System Dynamics Approach to Biofuels in Colombia

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ABSTRACT

Biofuels production in Colombia has been growing in the past few years, but due to low investment in refining capacity and crops, and difficulties to transport the biofuels to the distribution centers, it has not been possible to fulfill the demand at the blending percentage with fossil fuels proposed by the government. In order to analyze these problems a System Dynamics model was constructed for learning about the system behavior and for understanding the response mechanisms of the biofuels offer under different policies from the production side. An analysis of the current government policies such as incentives to refining facilities was developed in this paper. According to the model results, alternative or complementarily policies could be appropriated to accelerate the growth in the production of biofuels in Colombia.

Key words: Biofuels, Incentives, System Dynamics, Investment.

INTRODUCTION

The global warming, the long term decreasing oil reserves and the growing demand of energy, have pushed the development of cleaner and renewable fuels. Biofuels, as ethanol and biodiesel, are considered an alternative to fossil fuels, especially in the transport sector, since they come from biomass and may have fewer emissions than traditional fuels (Schneider & McCarl, 2003).

As a result of this, the Colombian government decided to promote ethanol and biodiesel production through incentives and subsidies. Nevertheless, the production has not been enough to supply the internal demand at the percentage of mixture of biofuels with the fossil fuels that the government has determined.

In order to analyze this issue a Systems Dynamics model was constructed to evaluate the effect of the government policies in the production of ethanol and biodiesel.

Next, there is a brief description of the biofuels supply problem in Colombia, followed by the description of the System Dynamics model and the simulations results. Finally there are some conclusions.

BIOFUELS PRODUCTION IN COLOMBIA

Some countries are stimulating the production of biofuels to diminish the fossil fuels dependency; nevertheless, most of them can´t deal with their internal consumption, since they do not have enough land nor the adequate climate for crops to grow efficiently.

That is not the case of Colombia, where there are millions of underused hectares, dedicated mostly to extensive cattle, which could be used for planting crops for biofuels production without major implications over food supply or natural reserves (Arias, 2007). Those hectares should be enough to satisfy the internal demand of biofuels and even export to other countries.

In addition, it is important to consider that Colombia has a wide experience in cultivation, and even refining, of Sugar Cane and Oil Palm, which are excellent sources for ethanol and biodiesel production (Agriculture y Rural Development Minister, 2007; Vera, 2007). Colombia also produces other crops that are developing industrially for biofuels, such as Yucca and Beet with good yields and quality. Additionally, the production of biofuels may give Colombia some level of energy independence from other countries, and become a good opportunity for exportation.

That is why the government has made important efforts to promote biofuels through incentives for the producers and consumers such as exemption on revenue taxes (Congress of Colombia, 2004), exemption on VAT (value added tax) (Congress of Colombia 2002, 2003, 2004, 2006), control on prices (Ministry of Mines and Energy 2005, 2006, 2007i, 2008i) and norms that force minimum blending percentages of 5% of biodiesel, or 10% of ethanol in the fossil fuels (Ministry of Mines and Energy et al 2008; Ministry of Mines and Energy 2003, 2007, 2008; Uribe 2007). However, the production capacity is not enough; the supply of biofuels is very limited even for the internal demand.

The System Dynamics model presented below was constructed to understand why is the offer of biofuels still failing to meet demand, even with the high economic and legal incentives to its production and consumption.

THE MODEL

The production of biofuels in Colombia is a relatively new business, and that makes it very difficult to collect enough amounts of data to develop an analysis using traditional mathematical tools. Besides, the supply chain of biofuels involves a large amount of variables and delays, which interact over time causing loops and making the analysis extremely difficult without a model.

It is possible to deduct from the characteristics of the system, as presented before, that a System Dynamics approach is adequate to analyze this problem (Forrester 1961), since it is possible and simple to construct a System Dynamics model considering all the important variables, delays and loops without a large amount of data. And it allows to experiment *a priori* to observe the effects of different conditions and policies over the system.

