the government instituted an emergency plan aimed at reducing electricity consumption. From June 2001 to February 2002, Brazilians were compelled to curtail electricity use by 20%. Severe penalties were imposed, such as 50% to 200% surcharges and the possibility of power cuts for users exceeding mandated consumption targets.

As shown in Figure 1, constructed with data readily available in [1], in the period 1990–2000 there was an increase of 52.3% in electricity consumption, whereas total generation capacity augmented by only 41.2%. In 1998, the gap between consumption

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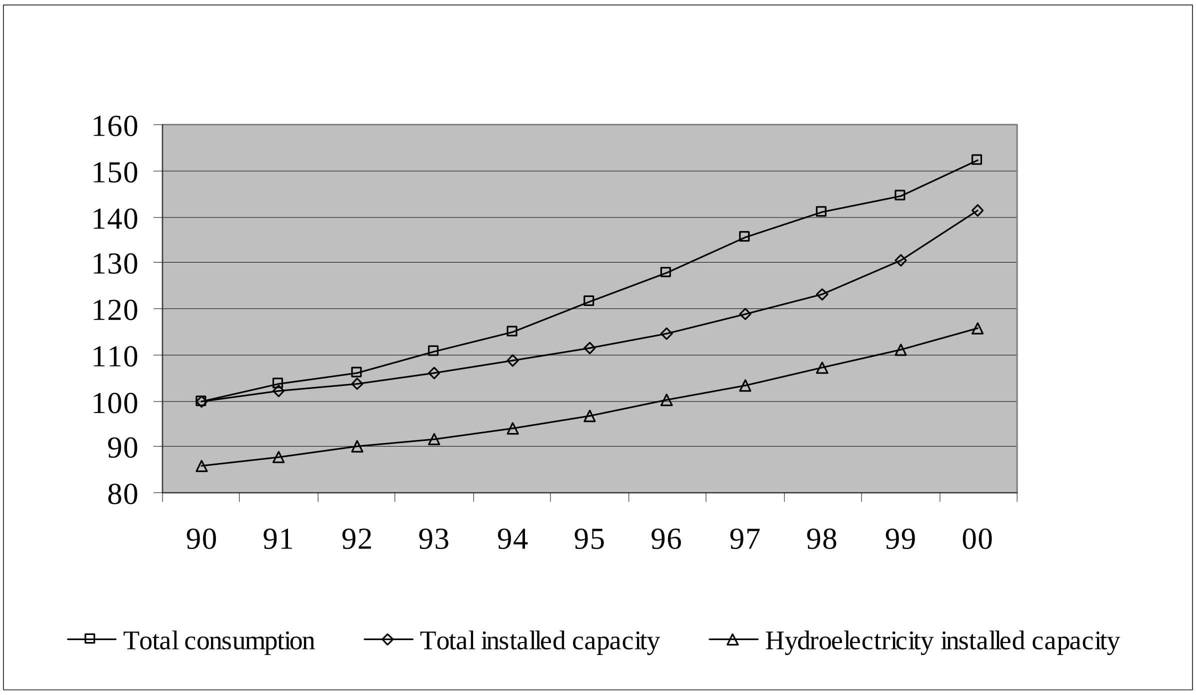

Figure 1. Relative values for electricity consumption and installed capacity during 1990-2000 period.

and installed capacity corresponded to 18.1 percentual points. So it is evident that the electricity system was in fact driven to its inevitable collapse in 2001. Since then energy policy in Brazil has been directed towards increasing thermoelectricity supply and promoting further gains in energy conservation. This work analyzes the economic impacts of constraining hydroelectricity supply and the possible penetration of energy generated from sugarcane residues in Brazil.

METHODOLOGY

Energy planning issues relate to several aspects of the economy, such as price formation, output determination, income generation and distribution, consumption, government action, etc. Computable general equilibrium (CGE) models represent a coherent framework capable of grasping most of these relevant aspects and therefore have been widely used to analyze energy policies (Bhattacharyya, 1996 [2]).

