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Review

# Can increasing gasoline supply in the United States affect ethanol production in Brazil?

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ABSTRACT

The increasing supply of non-conventional oil in the U.S. has changed the dynamics of crude oil market and the flow of oil products in the Atlantic Basin. The Gulf of Mexico (GoM) emerges as an exportation hub of oil products, contributing to a scenario in which gasoline prices tend to decline. Meanwhile, from 2010, the competitiveness of the Brazilian sugarcane ethanol has been ruptured by the country's gasoline price policy that had not followed international price parity. The political conjuncture of the U.S. incites high utilization rates of their refining system in the GoM. In this context the *profitability* of the ethanol business can be impacted in Brazil, by either the current policy of controlled domestic gasoline prices or a future scenario of declining gasoline international prices. Therefore, this study tests if this gasoline price scenario can compromise even more the competitiveness of the Brazilian ethanol. Particularly, for a scenario of falling prices, ethanol production in Brazil would be under strong pressure of gasoline supply coming from the U.S. This can impact Brazil's ethanol industry, whose development has been justified by climate change policies. In that sense, the paper also discusses the future opportunities and challenges for Brazil's ethanol industry.



**Contents**



## 1. Introduction

Different studies have investigated the linkages between gasoline and ethanol in Brazil. For instance [5], estimated the impacts that price variations of Brent oil price have had over the price of gasoline ex-refinery prices in the Brazilian market. Then, they analyzed the hypothesis of ethanol price in Brazil being influenced by the price of Brent. The price of oil generally refers to the spot price of a barrel of benchmark crude oil. A benchmark crude or marker crude is a crude oil that serves as a reference price for buyers and sellers of crude oil. Brent Crude is a mix of crude oil from 15 different oil fields in the North Sea. From 2002 onwards, Dated

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Brent predominates as the dominant layer. The market layers with a physical component always kept a dominant role in process of Brent price formation [36].

In turn, several studies indicate that sugarcane-based ethanol is a fuel of high competitiveness [26,27]. According to Crago et al. [7] Brazilian ethanol supply has a large expansion potential, due to the low utilization rates of the country's productive lands. Actually, only 5% of productive lands in Brazil are devoted to sugar cane ethanol production [4], whereas the U.S. deal with a significant agricultural limitation. This also means that the U.S. face the challenge associated to biofuel competition against food supply, since biofuel net production requires more than 30% of the corn produced in the country (Westcott, 2007). In addition to the considerable expansion potential, Brazilian ethanol has a higher productivity comparing to the U.S. one, as it is possible to obtain 45% more ethanol by land unity, in relation to the corn-based ethanol [7].

However, while Brazil's sugarcane-based ethanol has showed competitive gains in the last decade in relation to the US corn-based one [3], and the gasoline as well [38], the first three years of the new decade points to an inversion of this trend and also indicates a contraction tendency for ethanol margins in Brazil.

The constant increasing of crude oil supply in the U.S. in the last years [15] has led to a new concern about the future competitiveness of both ethanol and gasoline in the Brazilian market. The empowerment of Gulf of Mexico (GoM) as an exportation hub of oil products (Diesel and gasoline to Europe and, especially to Latin America) can affect projects associated with Brazilian ethanol supply expansion. The increasing supply of tight oil, concomitantly with the oil products demand drop in the U.S. provided the main conditions to make the GoM region a major oil products exporter.

This study aims to analyze how the evolution of tight oil production in the U.S. (on a ten-year horizon) can affect the Brazilian ethanol competitiveness, as well as its unfolding on investments of the sugarcane-based sector in Brazil.

In addition, in 2015/2016 the fall of crude oil price (Brent) below \$30 a barrel poses threats for the already challenged ethanol industry in Brazil. Ethanol has well developed manufacturing technology in comparison with long list of other renewable fuels that can be stored, such as biojet, biodiesel and green diesel found in literature. Hence ethanol can play an important role as energy storage device in smart grid technology. Notwithstanding, the importance of ethanol as green energy product should be highlighted in two directions:

1 Ethanol is the main fuel source liquid biomass that can be stored.
2 The ethanol is an agriculture product in which the living standards are interlinked.

This paper is structured as follow. Section 2 presents the driving factor behind the change in oil products flow in the Atlantic Basin. Section 3 analyses the competitive gains of Brazil's sugarcane-based ethanol along the last decade. Section 4 demonstrates how gasoline low prices can affect the utilization factor of ethanol plants in Brazil and the risk perception of the business, from the perspective of investing on new productive units. Econometric tests are also proposed to evaluate the impacts of an eventual drop of crude oil price on the gasoline exportations from the U.S. to Brazil, and on the ethanol profitability. In this section, the GoM marginal refining scheme is identified, being tested under different price levels, aiming to investigate the potential of gasoline exportation to Brazil and its competitiveness in relation to ethanol. Section 5 sums up the main conclusions of this article, highlighting the future opportunities and challenges for Brazil's ethanol industry, as the transparent pricing rule for oil products in Brazilian refineries and possible alternative uses for ethanol, as the utilization of flex vehicle technology in the electrical power production.

