



Research paper

Using system dynamics modeling to evaluate the feasibility of ethanol supply chain in Brazil: The role of sugarcane yield, gasoline prices and sales tax rates



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ABSTRACT

This paper explores how sugarcane yield, gasoline prices and sales tax rates affect the production and consumption of ethanol from sugarcane in Brazil. The system dynamics model of the sugarcane and ethanol production chain explores the impact of these variables to evaluate the feasibility of ethanol production. Using the VENSIM software different arrangements for sugarcane yield, gasoline prices and sales tax were simulated (horizon of 20 years). Brazil's Federal Government policy of gasoline price below the international price and the diversity of state sales tax rates produce distortions in the ethanol market and impose considerable constraints on the development of the ethanol industry. The simulations show that to ensure the feasibility of ethanol production, the pump price of regular gasoline would need to be US\$1.95 per liter, which is far higher than the US\$1.26 per liter currently charged. Public policies involving the liberalization of gasoline prices and the homogenization of the sales taxes on ethanol among the Brazilian states could reduce the distortions caused by these policies. These policies could contribute to reduce uncertainty in the ethanol sector and encourage technological and productive investments. Future research could add and evaluate the impacts of the environmental benefits of ethanol production and consumption (Carbon Trade Market, Payment for Environmental Services and Bioelectricity production) and of sugarcane byproducts on its feasibility. The sensitivity analysis revealed the effectiveness of the model to support policies and managerial decisionmaking process in the sugarcane ethanol sector.

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1. Introduction

In recent decades, the use of fossil fuels for energy production has become a major cause of concern for humanity. The main impacts of their use in automobiles are increasing pollution in urban centers and rising concentrations of greenhouse gases. Whether driven by environmental, economic, political or social interests, many countries are already implementing public policies to encourage the replacement of petroleum with biofuels in their energy matrixes [1–5]. Among them, the two major countries are the United States and Brazil, which together are responsible for 89% of the production and 88% of the consumption of ethanol in the

world [6,7]. Europe, Japan and China are also important producers and consumers of ethanol. In Brazil, ethanol as biofuel is used in two forms: blended with gasoline (anhydrous ethanol) to make the regular gasoline; and neat (hydrous ethanol), which is sold in filling stations and is popularly known as ethanol. Herein after in this paper hydrous ethanol will be referred to as ethanol.

Ethanol blended with gasoline in Brazil took off with the first oil shock in 1973, which demanded a reduction in the dependence on imported oil. In the 1970s, the Brazilian government created and implemented the *Proálcool* program, which among other policies, established ethanol production volumes and prices and encouraged the use of ethanol in vehicles [8–10]. With the prices of ethanol controlled by the government and tax incentives provided for ethanol powered vehicle sales, ethanol proved to be an advantageous alternative for consumers in the 1980s, as shown by the rising curve of ethanol sales between 1980 and 1989 (Fig. 1).

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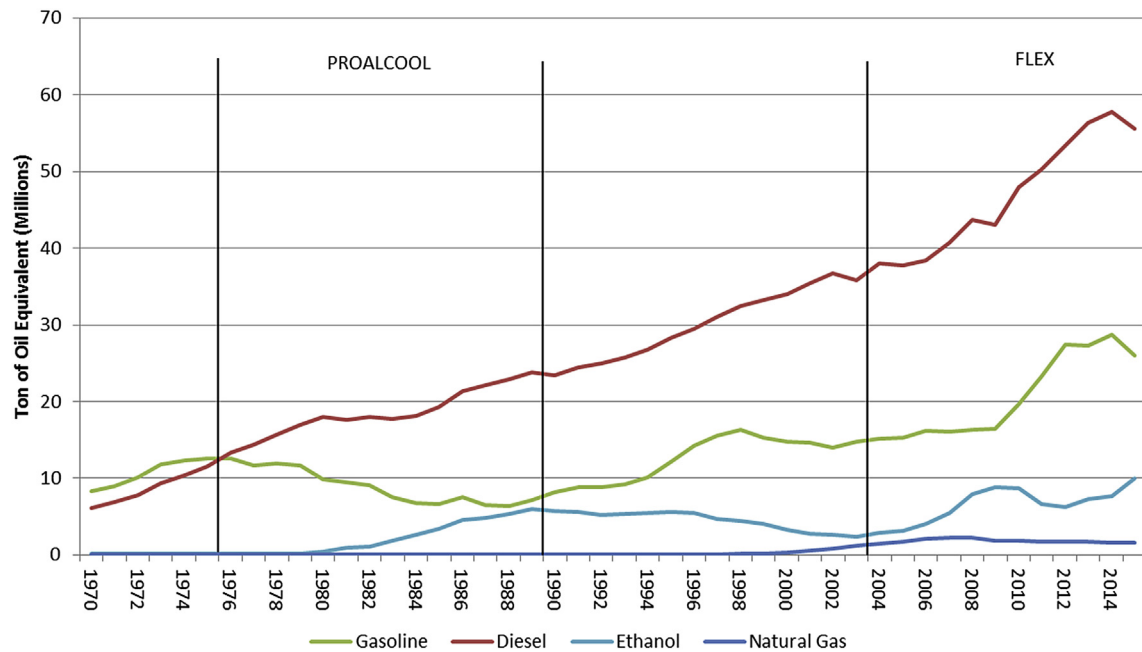