A CGE model is stylized representation of an economy involving producers, consumers, and markets, among other things, and having basically as endogenous variables prices and quantities associated with income flows. Formulation consists in attributing a theoretical setting convenient to the analysis of the proposed questions to the observed data. Thus CGE models are often referred to as theory with numbers or even numbers with theory. CGE models are typically used to simulate policies or exogenous events. A base case is constructed to reflect the observed reality. Scenarios are then built by altering some exogenous variables or parameters of the model as to reflect the intended or experienced changes. Post-shock equilibrium is computed, making it possible to quantify the overall economic impacts of the introduced modifications.

Constructing a CEG model requires the combination of at least three related but distinct areas: formulation (economic theory), parameter estimation (econometrics), and numerical solution (applied mathematics). This was the motivation for developing *Pegasus*, a language for formulating, benchmarking, and solving CGE models (Scaramucci, 1997 [3]; Scaramucci e Bordoni, 1998 [4]; Bordoni, 2001 [5]).

Solving a CGE model consists in finding fixed points for point-set correspondences. This may be a difficult mathematical problem. Some numerical methods for mixed complementarity problems are briefly discussed in the following section.

The importance of the sugarcane agroindustry in Brazil has motivated a great number of economic studies on biomass energy, mainly after the implementation of the Brazilian Alcohol Program (Proalcool) in 1975. Using a CGE model, for instance, Sampaio de Souza (1984) [6] made an economic assessment of the early stages of Proalcool. Income distribution between rural and urban sectors and the effects of Proalcool on food production were studied.

SOLUTION METHODS

The construction of a particular CGE model depends on the availability of numerical methods for solving it.

CGE models are formulated mathematically as mixed complementarity problem (MCP). Several methods have been used successfully to obtain solutions for MCPs.

Ferris and Pang (1997) [7] classify the main solution approaches for MCPs in:

- Extensions of Newton's method for nonlinear equations in that the search for directions becomes a complementarity problem;
- Path search methods that use a generalization of line search techniques;
- Quadratic programming based algorithms that extend the Gauss-Newton methodology;
- Descent methods for differentiable optimization that reformulate the complementarity conditions as a nonlinear equation or program;
- Projection and proximal methods that extend projected gradient techniques;
- Smoothing methods that replace the nonsmooth equations with differentiable approximations;
- Interior point methods that replace inequalities by an interior penalty.

A mixed complementarity problem is defined by a vector $x \in R^n$ of decision variables and a continuously differentiable function $F: R^n \rightarrow R^n$ satisfying the conditions:

$$F_j(x) > 0 \;\Rightarrow x_j = l_j$$
$$F_j(x) = 0 \Leftarrow\; l_j < x_j < u_j$$
$$F_j(x) < 0 \;\Rightarrow x_j = u_j$$

for all j = 1, …, n, where $l_j < u_j$ are the lower and upper for x_j, respectively.

The CGE model constructed here has small size and was easily solved by the SLCP (sequence of linear complementarity problems) method (Mathiesen, 1985 [8]).

DATA BASE

The implementation of a CGE model begins, in general, with a Social Accounting Matrix (SAM), detailing the income flows between the economic agents (producers, consumers, government, etc.). Seven production sectors (commodities) of the economy are considered: sugarcane, sugar, ethanol, fossil fuels, electricity generation, electricity distribution, and rest of the economy (ROE). The final demand components are: fixed capital gross formation, inventory changes, export, public sector consumption, and household consumption. Labor and capital constitute the primary factors of production.

A one-to-one correspondence between producing sectors and commodities is commonly assumed in CGE models. However, the make table of goods and services provided by the Instituto Brasileiro de Geografia e Estatística (IBGE) [9] shows sectors producing more than one commodity. It was necessary then to obtain a fictitious use table of goods and services considering that each sector produces only one commodity. The commodity by commodity approach and the industry based technology assumption were adopted (Miller e Blair, 1985 [10]).

The make and use tables currently released by IBGE refer to the year of 1996, having 42 sectors and 80 products. Nevertheless, some sectors of interest remain aggregated. The electricity, gas, and water sectors are all contained in industrial services of public utilities (ISPU), chemical elements comprise ethanol, and fossil fuels is included in oil refining. It was then necessary to disaggregate the available tables to include four sectors: ethanol, fossil fuels, electricity generation, and electricity distribution.[2]

It should be mentioned that the need to reconcile the IBGE database with the Brazilian Energy Balance provided by the Ministry of Mines and Energy makes it somewhat complicated to construct economic models for energy planning in Brazil. One soon realizes that it may be hard to mix *reais* (the Brazilian currency) with watt-hours.