## 2. Why did the United States increase its exportation of oil products?

The 2008 economic crisis brought down the demand for oil in the US, notably by diesel [18]. The fall in the price of fuel in the US market (DOE, 2014) encouraged exports to Europe and to Latin America. In this context, the high degree of complexity of US refineries, particularly the PADD3,[1] provided competitive advantages over other refining plants in the world, which contributed to the growth of exports from the GoM.

In 2010, the growth in supply of tight oil in the US, concomitant with the recovery of oil demand, helped strengthen the GoM as the most important exporter in the Atlantic Basin, mainly due to regulatory constraints which prevented the oil flows out of the US (see Fig. 1).

When comparing under more details the evolution of gasoline prices[2] in the four main refining centers in the U.S., there is a detachment in the GoM price trajectory[3] regarding the observed values in other PADDs, from 2011, when USGC gasoline exportations become more relevant (see Fig. 3). This event has became more prominent with the increasing of the tight oil supply in the GoM, mainly in Bakken and Eagle Ford play, which impelled an investment wave in logistics to reverse the flows of crude oil forward the refining plant core of the region. In fact, since crude oil importation in U.S. represented a historical necessity and there was a pursuit to cater to the oil products demand, the oil pipelines net were built in order to supply the states in the middle of the country. The way to do it was to send oil from the GoM Coast to Cushing hub, Oklahoma (PADD 2).

However, the recent light crude oil supply excess due to the increasing of Bakken[4] and Eagle Ford[5] production has been contributing to WTI[6] price discounts, which results in a significant direct reduction of the refineries' production costs (Table 1).

Alike WTI, other North-American currents perceived discounts with the increase of crude oil supply in the U.S. The three crude oils produced in the U.S. are similar in quality in relation to Brent (STRUBE et al., 2012). Hence, the price discount of these currents relatively to Brent means lower cost to obtain the same oil products yield. This fact results in higher refining margins and, thus, competitive gain for the refineries in the U.S. in relation to other refining centers in the Atlantic Basin.

The general quality characteristics of oil production in U.S., based on the tight oil, are related to light oils[7] and low sulphur content. In this sense, US refineries ran into an availability of those

[1] *Petroleum Administration* Defense District (PADD) refers to the division that was made during the 2nd World War, in order to manage the crude oil resources. The refining capacity of PADD 3 (GoM) is around 9 MM bpd, the greatest among the 5 hubs in the U.S. (PADD 1, 2, 3, 4 e 5) [10,14].

[2] Regular Reformulated Retail Gasoline Prices.

[3] The oil products prices in the U.S. usually have followed the crude oil market with a short time-lag [22]. Therefore, an alignment between GoM ex-Refinery prices and Brent was always expected (see Fig. 2), being the latter the most important crude oil marker in oil products pricing in the Atlantic Basin.

[4] Field located mostly in North Dacota. It is the largest tight oil production in U.S [11].

[5] Field located in GoM, with the 2nd largest tight oil production in U.S [11].

[6] West Texas Intermediate – reference current of light oil price in U.S., priced in Cushing.

[7] According to the American Petroleum Institute rankings for light oil corresponds to API above 31.1 [39].

