Simulation for assessing the Liberalization of Biofuels

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ABSTRACT

Global biofuel consumption has been growing in recent years as different countries worldwide have been exploring alternatives to gasoline and diesel fuel for transport. This is due to a hike in oil prices and their increasing volatility as well as both a high dependence of the transport sector on oil and also because, arguably, the supply chains of biofuels emit less CO2 than for fossil fuels.

Biofuels have been available around the world for a while, with the aid of some government support. Brazil pioneered this renewable solution for transport, from the early 1930s, as the country had little access to local fuels, while oil and other alternatives became more expensive. Biofuels are being widely considered as part of the solution to affordable fuels for transport. This research makes use of a system dynamics model to analyse the current leading policies aiming at increasing the penetration of biofuels.

In this context, and given multiple uncertainties including technology evolution and fuel prices, scenario analysis has been considered for the examination of different, extreme, though plausible, futures. SD under extreme scenarios helped in assessing the possibility of removing incentives (that is, leaving decisions to an open market) and a partial reduction of subsidies. This paper concludes that for the case of Colombia, the potential of biofuels seems promising.

KEY WORDS*: Biofuels, systems dynamics, incentives, free market.*

1. INTRODUCTION

Contemporary societies are confronting critical problems regarding high fuel prices, growing CO_2 emissions and climate variability. These are becoming more challenging, given the increasing energy needs around the world and the depletion of some non-renewable energy sources (Demirbas A. , 2009). In this context, governments are considering energy alternatives, such as biofuels (Bozbas, 2008; Sorda, Banse & Kemfert, 2010), as these are gradually becoming cost-competitive (Lamers, McCormick & Hilbert, 2008). At the current state of development of the industry, biofuels still seem to need some support, given the structural barriers that were created by fuel suppliers during the last century or more (Sorda & Banse, 2010).

However, as the main sources for the production of biofuels have been vegetable oils and sugars, and as the predominant crops are sugar cane, sugar beet, corn and oily seeds (Bomb, McCormick & Deurwaarder, 2006; Sorda & Banse, 2010), and as these are also used to produced biofuels, the sector has been blamed for increases in food prices (Mitchell, 2008; Johnson, 2007; Sorda & Banse, 2010). Although not the focus of this research, this paper considers biofuel stocks that are being produced in deserts and unexploited regions (or those marginal for food production).

It is important to note that we only examine first-generation biofuels. Figure 1 shows the conversion process from feedstock to biofuels. This article does not examine second or third generation biofuels (coming from residues or microalgae) as the focus here is to examine how far the industry can progress under the current circumstances, without significant effect on human food stocks.

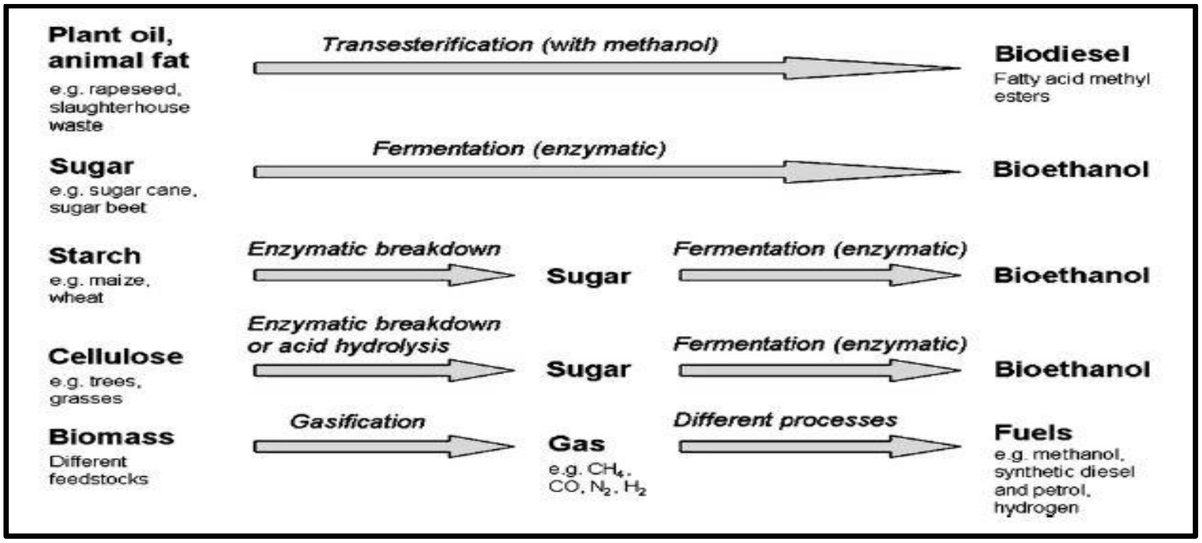

Figure 1 *Alternatives for fuel and biofuels productions* (Bomb, McCormick & Deurwaarder, 2006)**.**

Ethanol and biodiesel can be used in conventional vehicles. Biodiesel has been used in pure and blended forms in conventional diesel vehicles. The blend between biodiesel and diesel is known as B# where the B indicates biodiesel and "#" indicates the biodiesel percentage in the blend (for example B10 means 10% of biodiesel and 90% of diesel). This is similar to the ethanol, the highest blend that a conventional car support is E20 (Bozbas, 2008; Bomb, McCormick & Deurwaarder, 2006; Szklo, Schaeffer & Delgado, 2007). Table 1 shows some of the main advantages and disadvantages of ethanol and biodiesel.

	Advantages	**Disadvantages**
Ethanol	Extends engine life, decreases CO_2 emissions and provides higher octane (Pacini & Silveira, 2011)	E100 delivers 70% of the mileage of gasoline (for the same volume of fuel), while E85 delivers 74% of the mileage (Goettemoeller, 2007)
Biodiesel	Prolongs engine life, reduces need for maintenance and decreases CO_2 emissions. Also, efficient, clean, and better than diesel in terms of sulphur emission and biodegradability (Bomb, McCormick & Deurwaarder, 2006).	Blended biofuel-diesel contributes to some problems of fuel freezing, and reduces energy density (Bomb, McCormick & Deurwaarder, 2006)

Table 1. Advantages and disadvantages of ethanol and biodiesel.

Figure 2 shows the evolution of world production of ethanol and biodiesel, distinguishing the leading producers - Brazil and the US for ethanol; and the EU, the US and Argentina for biodiesel.

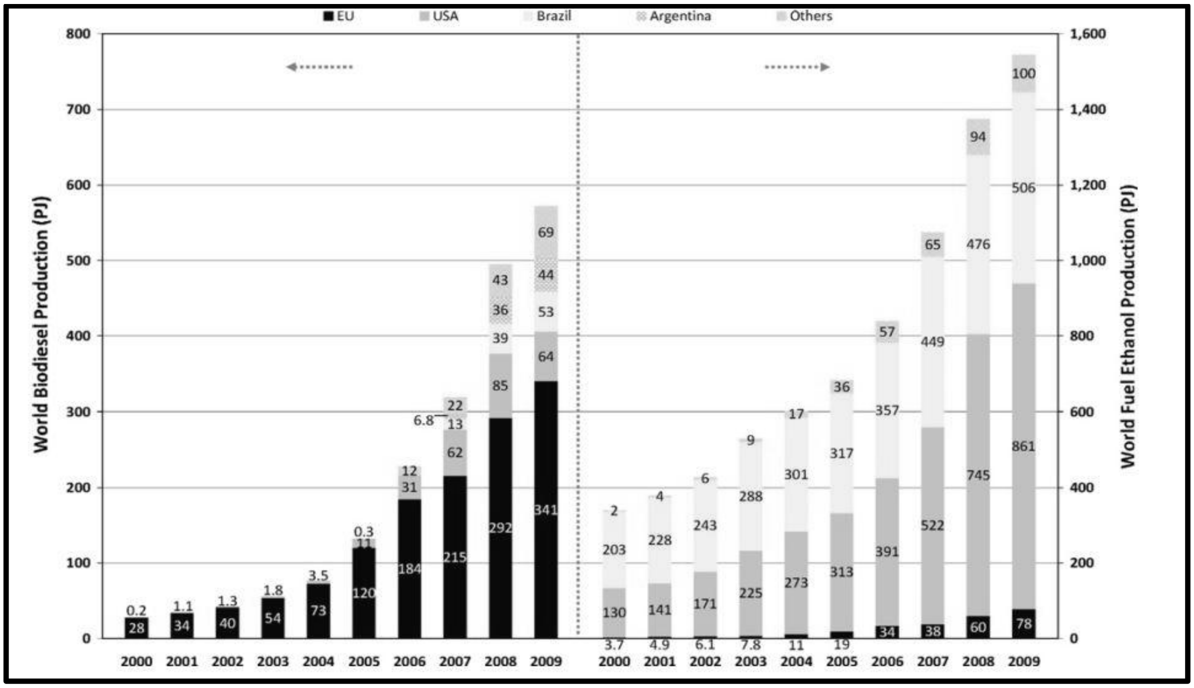

***Figure 2** Development of world biodiesel and ethanol production between 2000 and 2009 in PJ* (Lamers, Hamelinck, Junginger & Faaij, 2011)**.**

