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On The Substitution of Energy Sources: The Effect of Flex Fuel Vehicles in the Brazilian Light Road Transportation Revisited

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ABSTRACT
The substitution process resultant of the competition between two energy sources for the same market based on dynamic forecasting model derived from biomathematics, previously applied by authors in the Brazilian gasoline/hydrated ethanol consumption market is analyzed. The hydrated ethanol restriction supply due to decreasing production as a consequence of international price of sugar increasing was the prevailing motive of the forecast breaking. Again the *stop and go* process adopted by sugarcane private sector was the main reason of hydrated ethanol decreasing production.
***Keywords**:* Biomass fuel; Fossil fuel substitution; Market share

I. INTRODUCTION

The problem of competition and substitution between energy sources established on a particular final use market are a common and a recurring theme on the energy affair. Under specific conditions a replacement process of a given energy source by another is inexorable, being only a matter of time. In order to analyze problems involving such kind of substitution process, these authors presented a paper [1], in which the following set of coupled non-linear differential equations (NLDE) is proposed to describe the two products competition-substitution process:

dN1/dt = ε1.N1 – α12.N1.N2 Equation 1
dN2/dt = ε2.N2 + α21.N1.N2 Equation 2

The time variation growth of N1 (displaced product) is proportional to itself and one subtractive term proportional to N1xN2. Similarly, the time variation of N2 (substitute product) is proportional to itself *plus* one term proportional to N1xN2. In this sense **εi**represent the N1 and N2 *intrinsic or independent exponential* growth rate, while the **αij** represent the substitution coefficients of N1 by N2 product. The symmetry of the coefficient **αij** means that the decreased fraction of N1 variation is added to N2.

This coefficient represents mathematically, in this reduced model, the sum of all techno-economic and social efforts – trustfulness, competitive prices, technology, utilization easiness, environmental appeal, marketing and fiscal incentives to replace N1 by N2 product. Thus, the knowledge or the estimation of the **αij** value is the most important and sensitive point of the numerical analysis. This methodology was applied to analyze the dynamics of Brazilian Proalcohol Program of replacing gasoline in light vehicles by hydrated ethanol in two periods:

1. (1977-1985) years with the introduction of vehicles powered by hydrated ethanol alone. Adherence of model published in [1].
2. (2003 ahead) years with the introduction of *flex-fue*l vehicles powered by both gasoline or hydrated ethanol. Forecasting published in [2].

The replacement of gasoline by ethanol from an environmental point of view is very commendable since the complete chain of production and end-use of this energy source has a net balance of CO2 equal to zero or even negative if the bagasse produced have a more permanent use than a simple burning, for example in the production of MDF (Medium-Density Fiberboard) or cellulose pulp.

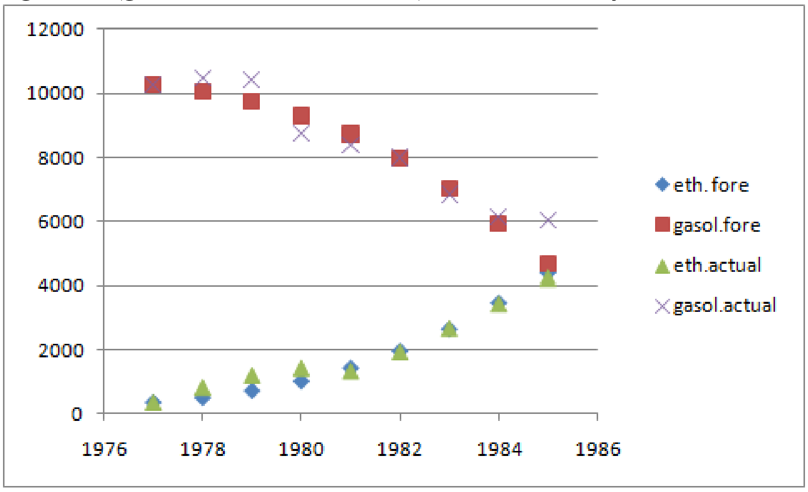
The objective of this paper is to highlight the merits of the model to make “what if…” uncertainty analysis and improve the communication between theoretical models appliers and decision makers. The robustness of the model is verified by analyzing the causes of the deviation between the actually gasoline and hydrated ethanol Brazilian consumption from the supposedly well-aimed model forecasts, if the initial constraint conditions remain unchanged.

II. THE BRAZILIAN PROALCOHOL PROGRAMIN THE SEVENTIES/EIGHTIES

The Proalcohol Program ([3], [4])was a government policy adopted in Brazil in order to encourage the substitution of gasoline by ethanol in light vehicles through market actions, such that this substitution process became inexorable and a matter of time. The Proalcohol Program first developed in the seventy/eighty decades by private sector distilleries was one of the biggest energy substitution projects in Brazil, in which gasoline was almost replaced by ethanol in Otto engine cars for several years.