The disaggregated sectors often show an unbalance between values of production (expenditures) and demand (receipts). The process of biproportional iterative adjustment or RAS method [10] was used in the corrections.

Finally, the data were disposed in the format used by GTAP (Global Trade Analysis Project) [11]. All transactions were evaluated at market and agent prices. Values at agent price include taxes paid in the consumption of goods and services. Taxes on production are contained in values at market price. Government income comes from the differences between values at market and agent prices in each transaction.

THE MODEL

The basic CGE model follows roughly the GTAP top-down setting [5]. The seven sectors/commodities mentioned above and the primary factors labor and capital are represented. Production and demand are described by nested CES (constant elasticity of substitution) aggregation functions [3]. Savings is met by the consumption of capital goods by a representative consumer. Investment is treated as the production of capital goods and follows investment decisions. Savings, investment, exports, and imports are determined endogenously; hence, the model has neoclassical closure.

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[2] An electronic version of the input-output matrix for 1980 from IBGE kindly provided by Joaquim J. M. Guilhoto (ESALQ/USP) made it simpler to separate ethanol, fossil fuels, and electricity sectors.

The representation, benchmarking, and resolution of the CGE model were made with *Pegasus* [3, 5].
A fictitious bottom-up sector generating electricity by burning sugarcane residues was then inserted in the economy. The result is an energy-economy integrated model.
Sugarcane bagasse availability is obtained endogenously from the production of sugar and ethanol, as summarized in Figure 2, below.

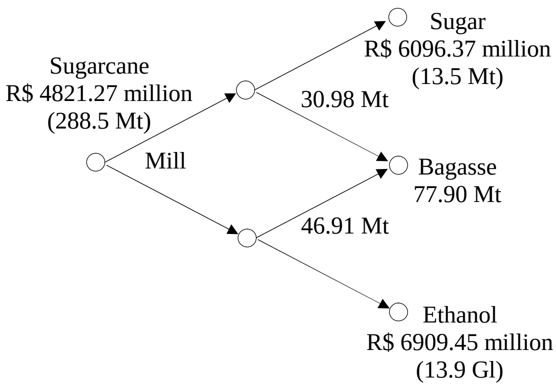

Figure 2. Bagasse production.

Values refer to the base year of 1996[3].
Transformation data were extracted from Moreira and Goldemberg (1999) [12]. Producing one ton of sugar requires 8.5 tons of sugarcane. It is necessary 12.5 tons of sugarcane to produce one cubic meter of ethanol. It was assumed that crushing one ton of sugarcane yields 270 kg of bagasse with relative humidity of 50%.
A detailed analysis of the costs involved in generating electricity with sugarcane residues is found in [13]. Only one intermediate case among several investments possibilities studied there was considered here. The selected alternative suggests installing in a typical plant a 61 ata pressure boiler and an extraction-condensing steam turbine and generator with capacity of 42.687 MW. It would be possible to generate 122.4 GWh of excess electricity by burning the bagasse obtained from milling 1.8 million tons of sugarcane. An incremental investment of R$ 31.6 million would be required; therefore, the annual capital costs would be R$ 3.71 million, supposing useful life of 20 years for the equipment and a yearly real interest rate of 10%.
Labor inputs necessary to operate such a typical plant is estimated in R$ 10 per each MWh of electricity generated [14].
A quantity of 77.90 Mt of bagasse is available in the base year. Each typical plant would consume 0.486 Mt of bagasse. Hence, it would be possible to operate 160.29 typical plants in 1996, leading to a potential sector for generating electricity from bagasse as described in Table 1.

Table 1. A possible bagasse-based electricity sector.