The introduction of flex-fuel vehicles has given consumers the possibility of choice between fuels (fossil and non-fossil), based on price differentials (Pacini & Silveira, 2011). It has also provided governments with the possibility of creating new laws for biofuel use. Note that the ethanol market has been liberalized in Sweden and Brazil (Demirbas A. , 2009; Pacini & Silveira, 2011).

These “flex-fuel” vehicles can use mixtures of ethanol and gasoline; they are designed for blends of 85% ethanol and 15% gasoline or E85 (Bomb, McCormick & Deurwaarder, 2006). In Brazil, the flex-fuel vehicles can use up to 100% of ethanol or E100 (Coelho S. , Goldemberg, Lucon & Guardabassi, 2006; Szklo, Schaeffer & Delgado, 2007).

The Brazilian experience regarding ethanol production dates from the early 1930s (Hira & de Oliveira, 2009). In 1975, Brazil established government subsidies for the ethanol industry under the Brazilian Proalcool Program. As a consequence of this, ethanol started to replace a significant proportion of gasoline-use in the transport sector (Lamers, Hamelinck, Junginger & Faaij, 2011).

In 2003, the Brazilian government introduced flex-fuel vehicles (FFV). This country liberalized the ethanol market in 2005 and rapidly increased foreign participation in this sector. As a consequence of this, the cost of ethanol production decreased and ethanol production increased; Brazil became the largest ethanol exporter worldwide (Hira & de Oliveira, 2009). Figure 3 shows the growing consumption of E100 in Brazil, between January 2005 and April 2009.

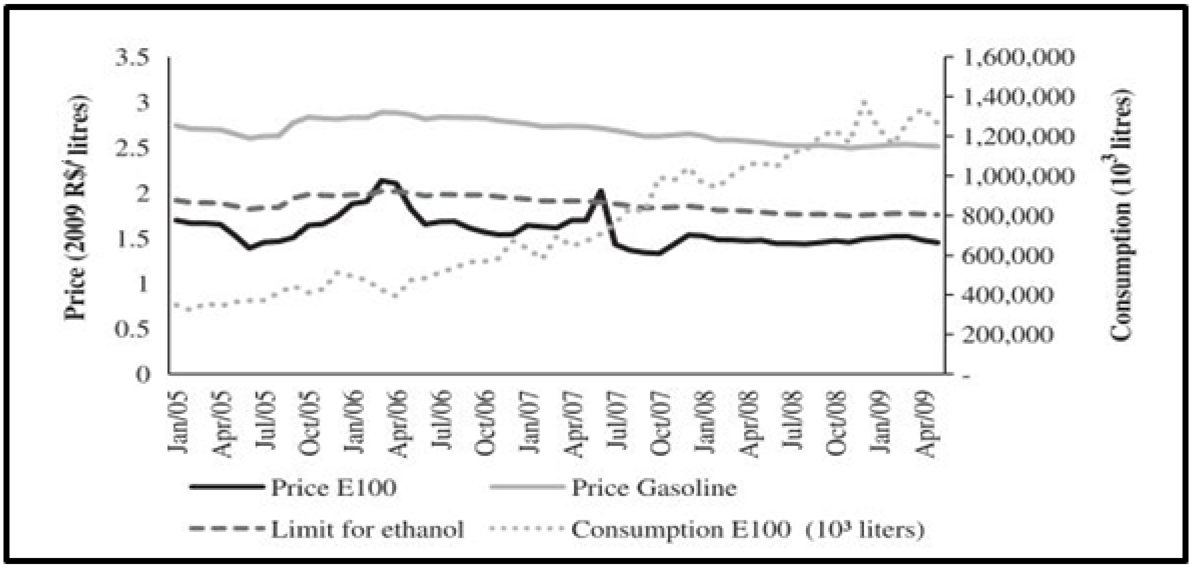

Figure 3** Brazil E100 consumption and E100 price* (Pacini & Silveira, 2011).***

The next section provides an overview of the SD literature on biofuels. Section 3 discusses the biofuels market in Colombia. In Section 4 we describe an SD model that has been built to study the dynamics of the actual and the potentially liberalized biofuels market that might be developed in Colombia. Section 5 discusses simulation results and policy analysis. And finally, conclusions are discussed in Section 6.

2. THE SYSTEM DYNAMICS LITERATURE ON BIOFUELS

The system dynamics (SD) literature on biofuels has been discussed by Banz and Deaton (2006). Their research group reported the impact of biodiesel production on the cost of soya. Musango et al. (2012) analyse the growth of biofuels production in South Africa. Florez and Franco (2010) discuss incentives for the biofuels market in Colombia; Flynn and Ford (2005) assess the introduction of clean energy such as biomass and biofuels. Pruyt and De Sitter (2008) developed a system dynamics model focused on food/bioenergy issues, to investigate the effects of the interactions between food production on bio-energy production worldwide. Bush, Duffy, Sandor and Peterson (2008) evaluate the biodiesel transition in the US. Vimmerstedt, Bush and Peterson (2012) developed a system dynamics model focused on the ethanol supply chain in the USA and analyse incentives and R&D investment.

SD research has neither reported work regarding the effect of the liberalization of the biofuel industry on security supply issues nor how this has been applied to liberalize the industry in a particular country - both of which this paper aims to cover. The next section discusses the biofuels market in Colombia.

3. THE BIOFUELS MARKET IN COLOMBIA

Colombia has promising conditions for becoming a major biofuels producer as it has sufficient land available for this purpose (located in regions that marginally produce human food, and in deserts or unexploited regions) as well as adequate climatic conditions and lower labour costs than most other producers (EIA, 2010).

The biofuels industry in Colombia started in 2001 with the enactment of Law 693 (Congreso Colombiano, 2001). With this law, the government defined different incentives such as: tax exemptions, subsidies, mandatory blending for the production of ethanol from sugar cane as well as biodiesel from oil palm, and a mandatory price that ensured profitability for producers (Conpes, 2008). In 2010, the GPC started production of ethanol from yucca (Fedebiocombustibles, 2011) that traditionally has widely been used for non-human food.

Colombia produces biodiesel from palm oil, and ethanol from sugar cane or yucca (Fedebiocombustibles, 2011; FedePalma, 2009). Biofuels production in Colombia is shown in Table 2.

Table 2. Biofuels production in Colombia (Fedebiocombustibles, 2011).

Biofuel	production (Lts/day)	Feedstock
Ethanol	875.000*	Sugar Cane
Biodiesel	1.967.904	African Palm Oil

*25000 litres per day of sugar cane are produced from yucca.

Colombia has been following demand (depending on the goals set for the fuel mix) but production does not significantly exceed demand due to: a) the incentives in place, b) the time that is needed to increase production levels (Fedebiocombustibles, 2011; Ministerio de Minas y Energía, 2011), and c) lack of further incentives to export.