The model was constructed to analyze policy scenarios applied to the biofuels supply chain. Different factors are considered such as the investment process in crops and refining, the government incentives to production and consumption, the exports and the prices, among others.

However, prices of biofuels in Colombia are controlled by the government, and there for we decided to consider them as exogenous variables, to keep the model as simple as possible. It may be thought as a very strong supposition, but all the dynamics that could involve the price variations, can only affect producers profits, since the demand cannot decide the amount of biofuels wanted when buying fuel, it is decided by law; so the dynamics are incorporated to the model as a variation of incentives to refining or crops, which affect producers profits through production costs.

Causal Diagram

The production of biofuels is limited by the amount of refining capacity and the availability of raw materials (crops). That is why the government has been focused on stimulating investment in these two sectors. The dynamics of investment and incentives to investment are shown in Figure 1.

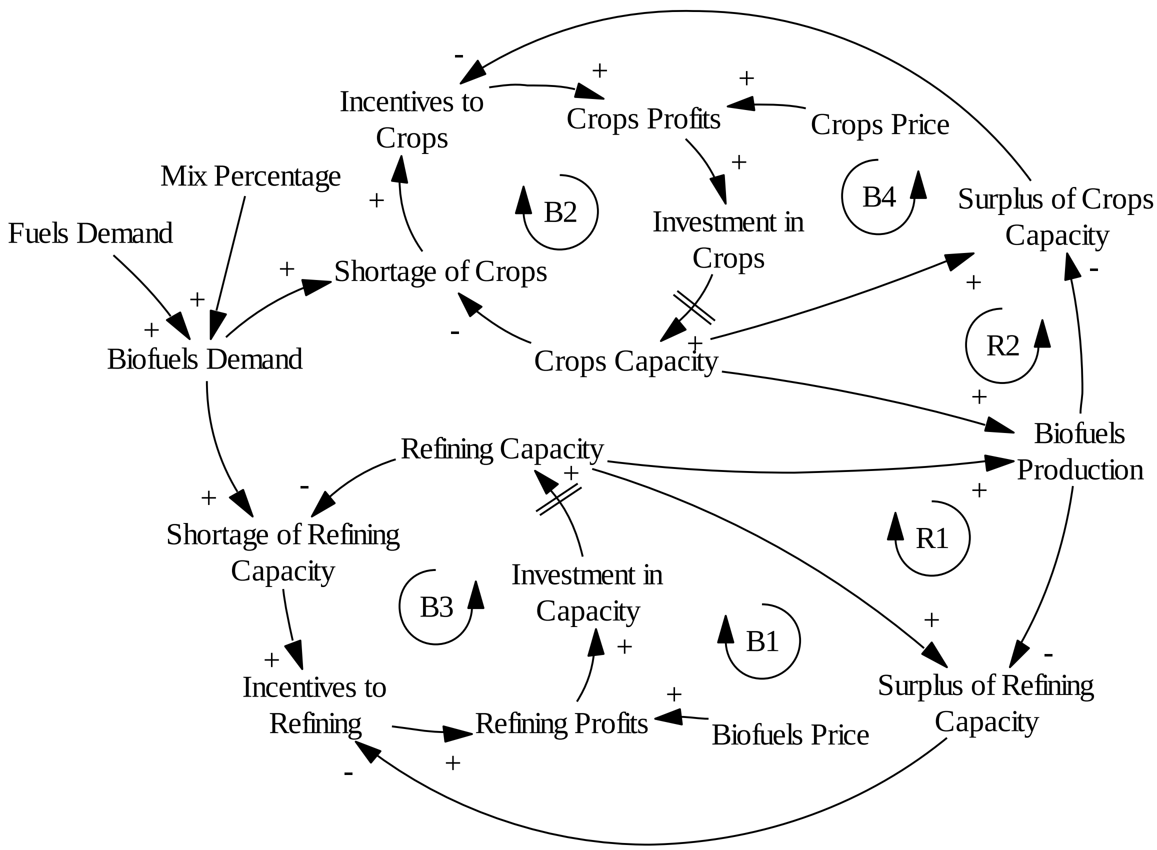

Figure 1. Causal Diagram

The demand of biofuels, both ethanol and biodiesel, was set as a percentage of the projected demand of fossil fuels (Ministry of Mines and Energy et al 2008; Mining and Energy Planning Unit, 2007). The prices of biofuels are exogenous accordingly to the government resolutions (Ministry of Mines and Energy 2005, 2006, 2007i, 2008i).