Labor (R$ million)	Capital services (R$ million)	Excess electricity (TWh)
195.55	594.68	19.62

According to the prepared data, the output value at market price for the existing electricity generation sector was R$ 8286.82 million in 1996. The amount of electrical energy produced in the same year was 291.24 TWh [1]. As a result, the market price for generating electricity was R$ 28.45/MWh. In consequence, the bagasse-based electricity sector would have had a revenue of R$ 558.19 million; however, labor and capital costs would be R$ 790.23 million. Operating a bagasse-based electricity sector in 1996 would be economically infeasible. The minimum price that would allow producing electricity with bagasse is calculated in R$ 40.28/MWh. It is possible to show that at the price of R$ 28.45/MWh, electricity from bagasse would be produced only if annual interest rate was 3.7%; the corresponding yearly costs for capital services would be then R$ 362.64 million.

SIMULATIONS

A collapse of the electricity generation sector existing in 1996[4] is assumed in the numerical experiments conducted here.
The economy is submitted to electricity supply shocks characterized by rationing levels of 5%, 10%, 15%, 20%, and 25%. The constraint on electricity production is supported by a surcharge imposed on the consumption of electrical energy. Such a tax is determined endogenously and its value depends on the rationing level.
Two scenarios are constructed here. It is assumed initially that electricity production is maintained only by the preexisting generation system. An additional sector for generating electricity from sugarcane bagasse is then introduced.
For simplicity, electricity imports were kept constant in relation to the base case.
The following figures summarize the resulting economic impacts for each rationing level.
Figure 3 shows the Gross Domestic Product (GDP) level changes relative to the base case. The penetration of electrical energy generated from sugarcane bagasse is indicated in Figure 4. Figure 5 depicts the income gained by generating electricity from bagasse. Finally, Figure 6 contains the income composition for the sugarcane agroindustry.

[3] Units are: R$ (real, Brazilian currency), Mt (million tons), and Gl (billion liters). Exchange rate: 1 R$/US$ in the base year of 1996 and 3 R$/US$ in May 2003, approximately.

[4] Relative contributions to installed capacity: hydroelectricity, 87%; thermoelectricity, 12%; and nuclear plants, 1% [1].

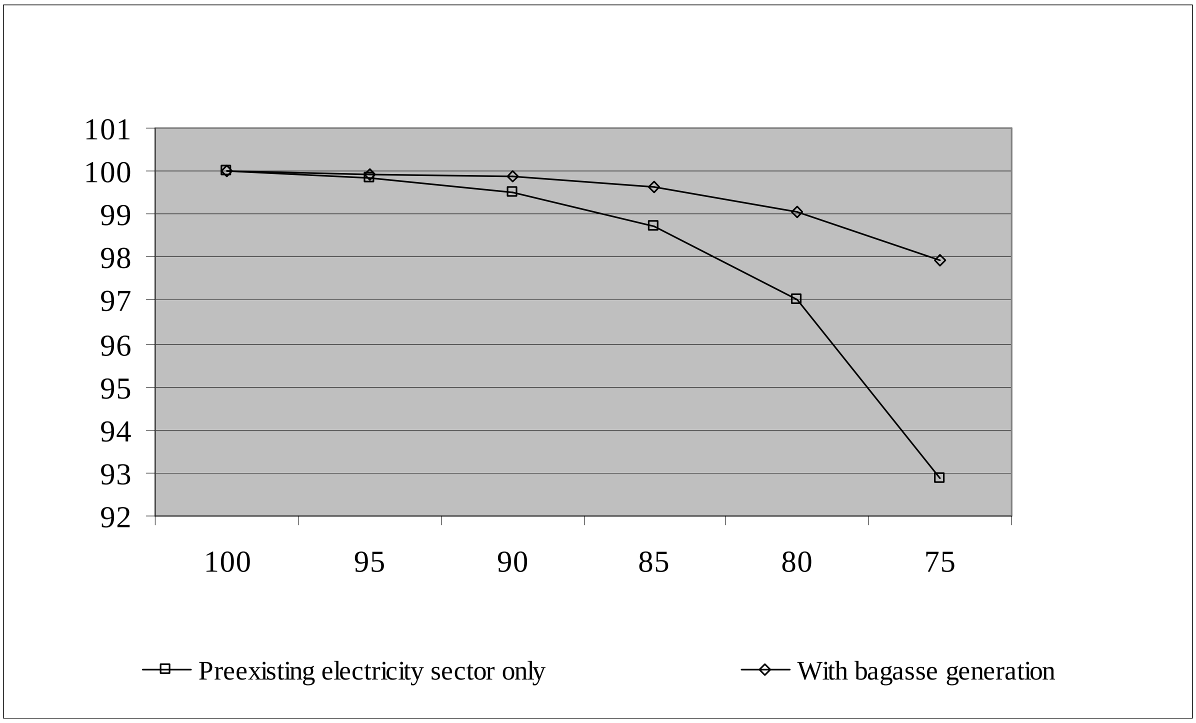

Figure 3. Relative value of Gross Domestic Product (GDP) for each operation level of the preexisting electrical system.