However, government has argued that under current regulation, ethanol production will not meet demand (Ministerio de Minas y Energía, 2011). Figure 4 shows government projections of supply and demand under current market conditions. These indicate a likely deficit by 2019, under the most optimistic scenario. This paper assesses the soundness of these predictions. It also examines the effect of partially eliminating some of the current incentives and, finally, examines the effect of completely liberalizing the industry; that is, establishing legislation allowing consumers to choose fuel blend and prices, the latter according to international fuel prices.

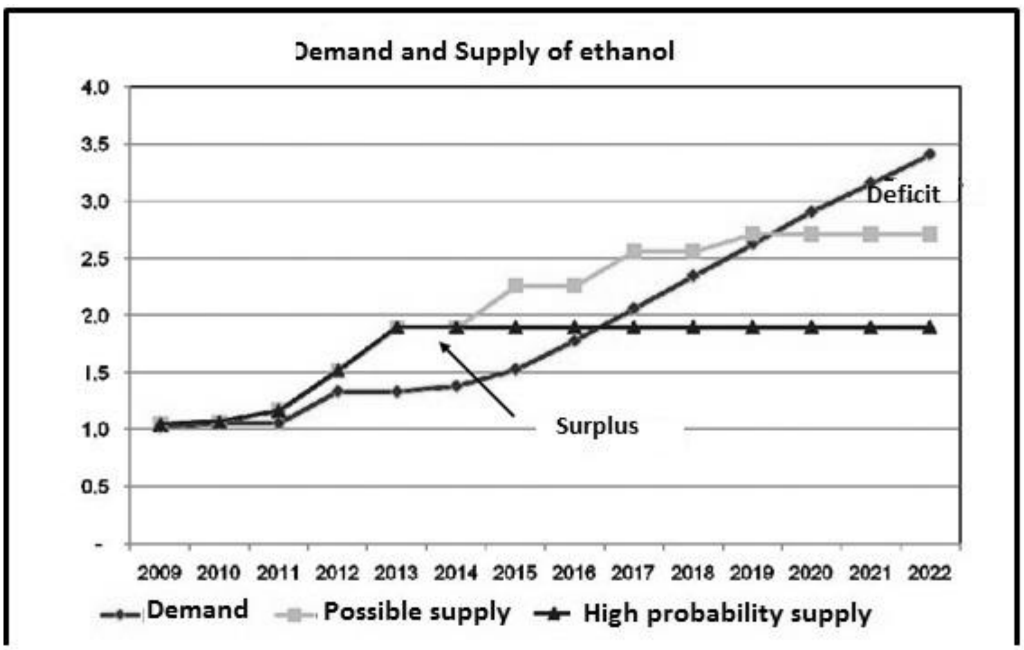

Figure 4 *Ethanol supply vs. Ethanol demand in Colombia (Ministerio de Minas y Energía, 2011).*

Colombia's Biofuel production is still small as shown in Tables 4 and 5. Table 4 shows the ethanol and biodiesel production in different countries during 2012. However, given its land availability and weather conditions Colombia may become an important biofuel player.

COUNTRY	Ethanol	COUNTRY	Biodiesel
United States	50345.9	United States	2747.52

Brazil	**21035.53**	**Canada**	114.48
Europe Union	**4311.584**	**Germany**	2804.76
Canada	**1699.65**	**China**	515.16
China	**2100.904**	**Brazil**	1488.24
Colombia	**368.447**	**Colombia**	171.72
		Others	7841.88

Table 4. *Ethanol and Biodiesel production by country in Thousand millions of litres in 2012* (Enegy Ethanol Outlook, 2012). (Fredrik, 2012).

The liberalization of the biofuels market in Colombia should lead to greater production efficiency and cost reductions due to competition (Hira & de Oliveira, 2009). We developed a system dynamics model of the evolution of biofuel production to analyse the long-term effects of the liberalization of the biofuels market in Colombia. A description of the system dynamics model is presented next.

4. MODEL DESCRIPTION

This section analyses the biofuels market in Colombia using a system dynamics model, where investment in crops, refinery capacity, biofuels and fuels demand are modelled. Figure 5 shows our dynamic hypothesis for a free biofuels market.

4.1 Dynamic Hypothesis

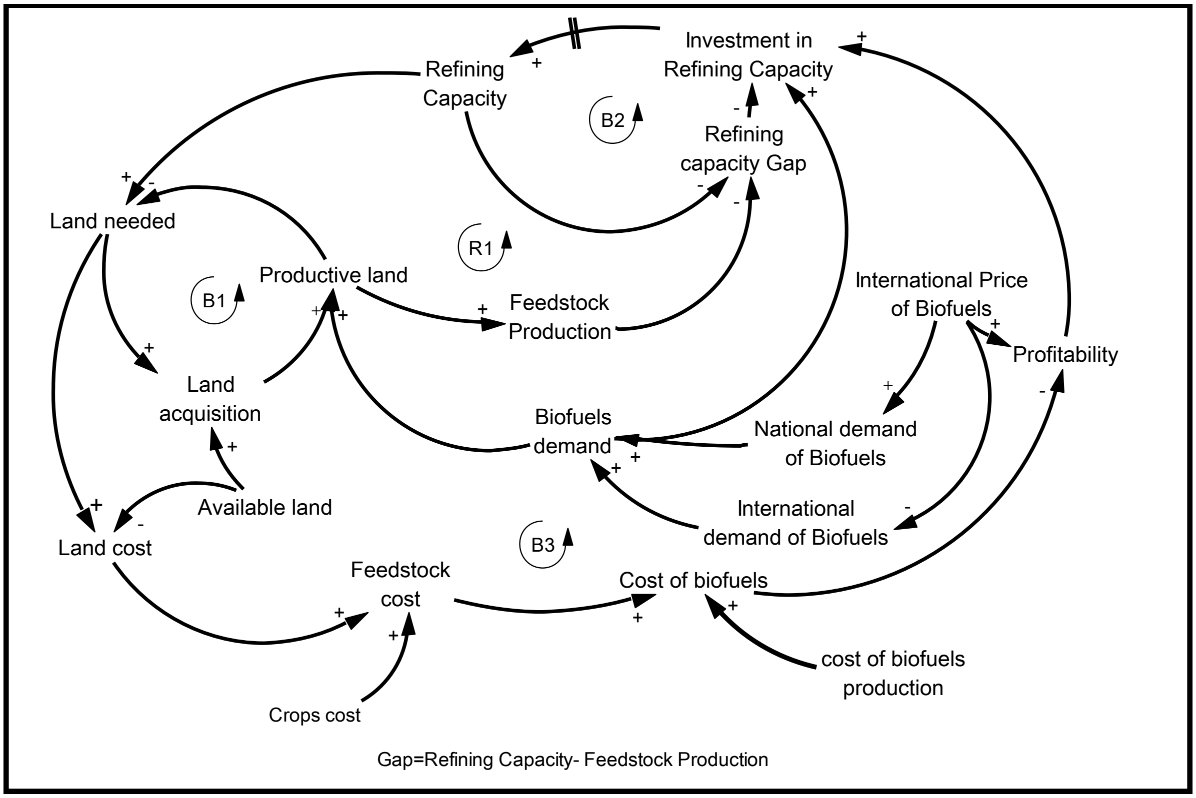

***Figure 5** Dynamic hypothesis for biofuels under market liberalization in Colombia.*

The raw materials for biofuels production in Colombia are sugar cane and yucca for ethanol, and the African oil palm for biodiesel, but they are needed also for food production. According to government requirements, domestic food demand has to be met first, and surpluses can be used for export or the production of biofuels (Londoño, 2010).

As can be observed in Figure 5 (Loop B1), depending on the refining capacity, the effect of an increasing need for land will incentivize the farming activity, and thus new land acquisition will be undertaken; after a lag, this will lead to increased planting.

Refining capacity and feedstock production, together, define the refining capacity gap. By increasing investment, new refining capacity will be built and, consequently, increasing land needed to satisfy demand for feedstock and increased planting and feedstock production. These describe the investment-refining loop, and the refining-capacity gap loop (B2, R1 respectively).

Land needed depends on refining capacity. If land needed is high, land cost is high, which affects the feedstock cost and biofuels costs. If cost of biofuels is high, profitability is low and affects investment in new refining capacity. If new refining capacity is high the refining capacity expands quickly (loop B3).