Initially it was assumed a level of incentives of 20% to refining and 10% to crops, which are approximate values calculated from different incentives like tax exemption, especially the VAT and the rent (the Congress of Colombia 2002, 2003, 2004, 2006), these incentives vary according to the difference between demand and production of biofuels, taking into account the surplus or shortage in each sector of the supply chain.

Investment, in refining capacity and crops, responds to profits, as is shown in Figure 1. Crops profits are calculated independently for each raw material from its costs of production and its prices. Refining profits are calculated for each biofuel: ethanol and biodiesel, considering the raw materials used in each case, costs of production and facility. In both cases, costs may vary according to incentives given by the government.

Incentives are higher when supply cannot meet demand, and will go down gradually when production rises and the amount of demand not attended diminishes. Incentives will fall as well, for some part of the supply chain when there is any surplus compared to other sectors of the chain.

Prices of raw materials were assumed as externalities, considering that the amount demanded for food is much higher that the amount demanded for biofuels production, so the last one should not have a significant effect over prices. However, there are some studies in which the opposite is demonstrated (Boron 2007; Gürkan 2008).

The Forrester Diagram of the invetment in refining capacity is presented in Figure 2. The probability of investment is calculated for each raw material by a logic function, which compares its profitability with the others and with an expected return of a safe investment, as if one were to make a desicion on what kind of refining facility to invest. However, if there is surplus of refining capacity, there will be no investment.

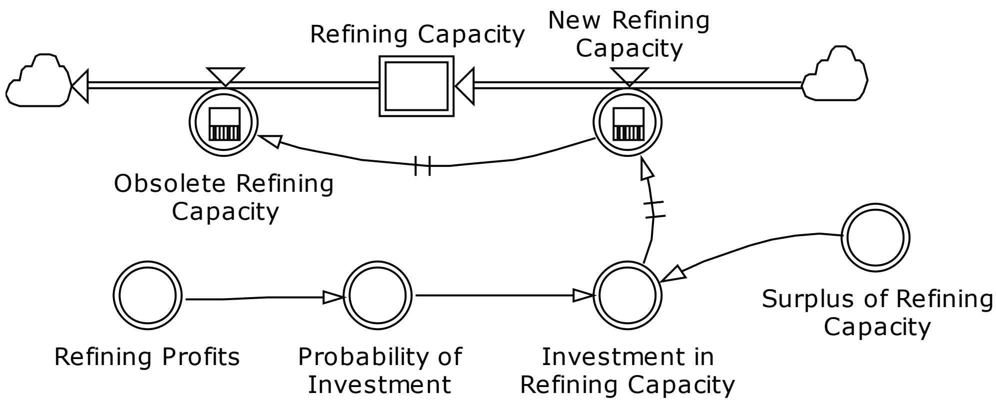

Figure 2. Forrester Diagram of Investment in Refining Capacity

RESULTS

Investment scenarios were evaluated considering the main raw materials in Colombia, although due to the information shortage some were discarded. Finally, it were considered: Sugar Cane, Yucca, Sugar Beet, Sweet Sorghum and Corn for ethanol, and Palm, Castor Bean and Soybean for biodiesel. The current government incentives were used, also the investment growth rate reported in Brazil. The model results are in Table 1.