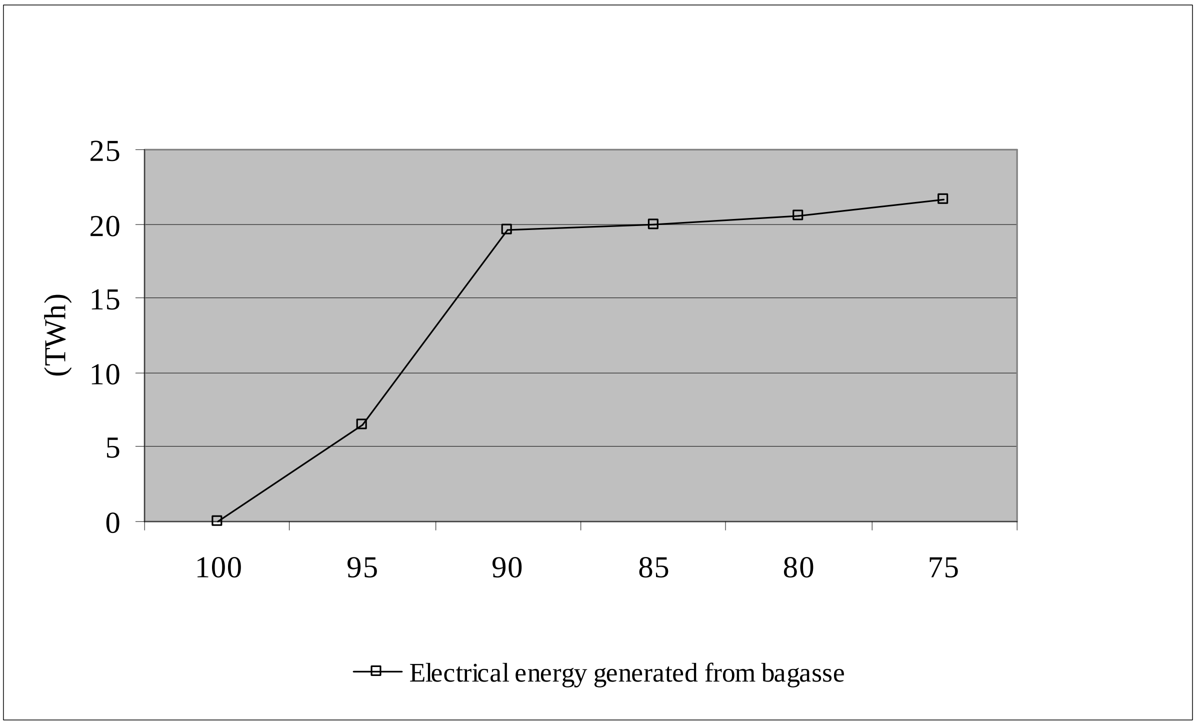

Figure 4. Penetration of the electricity generated from bagasse for each operation level of the preexisting electrical system.