4.2 Stocks and flows diagram

To analyse market dynamics we develop a stocks and flows diagram, as shown in Figure 6. This was undertaken for the purpose of assessing biofuels policy, particularly regarding market sustainability under current circumstances and also considering market liberalization. These we assess through the evolution of variables such as feedstock cultivation, refining capacity and demand for ethanol and biodiesel (this, under different market conditions).

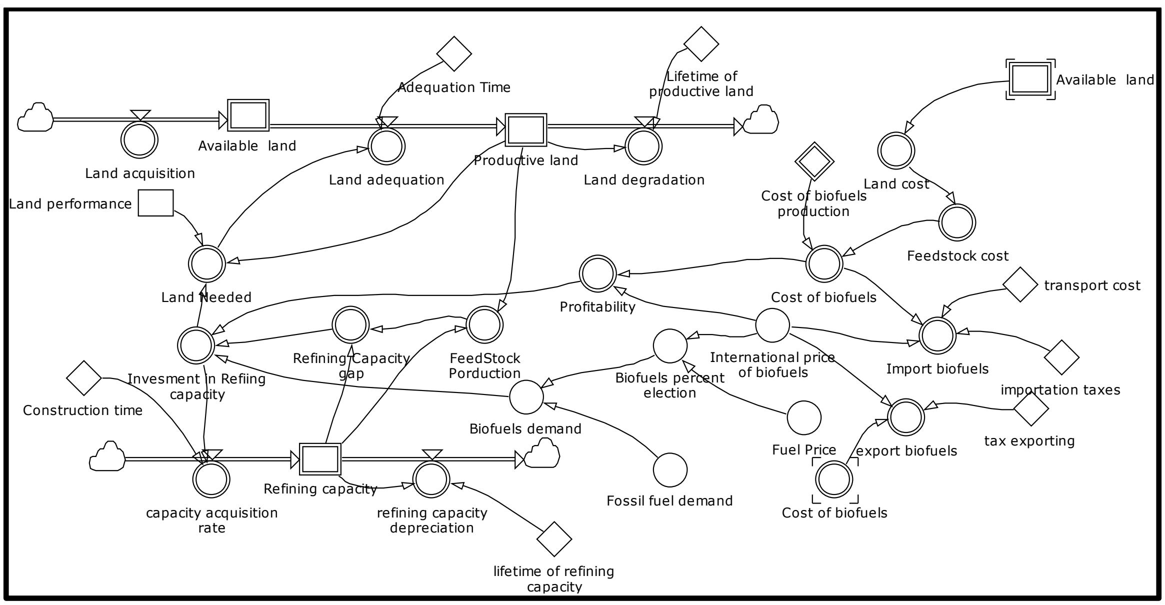

Figure 6 *Stocks and Flows diagram of biofuels under market liberalization in Colombia.*

Capacity investment depends on profitability. After deciding investment in each period, the new refining capacity will be available four years later, which is the time that has been stipulated for plant construction, with a plant-life of 25 years (IEA Bioenergy, 2005; Dias and others, 2010). Biofuel demand was modelled according to a logit model that depends on fuel price and performance.

4.3 Model equations

Crop capacity depends on planting and harvesting.

$$\frac{dC}{dt} = P - CO$$

C represents crop capacity; P is the rate of planting and CO recollection.

Refinery capacity depends on capacity under construction and refinery reduction

$$\frac{dR}{dt} = CAR - RCD$$

R represents refinery capacity, CAR capacity acquisition rate and RCD refining capacity depreciation.

Biofuels demand was modelled using a logit model; the corresponding equation is

$$BD = \frac{\frac{BP}{BPP}^{\gamma}}{\left(\frac{BP}{BPP}^{\gamma}\right) + \left(\frac{FP}{FPP}^{\gamma}\right)}$$

Where BD represents the percentage of biofuel with respect to the total, BP biofuel price, BPP biofuel performance, FP fossil-fuel price; FPP fossil-fuel performance; and γ is a parameter (Fox, Kim, Ryan & Bajari, 2012). The model was calibrated using the E85 demand data for Sweden. Figure 7 shows the evolution of Swedish consumption and ethanol price.

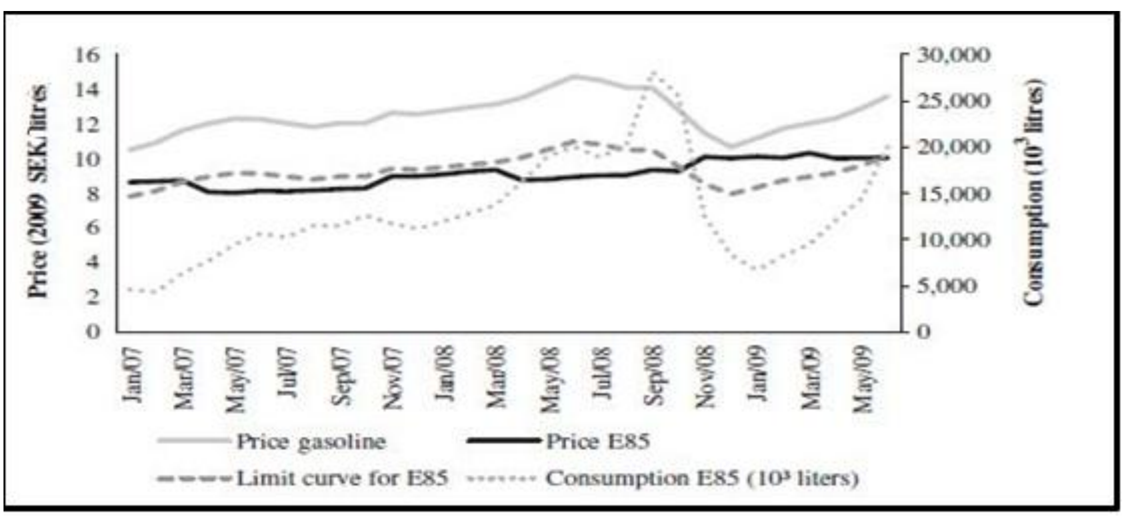

Figure 7 *Gasoline and E85 price series compared with ethanol consumption, Sweden* (Pacini & Silveira, 2011)**.**

The next section discusses simulation results for the effect of liberalizing the biofuels market in Colombia. We use a time horizon of 18 years, from 2013 to 2030; this horizon is long enough to observe the expansion of biofuel demand and production.

5. POLICY ANALYSIS

At the present time, the biofuels market in Colombia is regulated by government (Congreso Colombiano, 2001). Government regulates fossil fuels as well as the biofuels blend and the price of biofuels. Four scenarios are being considered in order to analyse the possible evolution of the actual market, as shown in Figure 8.

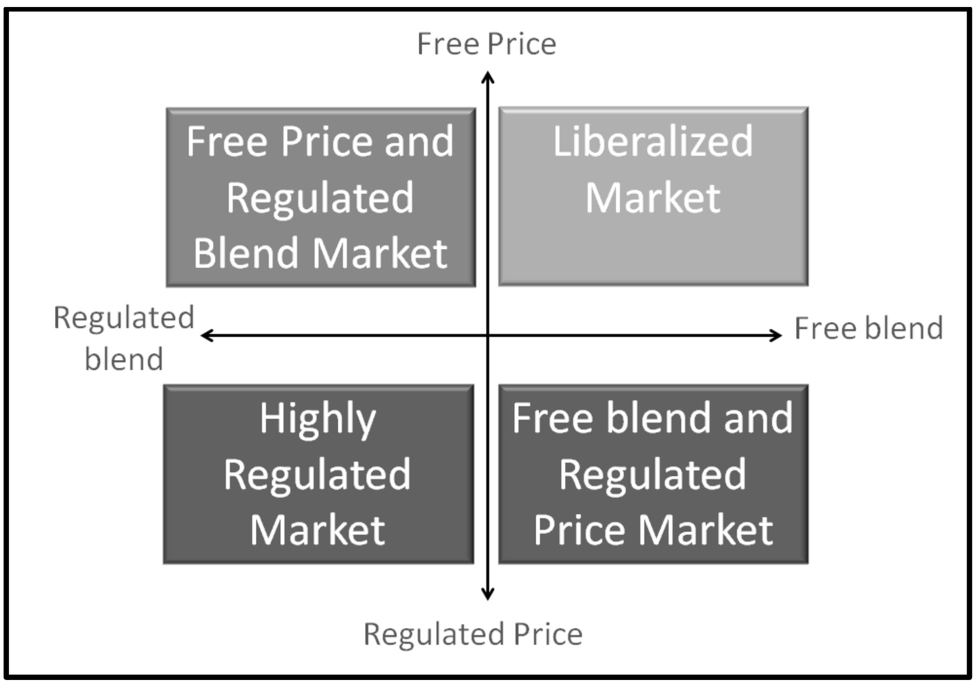

Figure 8 *Scenarios for analysing biofuels markets.*

Liberalized market. Price and blend percentage are not regulated, blend percent variable is endogenous to the model. Price depends on the international price of biofuels and the blend depends on the relationship between the fossil-fuel price and the biofuel price.