Production (millions of liters per year)								
Year	**Ethanol**					**Biodiesel**		
	Sugar Cane	**Yucca**	**Sugar Beet**	**Sweet Sorghum**	**Corn**	**Palm**	**Castor Bean**	**Soybean**
2.008	315	1.5	0	0	0	684	0	0
2.010	315	6	0	0	0	684	0	0
2.012	472	6	0	1	0	684	0	0

2.014	517	6	0	8	0	684	0	0
2.016	765	6	0	10	0	684	0	0
2.018	911	6	0	12	0	684	0	0

Table 1. Biofuels Production by Crop

In Table 1 it is observed that most of the biofuels production is obtained from sugar cane and palm, for ethanol and biodiesel respectively. This production is limited by the minimum capacity between the refining facilities for each raw material and the availability of crops, for instance the soybean production is zero, although the crop capacity would allow a bigger production, as it is shown in Figure 3, where the crop capacity overcomes the refining capacity. This evidences a problem in the incentives assignment, because these are being applied in the same way to all refining facilities, without considering the raw materials.

In this case, the crops are going down because we did not consider any other use for the raw materials, so when there is a surplus of any crop, it becomes non-profitable and starts to fall. This does not happen in reality, but assuming that does not have much importance for this problem, and makes it simpler to model.

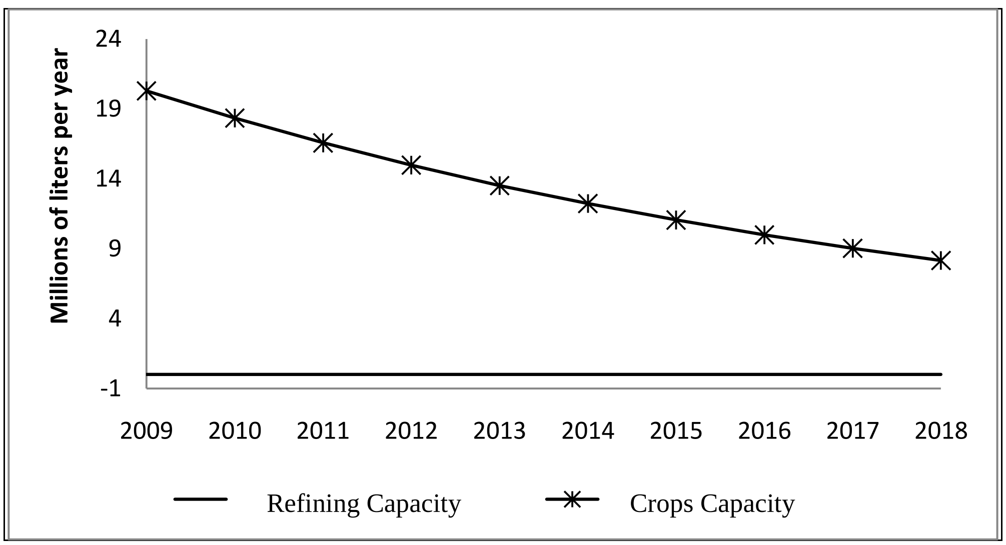

Figure 3. Refining Capacity vs. Crops Capacity of Soybean

With the base scenario of investment, the production can´t reach the ethanol demand with the percentage of blending indicated by the government, however, it would be possible to fulfill levels of 10% ethanol by the year 2014, as it is observed in Figure 4. On the other hand, the government proposal of 20% of ethanol in gasoline by the 2012 (Ministry of Mines and Energy et al 2008; Ministry of Mines and Energy 2003, 2008) cannot be supplied in the simulation horizon.