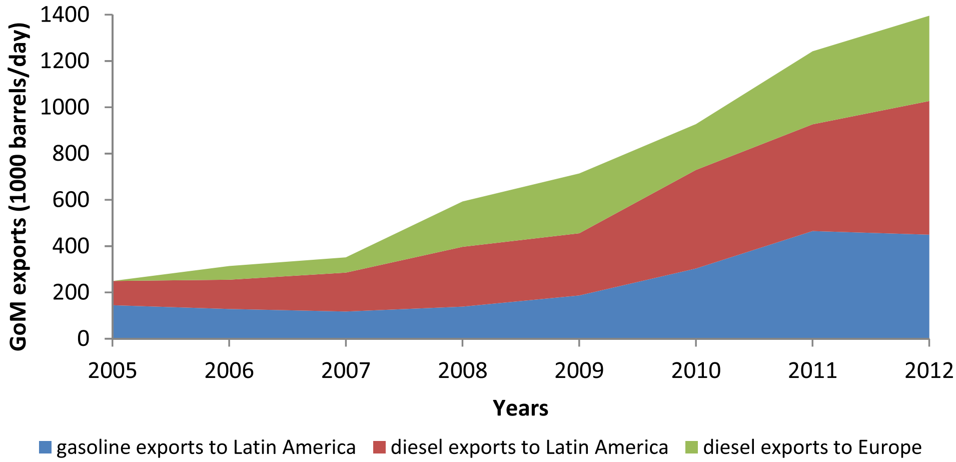


**Fig. 1.** Evolution of diesel and gasoline exportations in the U.S. to the Atlantic Basin regions. Source: [15].

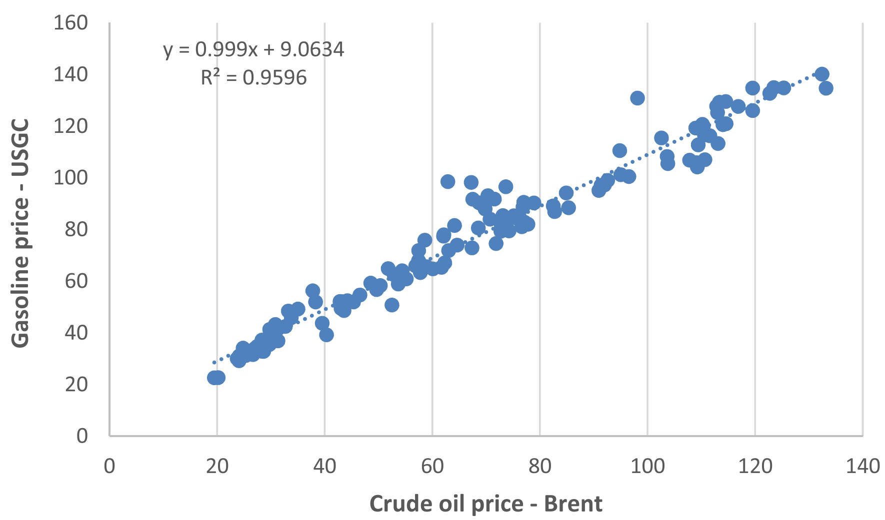


**Fig. 2.** Variation of gasoline price in the GoM (USGC.Mogas_87) in relation to Brent (Global.BRT_FOB) oil price, between 2002 and 2012 (monthly basis). Source: Platts adapted [33].

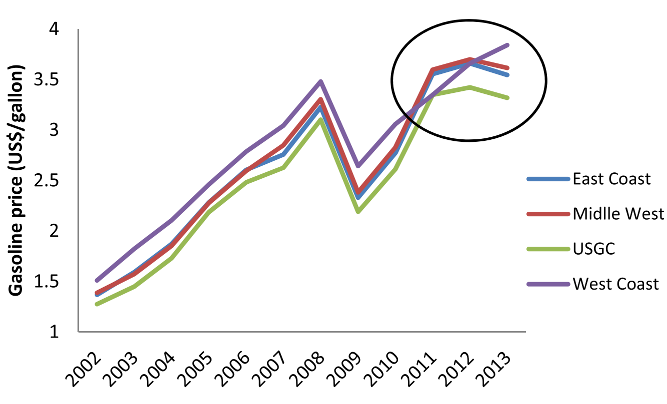


**Fig. 3.** Historical average of the gasoline price in the U.S. between 2002 and 2013 (Regular Conventional Retail Gasoline Prices). Source: [11].

crudes, whose chemical characteristics[8] were not those with which it had been planned to process.[9]

Under the US context of dropping demand for oil products and increasing light crude oil supply at price discounts, oil products from US have been diverted to fulfill increasing deficits in Latin

[8] Crude Oil Density (API), Sulphur Content (S), Total Acid Number (TAN). The American Petroleum Institute (API) is the major United States trade association for the oil and natural gas industry. One of the most important standards that the API has set is the method used for measuring the density of petroleum. This standard is called the API gravity. For currents definition and characteristics concepts see STRUBE et al., 2012. Sulphur is a naturally occurring compound in crude oil. When fuel is burned the Sulphur combines with oxygen (SOx) to create emissions that contribute to decreased air quality and have negative environmental and health effects. For currents definition and characteristics concepts see [28]. The total acid number (TAN) is a measurement of acidity. The TAN value indicates to the crude oil refinery the potential of corrosion problems. It is usually the naphthenic acids in the crude oil that cause corrosion problems. For currents definition and characteristics concepts see STRUBE et al., 2012.

[9] When refineries are conditioned to process a different type of oil that would optimize its operation, they impose discounts on the load price, in order to compensate for losses associated with the intake crude profile.