Free price and regulated blend market. The blend is an exogenous variable and biofuels' prices depend on international price. This scenario will not be analysed in this article.

Highly regulated market. The price and blend percentage (biofuels and fossil fuels) are imposed by the government (exogenous variables). This scenario is the base-case scenario.

Free blend and regulated price. The blend (biofuel and fossil fuel) is an endogenous variable and the blend percentage is based on the relation between fossil fuel and biofuel prices. Biofuels' prices are exogenous. Regulated biofuel prices are higher than the fossil fuel price. This scenario will not be analysed in this article.

The following scenarios are analysed next.

5.1 Base-case scenario: Highly regulated market

This scenario represents the current state of the ethanol and biodiesel market, where biodiesel and ethanol prices are regulated and government ensures the profitability of investors. The blends are at the present time E10 for ethanol and B10 for Biodiesel.

5.1.1 Base-case scenario: without external market (Scenario 1)

Figures 9 and 10 show simulations of demand and production capacity for both ethanol and biodiesel. In both cases, it can be observed that biofuels production meets demand within the initial years of the simulation; once production capacity reaches demand, production closely follows demand.

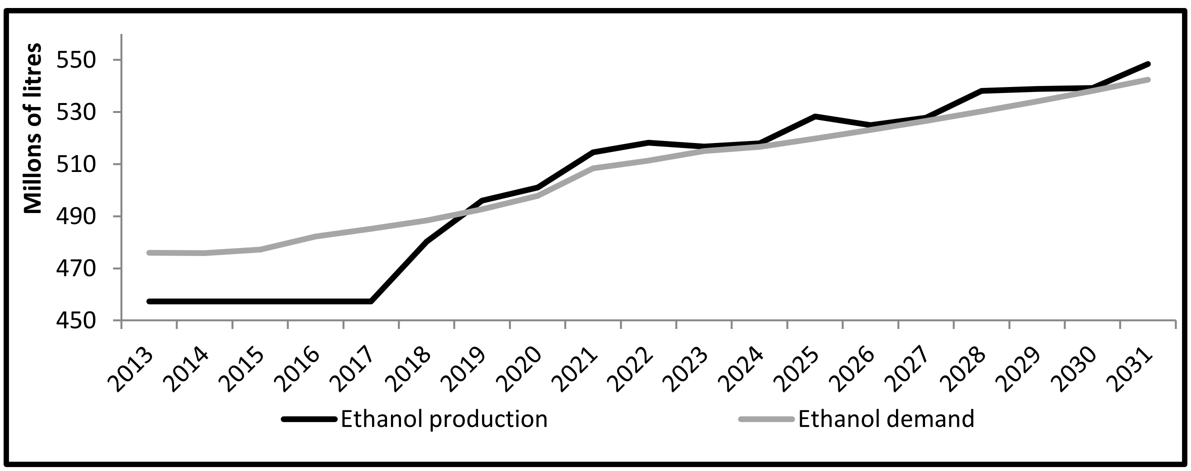

Figure 9 *Ethanol demand vs. Ethanol production, Base Scenario*.

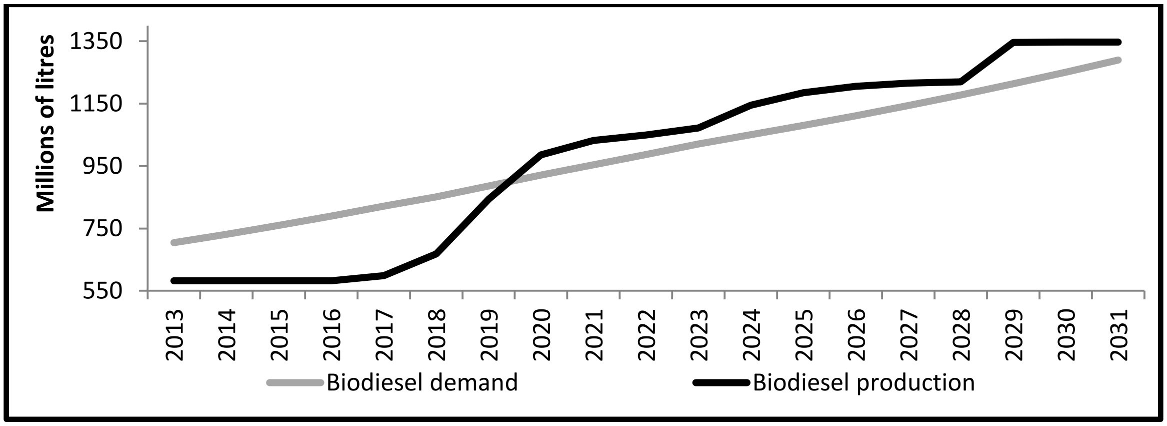

Figure 10 *Biodiesel demand vs. Biodiesel production, Base Scenario.*

The current market guarantees high profitability and stability to investors. Under these conditions, biofuels growth will be low, missing the opportunities provided by Colombia's great natural potential, as discussed previously.

5.1.2 Base-case scenario: with external market (Scenario 2)

Figures 11 and 12 show simulations of demand and production capacity for both ethanol and biodiesel. The ethanol market shows imports at the beginning of the simulation and then ethanol production capacity meets demand within the early years of simulation; once this stage is reached, production closely follows demand. The biodiesel market at the beginning shows production being below demand but then production capacity exceeds demand and the surplus biodiesel is exported.

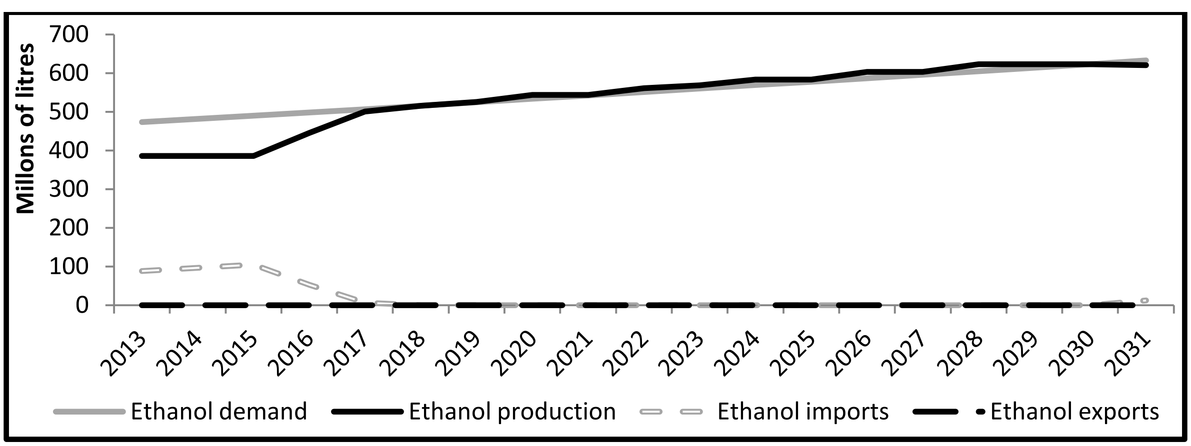

Figure 11 Ethanol Demand, Production, Imports and Exports, all over 2013 to 2031*, Scenario 2*.