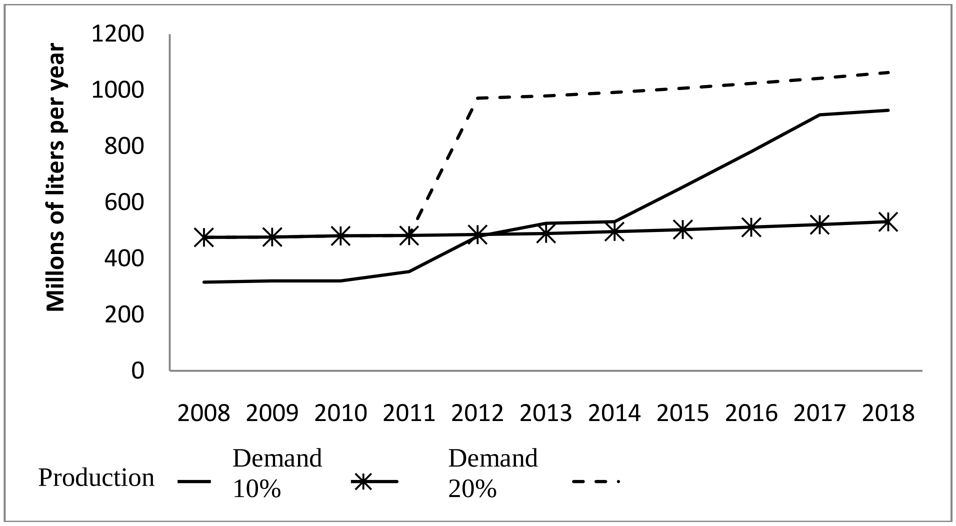

Figure 4. Ethanol production and demand

In the case of biodiesel, the production remains constant throughout the simulation horizon, as shown in Figure 5. It may be possible to fulfill demand with mixtures of 5% biodiesel, but not with an increase to 10% as government proposes by the year 2012 (Ministry of Mines and Energy et al 2008; Uribe 2007; Ministry of Mines and Energy 2007, 2008).

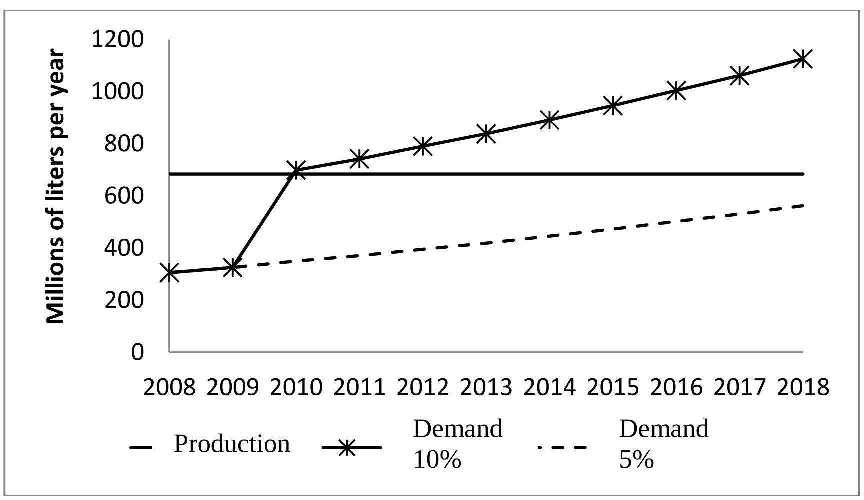

Figure 5. Production vs. Demand of Biodiesel

The production of biodiesel remains constant because refining is not profitable, limiting the production. However, in this issue the model does not reflect the real world, because the decision of investment in refining facilities is considered completely independent of the investment in crops. This model assumption should be avoided in future developments by considering the possibility of integration.

In the case of ethanol, which becomes almost totally from sugar cane, both refining and planting are profitable with the incentives given by the government; then both capacities grow, being limited by temporal surpluses created by delays from investments to production in both refining and crops capacities, as shown in Figure 6.