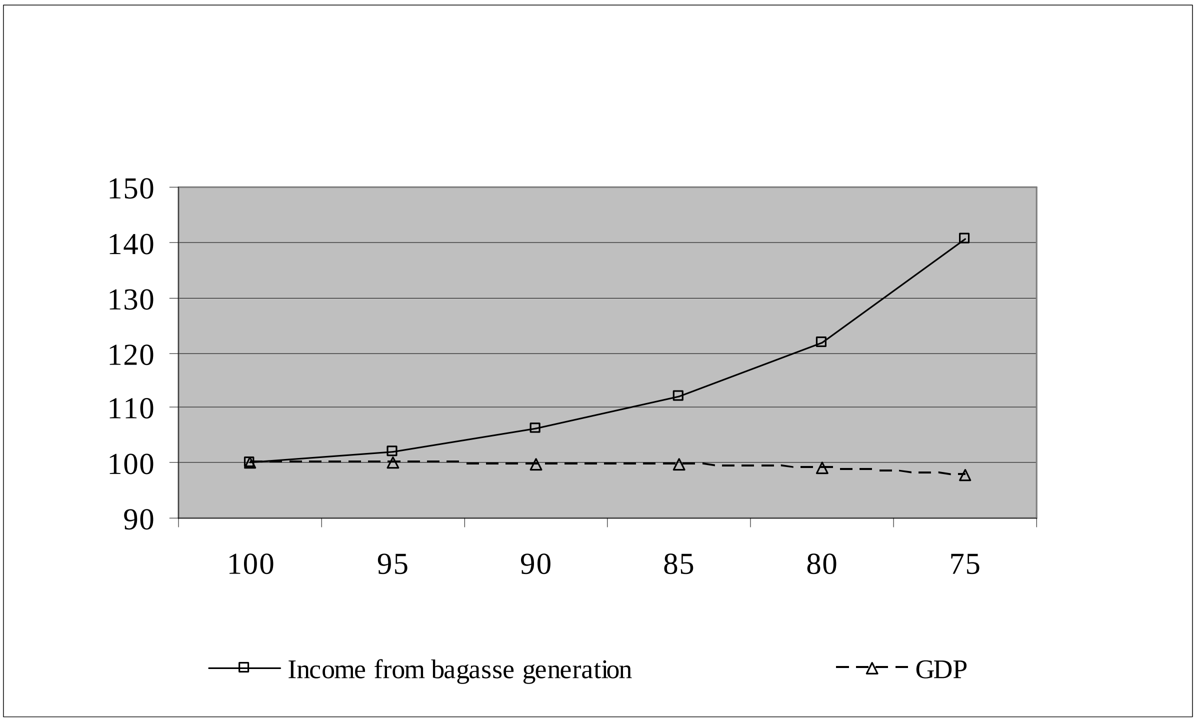

Figure 5. Relative value of the income gained by generating electricity from bagasse for each operation level of the preexisting electrical system.