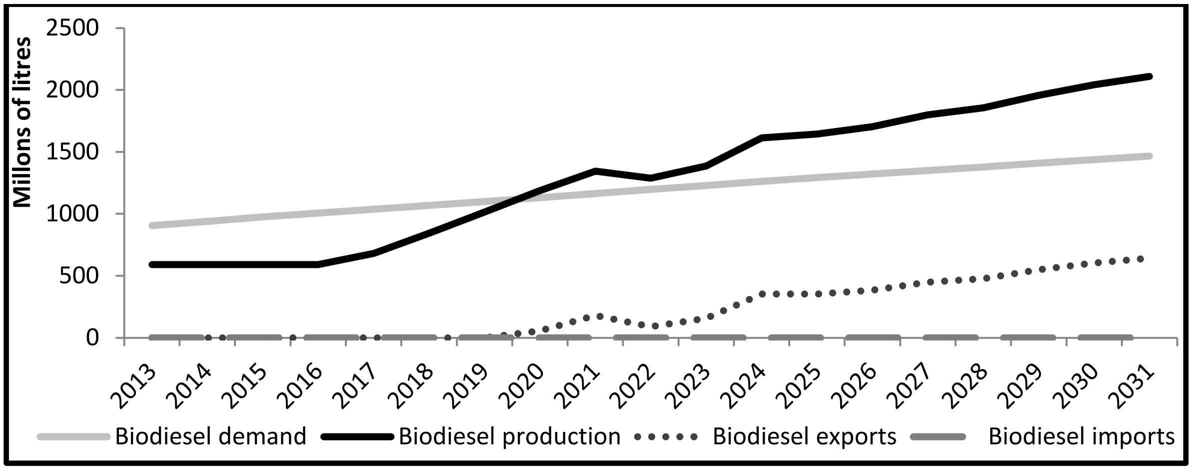

Figure 12 Biodiesel Demand, Production, Imports and Exports, all over 2013 to 2031*, Scenario 2*

5.2 Liberalized market

In this scenario, blend and price are not regulated by government, and some consumers choose between Gasoline and E85; others choose between Diesel and B100 (this is represented by a logit model).

5.2.1 Liberalized market: without external market (Scenario 3)

Figure 13 shows simulations of ethanol demand and ethanol capacity production. In this case, production meets demand after a fairly long period of simulation. This is because ethanol demand is higher than the regulated market can supply, and profitability is lower.

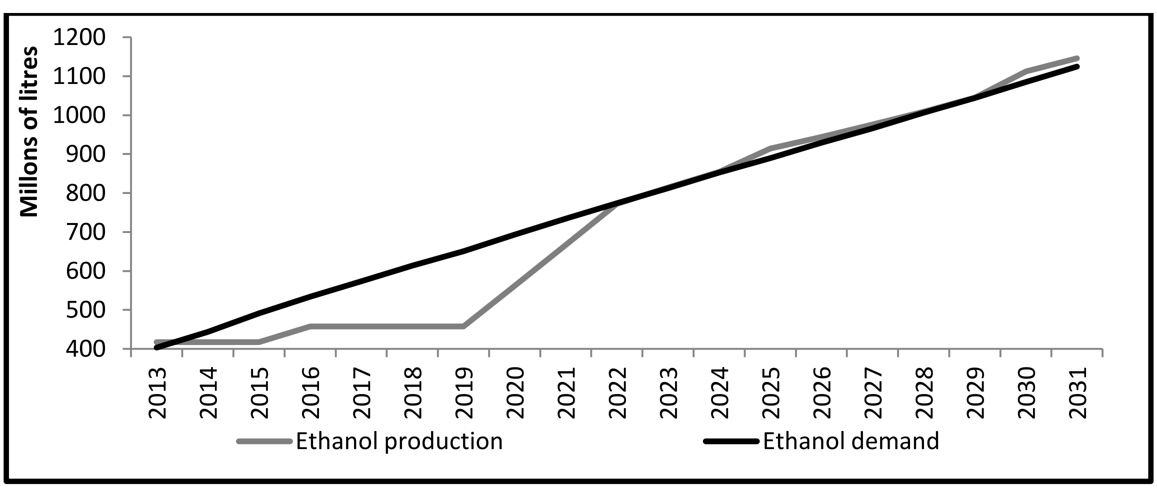

Figure 13 *Ethanol demand vs. Ethanol production under a liberalized market scenario.*

Figure 14 presents simulations of biodiesel demand and biodiesel production. In this case, biodiesel production closely follows demand.

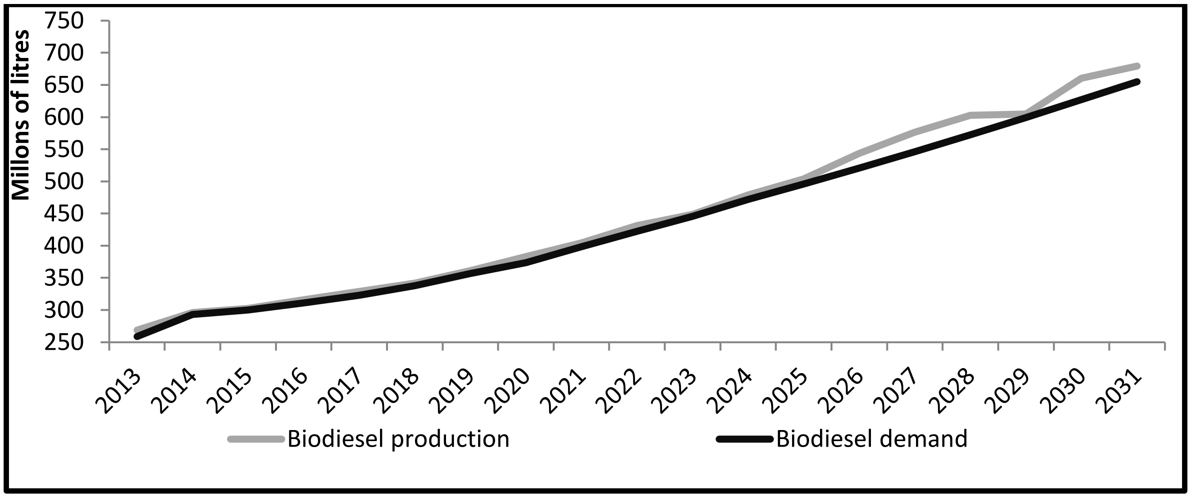

Figure 14 *Biodiesel demand vs. Biodiesel production, Scenario 3.*

5.2.2 Liberalized market: with external market (Scenario 4)

Figure 15 shows simulations of demand, imports, production and exports of ethanol. In this case, production meets demand at the beginning of the simulation. Simulation shows that during the initial years, ethanol imports take place when production is lower than demand; when ethanol production meets demand, ethanol imports are negligible as national production is cheaper than imports.

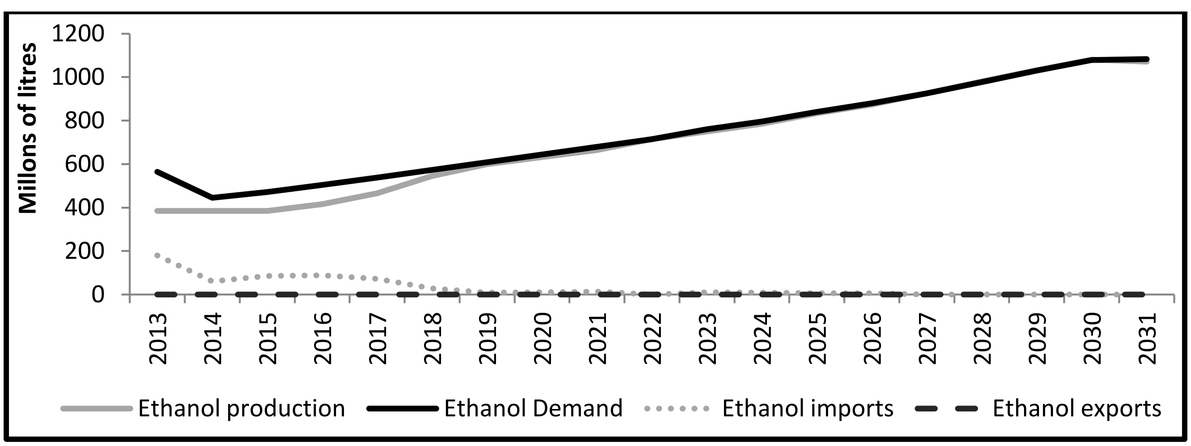

Figure 15 *Ethanol demand, production, imports and exports, Scenario 4*.