Figure 1 shows both the model *ex-post* forecasting[1] and actual gasoline and total ethanol (anhydrous plus hydrated) consumed from 1977 to 1985 years in thousands of tOE (10^3tOE), according to [5]. This program took place, basically, via taxes incentives and final consumer prices applied to both, cars and ethanol fuel. The figure shows that the deviation between the model forecast and actual consumption begins in 1985. From this year a systematic supply restriction of alcohol starts due to increasing of international sugar price which displaced the sugar cane raw material from ethanol production. Indeed, in 1985 (see table 4 of ref. [9]) the ratio of raw material to produce sugar and total ethanol was respectively 27.9% and 72.1%. This ratio becomes (37.9%, 62.1%) in 1995 and (46.9% , 53.1%) in 2000. This led to a gradual ruin of Proalcohol Program with the discredit and decay of the vehicle powered exclusively by ethanol. Indeed, in 1985, the hydrated ethanol consumption represented 51.4% of gasoline consumption, falling to 14.6%, in 2003 [5].

Figure 1 Gasoline and total ethanol *ex-post* forecasting (gasol.fore and eth.fore) and respectively observed actual consuming values (gasol. actual and eth. actual) for 1977 – 1985 years. Source: [1] and [5].



This forced the state company Petrobrás, responsible for a task of the effective fossil fuel supply planning and is the largest exploiting, producing, refining and distributing Oil Company in the country, to import a large amount of methanol to supply the huge fleet market powered exclusively by alcohol. In addition, this company accumulated a big economic loss by the fact that it had to export gasoline with burdensome price.

III. THE PROALCOHOL PROGRAM: 2003 ONWARDS

In 2003, as a reaction of the hydrated ethanol use decreasing, the car industry introduced into light vehicles fleet the *flex-fuel* cycle Otto engines propelled simultaneously by both, ethanol and gasoline, with similar efficiency per unity energy content, allowing the direct competition in the same engine between these fuels.

Since the energy content of ethanol per unit volume is lower than gasoline, a relentless criterion behavior adopted by users has been settled: the consumer will use ethanol *if and only if* there is an unrestricted ethanol supplyand the volumetric relation price of this fuel respect to gasoline *(relation price parameter*) is lower than 0.7, as was the case on 2006, 2007, 2008, 2009 and 2010 (Table I).

Table I. Gasoline, hydrated ethanol current average prices (US$/m^3) and parameter unit volume price relation. Source: [5]

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
gasoline	1157,3	1256,5	1361,6	1255,2	1458,3	1631,8	1399,9	1321,1	1263,5
hydr.ethanol	683,9	872,4	924,8	827,8	943,1	1202,1	990,4	935,9	878
ethanol/gas	**0,59**	**0,69**	**0,68**	**0,66**	**0,65**	**0,74**	**0,71**	**0,71**	**0,69**

This parameter condition coupled with an unrestricted hydrated ethanol supply constitute a *necessary and sufficient condition* to gasoline/ethanol substitution take place in an inexorable way and this substitution process will be only a matter of time, if the initial constraint conditions remain unchanged.

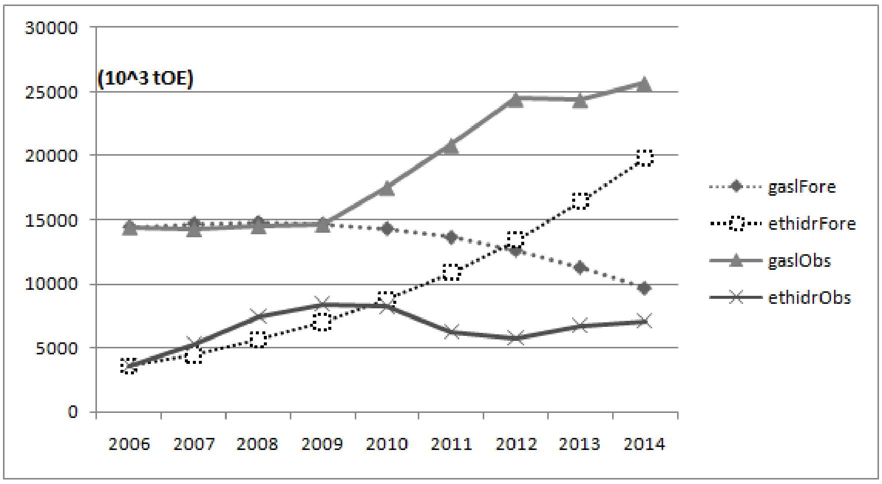
Then from 2003 a spectacular recovery of the ethanol use can be observed [5]due to the gradual and constant increasing of the petroleum price, which benefits the ethanol price relative to gasoline (in average R$ 2.50/liter and R$ 1.30/liter, respectively). In fact, the domestic wholesales of *flex-fuel* (cars plus light commercial) was 1,655,779 vehicles (almost 89% of the total) facing only 206,116 gasoline vehicles selling, from January to October 2007 [6]. This provided a new breath to theProalcohol hydrated ethanolprogram fuel.In 2009, the summit of the second phase Proalcohol program, the ethanol consumption achieves 57.2% of gasoline consumption. However, in 2010 there is a change in the series trend.