Fig. 1. Evolution of the demand for fuels in Brazil.
Source: elaborated from Ref. [88].

However, the fall in oil price, that occurred in the second half of the 1980s, and the low prices paid to the ethanol production plants, prevented any increase in domestic production and consumption. In the early 2000s, the price of oil jumped and the price of ethanol became attractive again. Growth in the consumption of ethanol only resumed with the introduction of flex-fuel vehicles in the Brazilian automobile market in March 2003. The cars and light vehicles that run on the ethanol and gasoline blend, the neat ethanol, gasoline or any mixture of the two are called flex-fuel vehicles. As shown in Fig. 1, this new technology gave the domestic consumption of ethanol a boost, reaching 10.0 million tons of oil equivalent (Toe) in 2014 [88].

Although it is suggested that the sugarcane-based ethanol produced in Brazil is the most economically viable in the world

[4,7,12] and the country is internationally renowned for having one of the highest proportions of renewable fuels in its energy matrix, the production and use of ethanol among the Brazilian states and regions are far from homogeneous [13]. The sugarcane producing regions are determined by soil and climate conditions that enable or limit its production. As Brazil has continental dimensions and, consequently, a wide variety of climates and soils, ethanol production is concentrated in two sugarcane producing regions (Northern and Southern), as shown in Fig. 2.

When it comes to the effectiveness of implementing policies for the production and consumption of bioenergy, and more specifically ethanol, because it is of plant origin, elements other than government incentives and regulatory policies can be seen to be relevant for its feasibility. For example, territorial dimensions and climatic variations between regions and countries may determine both the levels of agricultural productivity (yield) of the feedstock that will be used for the production of ethanol (sugarcane, corn, beet, cassava) and the logistical costs of transporting ethanol between producing and consuming regions [11–19]. Another element that emerges, particularly in countries or economic blocks of continental dimensions, is the difference in tax rates between states in the same country (Brazil and USA) or between different countries within the same economic block (EU) or continent (Africa).

The structure of fuel taxes in Brazil is quite complex. The taxes currently levied on transactions involving sales of ethanol fuel in Brazil are:

- Sales Tax on the circulation of goods and provision of interstate and inter-municipal transport and communication services (ICMS);
- Contribution to the Social Integration Program of the worker and the equity fund for public servants (PIS/PASEP);
- Social Contribution to Social Security Fund (COFINS);
- Contribution to the Economic Domain - CIDE (federal tax on fuel imports – Law 10.336/2001)

The PIS/PASEP, COFINS and CIDE are federal taxes, defined by

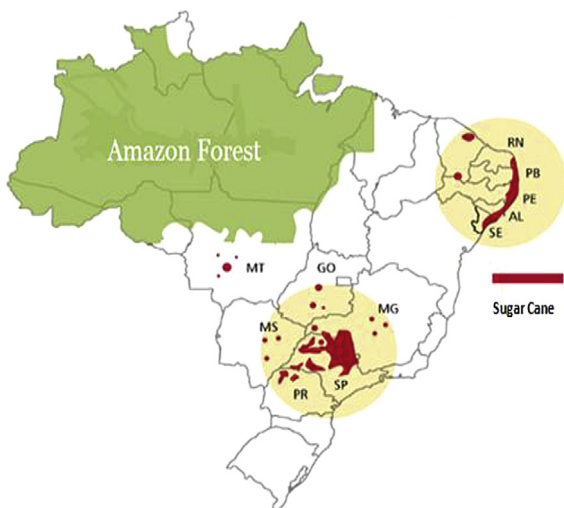


Fig. 2. Concentration of sugarcane production in two regional clusters in Brazil.
Source: [20].

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