Figure 16 shows simulations of demand, imports, production, and exports of biodiesel. In this case, production meets demand at the beginning of simulation. In this scenario it is possible to observe biodiesel exports during the whole simulation period. This, because international prices are higher than local prices and this represents an opportunity to expand biodiesel production.

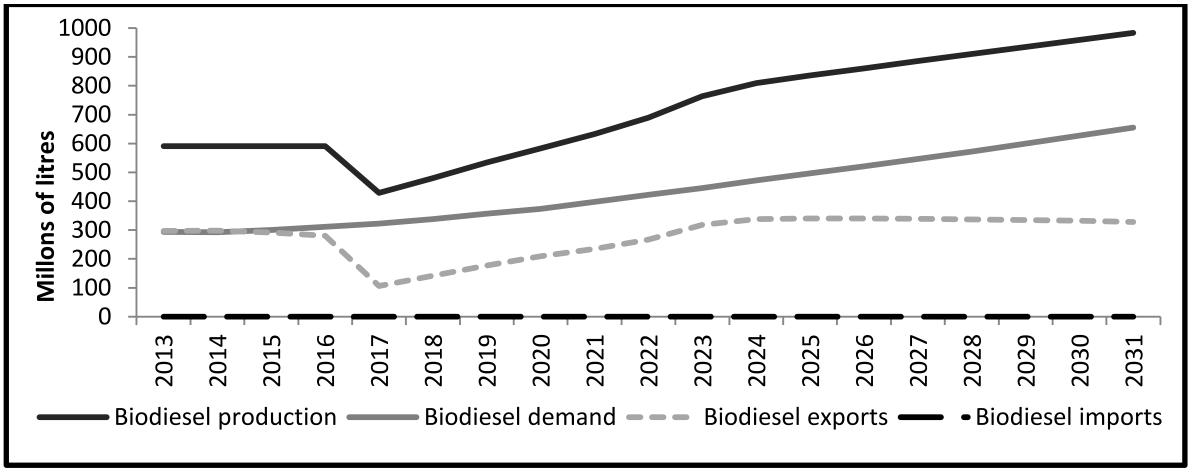

Figure 16 *Biodiesel demand, production, imports and exports, Scenario 4*.

5.3 Comparison between scenarios

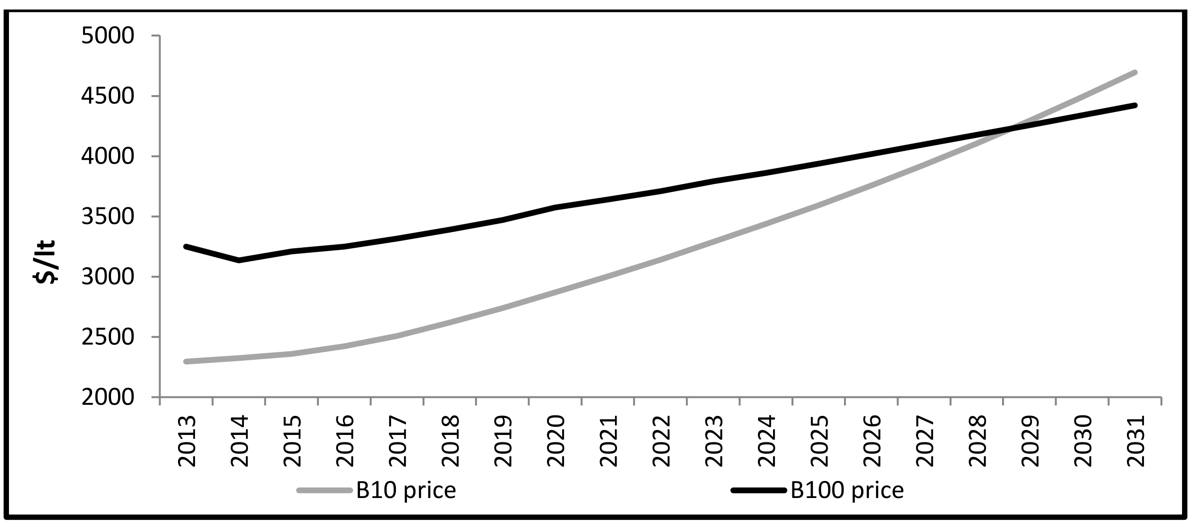

Figure 17 *Biodiesel price under different scenarios.*

Figure 17 presents simulations of biodiesel price for the four abovementioned scenarios. B10 and B100 for regulated and liberalized market respectively, it is possible to observe that the B100 prices is higher in the most part of the simulation, for the highest price and lower performance the biodiesel demand is low, because users do not want to pay more for their fuel.

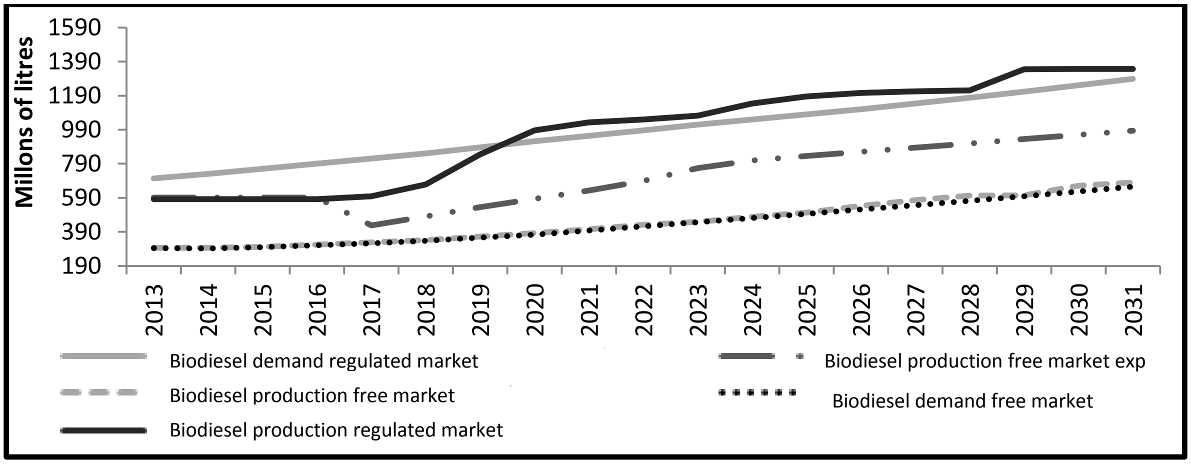

Figure 18 *Biodiesel production and demand under different scenarios.*

Figure 18 presents a production comparison between the four scenarios. The results show that a liberalized market for biodiesel has lowest production when there is no external market, and the regulated market with import/export attains the highest production, as demand is higher when the market is liberalized and exports expand rapidly.