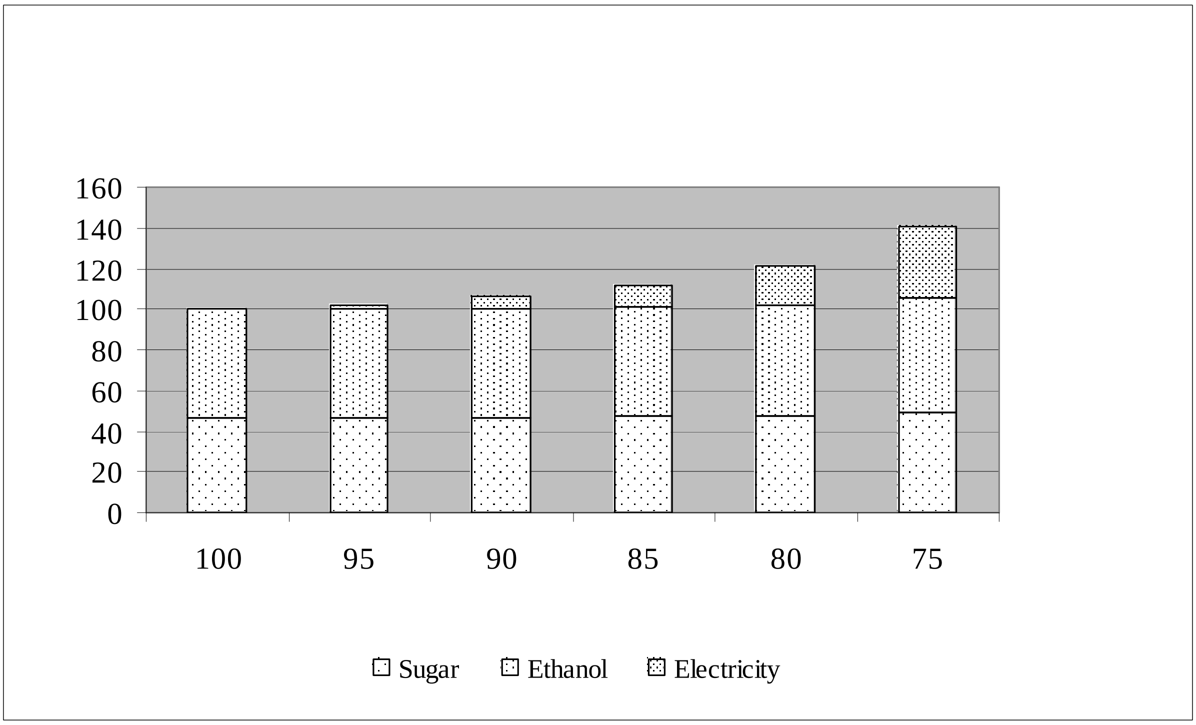

Figure 6. Income composition for the sugarcane agroindustry for each operation level of the preexisting electrical system.

It can be noticed that GDP falls by about 3% as a consequence of a rationing level of 20% — the reduction in electricity consumption set by the Brazilian government in 2001. Depressing the economy lessens the demand for energy inputs. On the other hand, introducing a bagasse-based electricity generation sector causes the economic activity to diminish by less than 1% if a rationing level of 20% is imposed. It should be mentioned that apparently a rationing level above 20% would bring serious consequences for the economy; requiring the preexisting electrical system to operate at 75% of its capacity, for instance, would cause GDP to decrease by about 7%, in the absence of a bagasse-based electricity sector.

The penetration rate of electricity generated from bagasse is large until the rationing level of 10%. Table 2 below shows prices and quantities associated with each rationing level.

Table 2. Supply curve for electricity generated from bagasse.

Rationing level (%)	Price (R$/MWh)	Electricity from bagasse (TWh)
0	28.45	0
5	39.99	6.45
10	42.10	19.62
15	72.71	19.94
20	122.84	20.50
25	207.95	21.65

As expected, increasing electricity prices renders feasible the generation from bagasse. After the potential for the sugarcane agroindustry to produce electrical energy is realized, however, further increments in electricity generation will depend on bagasse availability. At the rationing of 20%, for example, sugar and ethanol prices are reduced to 87% and 83% of their base case values, respectively. Lower prices raise the demand for sugar and ethanol so that bagasse supply is increased. In this sense, electricity scarcity can make sugarcane bagasse a product more important than sugar and ethanol.

The income earned by the sugarcane agroindustry augments as the operation level of the preexisting electrical system decreases. For instance, at rationing level of 20%, revenues from producing electricity increase around 20% in relation to the base case.

CONCLUSIONS

The results above indicate that the effects of constraining the preexisting electrical system may be significant. The possibility of generating electricity from sugarcane bagasse could be important to attenuate the resulting economic impacts.

It is important to stress that the only complement to the preexisting electrical system considered here is a bagasse-based electricity sector. Introducing a module describing the possibilities of generating electricity from natural gas would be essential to better capture the recent changes incurred by the Brazilian electrical system. Thus, some caution should be exerted when interpreting the results obtained here.

Nevertheless it is interesting to observe that generation capacity for thermoelectricity increased by 4586 MW — or 32.139 TWh, using a capacity factor of 0.8 — from 1996 up to 2000 [1]. This could explain why the estimated reduction in economic output caused by the electricity shortage in Brazil was no greater than 1%.

Other modules describing alternative energy sources such as solar and wind power could also be inserted in the CGE model.

An interesting idea is to consider a possible enlargement of fuel ethanol production, resulting in a greater availability of sugarcane bagasse.

It is evident that in 1996 the electricity generation sector in Brazil was already under considerable strain (Figure 1). However, the price set then by the government for generating electrical energy was R$ 28.45/MWh, rendering it difficult for a bagasse-based electricity sector to fully emerge (Table 2).

Yet crises represent opportunities. In 1975, the first oil shock led to the creation of the Brazilian Alcohol Program (Proalcool). The recent electricity shortage crisis has promoted a rapid penetration of thermoelectricity. It is expected that the Brazilian sugarcane agroindustry assumes once and for all the condition of an energy-producing sector, as suggested in Figure 6. Vasconcellos (2001) [15] believes that the energy from sugarcane biomass may constitute a basis for a national development program.

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