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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 electric sectors initiated in the 1990s, a serious electricity shortage crisis developed in 2001. As an alternative to blackout, 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 the late 1990s, but especially after the electricity crisis, energy policy in Brazil has been directed towards increasing thermoelectricity supply and promoting further gains in energy conservation. Two main issues are addressed here. Firstly, we estimate the economic impacts of constraining the supply of electric energy in Brazil. Secondly, we investigate the possible penetration of electricity generated from sugarcane bagasse. A computable general equilibrium (CGE) model is used. The traditional sector of electricity and the remainder 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 model constructed is used to study the effects of the electricity shortage in the preexisting sector through prices, production and income changes. It is shown that installing capacity to generate electricity surpluses by the sugarcane agroindustrial system could ease the economic impacts of an electric energy shortage crisis on the gross domestic product (GDP).

Keywords: Energy policy; General equilibrium modeling; Impact and scenario analysis

1. Introduction

In the midst of the institutional reforms of the Brazilian electric sectors initiated in the 1990s, a serious electricity shortage crisis developed in 2001. Hydroelectricity represents approximately 90% of the total electricity produced in Brazil. Water in reservoirs typically attains its maximum volume at the end of the rainy season that extends from November to April. However, in May 2001, the average water level for reservoirs in the southeastern, central western and northeastern regions corresponded to about 30% of maximum storage capacity. As an alternative to blackout, 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 50–200% surcharges in the monthly bills and the possibility of power cuts for users exceeding mandated consumption targets.

Firm energy is the electricity a hydropower plant can produce under the worst precipitation conditions. As a rule, the expansion of a hydroelectric system should be

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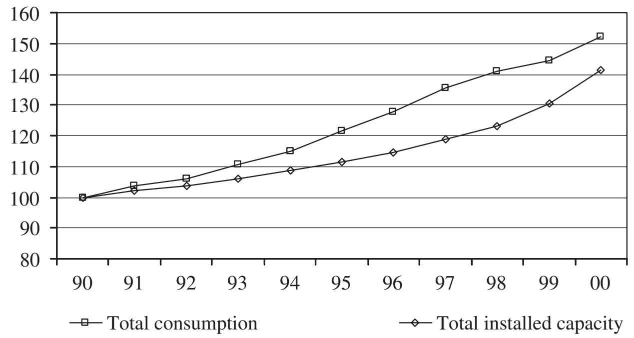

Fig. 1. Electricity consumption and installed capacity gap (1990–2000).

based on the supply of firm energy. Above-average levels of precipitation prevailed from 1997 to 2000. Yet, over the same period, the successive yearly curves for the average water level of important reservoirs in Brazil declined. As pointed out by the so-called Kelman report (Kelman et al., 2001), the level of energy stocks at hydropower plants in Brazil, observed in November 1999, corresponded to 20% of maximum storage capacity. At the time, the probability of an energy deficit for the year of 2000 was estimated at about 14%, well above the 5% threshold value commonly accepted for the electric sector. The persistent depletion of the water reserves demonstrates that electricity production was held above firm-energy level. Thus, it is clear that the energy deficit was caused by the lack of investments in electricity generation.

In fact, as shown in Fig. 1, constructed with data readily available in (MME, 2003), in the 1990–2000 period, 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 and installed capacity reached the largest relative value of 18.1 percentage-wise. So, it is evident that the electricity system was, in fact, driven to its inevitable collapse in 2001.

This work analyzes the economic impacts of constraining hydroelectricity supply and the possible penetration of energy generated from sugarcane residues in Brazil.

2. 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).

A CGE model is a stylized representation of an economy involving producers, consumers and markets, among other things, and basically having prices and quantities associated with income flows as endogenous variables. Formulation consists of attributing a theoretical setting convenient for 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 CGE 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; Scaramucci and Bordoni, 1998; Bordoni, 2001).

Solving a CGE model consists of finding fixed points for point-set correspondences. This can 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) 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.

3. 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 problems (MCP). Several methods have been used successfully to obtain solutions for MCPs.

Ferris and Pang (1997) 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;