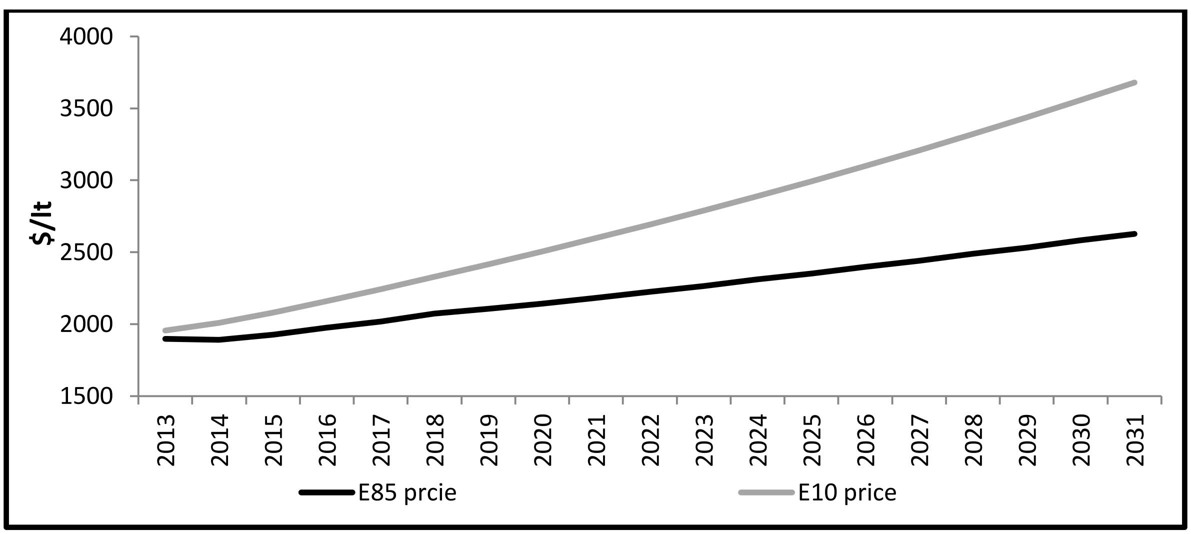

Figure 19 *Ethanol price under different scenarios.*

Figure 19 presents simulations of ethanol price for the four abovementioned scenarios. B10 and B100 for regulated and liberalized market respectively, it is possible to observe that the E85 prices is lower than E10 price, despite the prices is lower, the E85 is very low and for that reason the ethanol demand does not grow rapidly as is expected.

The comparison between scenarios suggests that is needed in both cases biodiesel and ethanol I&D investment if Colombia wants to have biofuels prices more competitive with the international prices and the fossil fuel prices.

Figure 20 presents simulations of ethanol production for the four abovementioned scenarios. Results show that under the liberalized market without an external market, ethanol reaches higher levels of production. This is due to the facts that ethanol price is lower than gasoline price and that ethanol production in a liberalized market grows to meet demand (at a higher level of ethanol concentration).

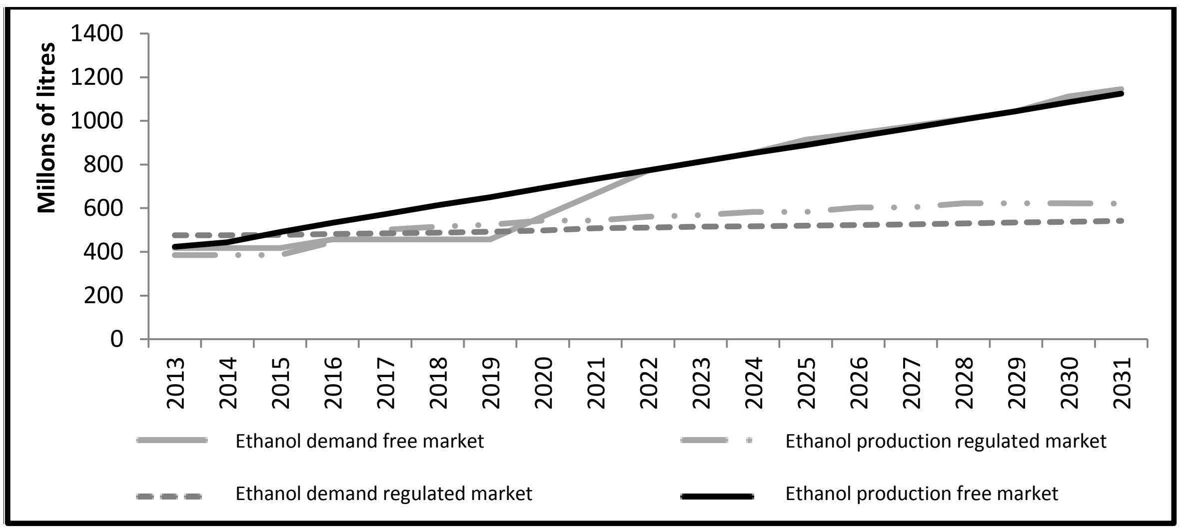

Figure 20 *Ethanol production and demand under different scenarios.*

5.3.1 CO2 Scenarios CO2 emissions

Figure 21 presents CO2 emissions comparison between free and regulated market, in this Figure is possible to observe that in the free market has lower emissions than regulated market, this is due to in the free market the biofuels consumption is higher in the liberalized market than regulated market. The biofuels has less emissions in high blends that low blends. this is another incentive to liberalize the biofuels market (Bomb, McCormick & Deurwaarder, 2006).

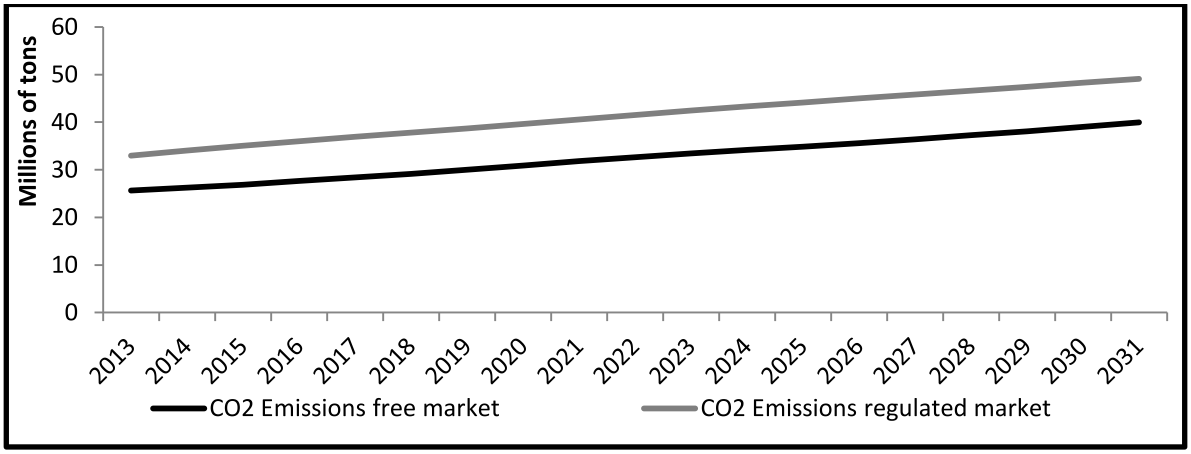

Figure 21. CO_2 emissions comparison between liberalized and regulated market.

6. CONCLUSIONS

This paper provides insights into the potential of the biofuels industry in Colombia. As indicated, the biofuels market in Colombia, under current conditions, does not offer an inviting business to producers, as regulation does not stimulate a higher biofuel mix and exports. However, this paper shows that the potential is significant and that a more vigorous industry is feasible.

Liberalization seems to be a promising option for ethanol, as demand, under a liberalized market, may largely exceed regulated demand. With respect to biodiesel, the liberalized market is not a good option yet, because the simulated demand does not exceed the regulated demand, as a result of biodiesel prices and performance.

The external market seems to be a promising option for the Colombian biodiesel market given the favourable cost differentials and Colombian potential. With respect to ethanol, the external market does not seem to be a good option in terms of price and suitable land availability.

Although sugar cane is the most efficient feedstock for first-generation ethanol in Colombia – and Colombian land is the most fertile worldwide (arable land available for sugar-cane) for ethanol production – available land is limited. The need to use some of the land for other crops has the effect of reducing Colombian ethanol competitiveness internationally. R&D might help with this problem.

From this perspective, and also from an environmental point of view, Colombia might need to invest in R&D applied to the biofuels industry in order to reduce costs, and aim at a faster rate of growth for the industry, providing opportunities matching its natural potential and the export sector.

The model helps us to understand the possible behaviours of the system and also to identify key factors that should be considered. For ethanol, the liberalization scenario shows that there are favourable conditions for a liberalized market. For biodiesel, the model suggests that under current conditions the best option is a regulated market.

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