The Table II and Figure 2 show the gasoline and hydrated ethanol model forecasting (gasFore and ethiFore) and respectively observed actual consuming values (gasObs and ethiObs) for 2006–2014 years obtained through the model described before(Source: [2] and [5]).

Table II. Gasoline and hydrated ethanol forecasting (gasFore and ethiFore) and respectively actual observed values (gasObs and ethiObs) for 2006 – 2014 period. Source: [2], [5]

(10^3tOE)	gaslFore	ethidrFore	gaslObs	ethidrObs
2006	14449	3610	14449	3610
2007	14702	4494	14287	5287
2008	14795	5610	14538	7480
2009	14682	7009	14674	8400
2010	14310	8747	17525	8243
2011	13634	10875	20838	6230
2012	12625	13429	24454	5763
2013	11284	16411	24393	6717
2014	9662	19778	25682	7126

Figure 2. Gasoline and hydrated ethanol model forecasting (gasFore and ethiFore) and respectively observed actual consuming values (gasObs and ethiObs) for 2007 – 2014 period. Source: [2], [5].



This figure shows clearly the model adherence in the years when the parameter remains below 0.7 (according Table I) and an unrestricted supply of ethanol did happen (2006, 2007, 2008 and 2009). For the 2010 year, in despite this parameter remains below the thresholdthere was a restriction in the foreseen supply of ethanol, i.e. the increase of international sugar prices which displaced *again* the sugar cane raw material from ethanol production, similarly to what happen in the first phase of Proalcohol. Indeed, in the 2008 – 2011 years the international white sugar price nearly double: 37.4% (2009), 26.8% (2010) and 14.3% (2011), to fall in subsequent years (Table IV). As a consequence, the growth of production of sugar in 2009-2012 years was 16.1% while the growth of ethanol production was negative (**-28.2%)** in the same period (TableIII), which forced Petrobras to import gasoline to cover the increased fuel demand (see TableV). The international price decreasing of sugar after 2012 causes the ethanol production increasing and consequently recovery of ethanol consumption in 2013.

Table III. Sugar (10^3 ton) and Hydrated ethanol (10^3 m^3) production. Source: [7]

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Sugar	**29988**	**31026**	**31049**	**32956**	**38006**	**35925**	**38246**	**37562**	**35548**
Hidr. Ethanol	**9814**	**14333**	**18190**	**18626**	**19053**	**14101**	**13382**	**15319**	**16300**

Table IV. White sugar average price at London stock market. Source: [8]

year	**US$/ton**	**growth rate(%)**
2008	**353,52**	
2009	**485,89**	**37.4**
2010	**615,94**	**26.8**
2011	**703,79**	**14.3**
2012	**587,56**	**- 16.5**
2013	**489,77**	**-16.6**
2014	**440,24**	**-10.1**
2015	**369,64**	**-16.0**

Table V. Gasoline export and import 10^3 m^3. Source: [5]

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Export	2701	3706	2599	2519	772	324	151	347	365
Import	28	10	0	13	511	2193	3786	2265	2111

Another forecast trend breaking was due to economic growth mistake. High economic growth, based essentially on the population demand side consumption, encouraged a considerable economic improvement in the first decade, so that the total fuel consumption (gasoline plus ethanol) was 11.14 % above the forecast value in 2014.

IV. CONCLUSION

The proposed model handling with the problem of competition and substitution between energy sources established on a particular final use market seems to be useful to increase the knowledge of the relationship between input and output variables in a system and the results can improve the rapportbetween theoretical modelers and decision makers. A simple application of the model on the Brazilian light road transportation fuel sector has requested a reflection on variables interacting each other in a systemic way and was possible to conclude, for example, that a national energy fuel supply depends on large investments from the partnership of public/ private sectors and cannot be subject to opportunistic mood of the short term free market. The relative stiffness of the oil refineries does not allow a rapid change in the oil products structure for consumption modulation. The *stop and go* practiced by the sugarcane sector, showed in section 3, can compromise an entireNational Planning process, with huge losses for the whole society, which could be avoided by other means. For example, as is done in the electric power sector, the supply market is divided in long-term contracts with the private sector negotiation and a *spot market* in which a short-term free market prevails.

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