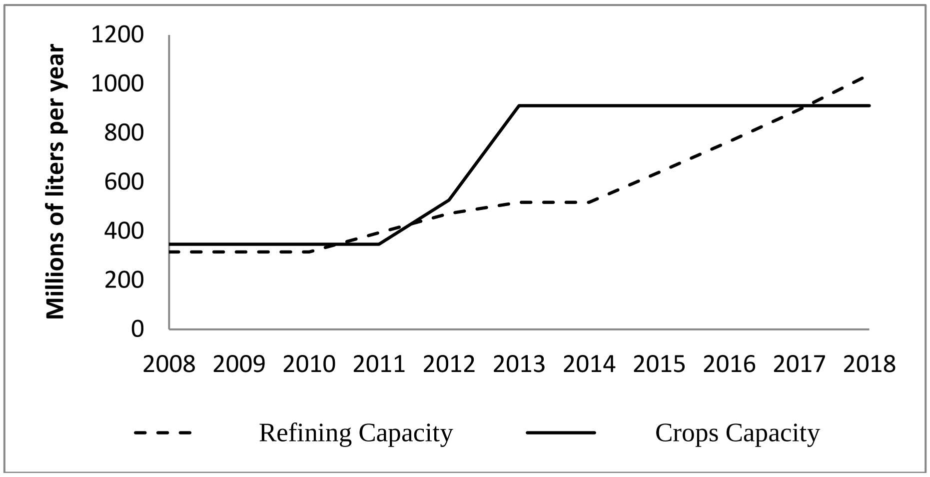

Figure 6. Crops Capacity vs. Sugar Cane Refining Capacity

Considering other investment scenarios, ethanol production could grow faster, as shown in the Figure 7. The three sensitivities used are: increasing five times the investment in refining facilities, increasing five times the investment in crops, and increasing five times the investment in both sectors.

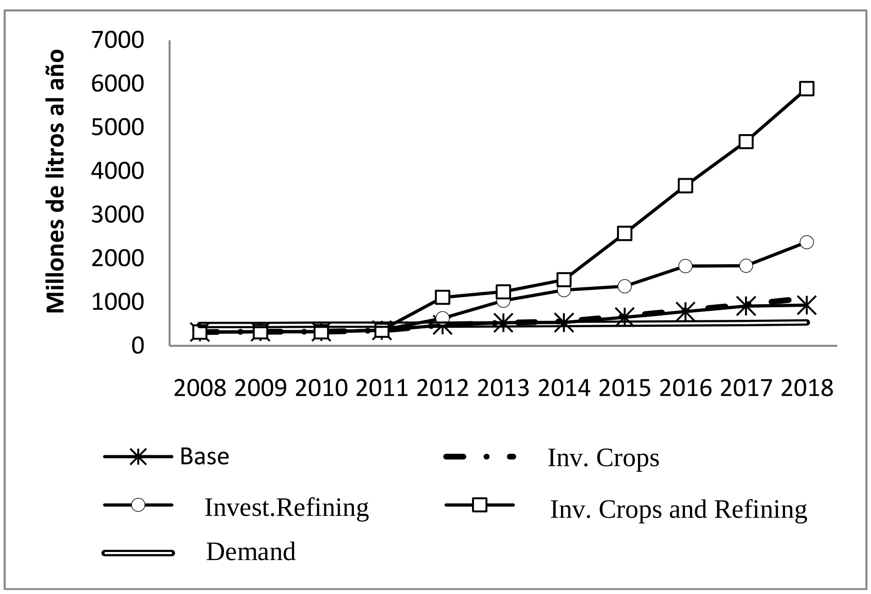

Figure 7. Demand vs. Offer of Ethanol under different investment scenarios

Note that the production increases when there is more investment in crops, but grows much more if the investment in refining facilities is increased, and still more if both investments are increased. The surplus of production found by the middle of the simulations could be exported, or the percentage of the mixture could be increased.

CONCLUSIONS

- The model results show as leading crops in Colombia the Sugar Cane and Palm Oil, for ethanol and biodiesel, respectively.

- The ethanol refinement and sugar cane planting are profitable; That is why the supply of ethanol is increasing, even in the base scenario. However, the actual level of investment is not enough to supply the future demand.

- To supply the internal demand of biofuels it is necessary to increase the investment, especially in refining facilities.

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