**Table 1**
Quality and price levels and differentials for Atlantic Basin crude oils.

| Oil price (US$/bbl) | Oil price benchmark | Oil price produced in the U.S. | | | Price differential | | |
|---|---|---|---|---|---|---|---|
| | Brent | LLS[a] | WTI | Bakken | LLS − Brent | WTI − Brent | Bakken − Brent |
| Average 2010 | 79.7 | 82.8 | 79.4 | 79.5 | 3.1 | −0.3 | −0.2 |
| Average 2011 | 111.2 | 112.3 | 95.1 | 99.1 | 1.1 | −16.1 | −12.1 |
| Average 2012 | 111.6 | 111.7 | 94.2 | 91.2 | 0.1 | −17.4 | −20.4 |
| Average 2013 | 108.6 | 107.1 | 97.8 | 84.4 | −1.5 | −10.8 | −24.4 |
| API[b] | 37 | 36.2 | 38.7 | 42–60 | – | – | – |
| S (%)[c] | 0.4 | 0.3 | 0.4 | 0.2 | – | – | – |
| TAN (mg KOH/g)[d] | 0.1 | 0.4 | 0.1 | 0 | – | – | – |

[a] Light Louisiana Sweet – crude oil produced in Louisiana State, in the GoM.
[b] The American Petroleum Institute (API) is the major United States trade association for the oil and natural gas industry. One of the most important standards that the API has set is the method used for measuring the density of petroleum. This standard is called the API gravity. For currents definition and characteristics concepts see STRUBE et al., 2012.
[c] Sulphur is a naturally occurring compound in crude oil. When fuel is burned the sulphur combines with oxygen (SOx) to create emissions that contribute to decreased air quality and have negative environmental and health effects. For currents definition and characteristics concepts see STRUBE et al., 2012.
[d] The total acid number (TAN) is a measurement of acidity. The TAN value indicates to the crude oil refinery the potential of corrosion problems. It is usually the naphthenic acids in the crude oil that cause corrosion problems. For currents definition and characteristics concepts see STRUBE et al., 2012.
Source: EIA-DOE, 2014.

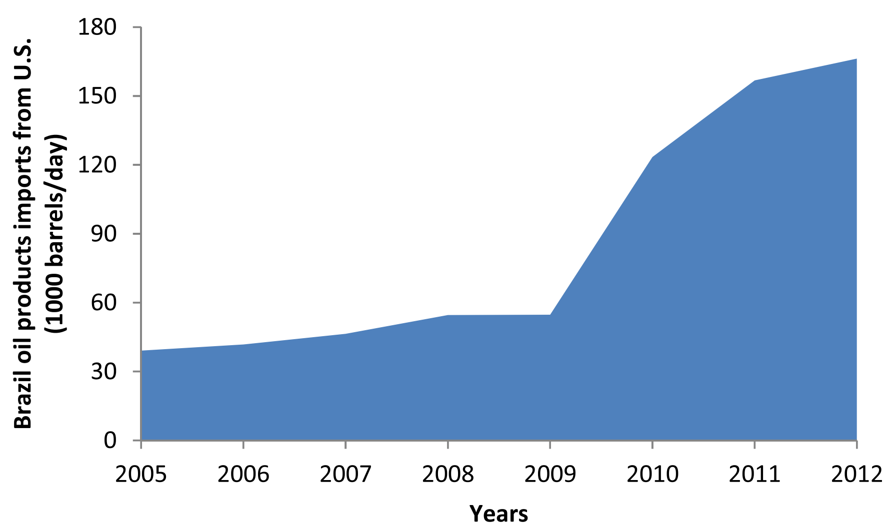


**Fig. 4.** Evolution of oil products exportation from U.S. to Brazil (Mbpd). Source: [11].

American countries, mainly in Brazil (Fig. 4).

Finally, two factors related to the U.S. regulation contributed to this upward trajectory of oil products exportation in the GoM. The first refers to the restriction of crude oil exportations in USA. At the end of 1973, crude oil was included in the list of controlled commodities in the US, under the jurisdiction defined in the regulatory framework of the Export Administration Act of 1969, in which a series of restrictions on exports of mining was established when arising of US originating resources. Two years later, another legal play was enacted, which dealt with restrictions on US oil exports under the regulatory framework defined as The Energy Policy and Conservation Act of 1975. The U.S. Legislation conditioned exportation permissions to few countries, Canada and Mexico, subject to the approval of the Energy Security Division of the Department of Commerce [30]. Therefore, the increase of crude oil supply is forcibly directed to domestic refineries, so as not to be commercialized in the foreign market. On December 18, 2015, the US Congress approved the release of oil exports, after 40 years of restrictions on foreign trade commodity. The bill was signed by President Obama on the same day [41].

The second factor refers to the sea transport in the coast of the country, The Jones Act. This Legislation [20] requires that the transport of goods between US ports is done by ship and the American crew. Thus, the shipping domestic oil gets more expensive. As a result, the light currents of the Gulf of Mexico with potential to supply the East Coast refining center (PADD 1) suffer high discounts, encouraging the import of oil from other regions such as Africa and South America. A possible relaxation of the Jones Act could reduce freight between the two US regions, thereby increasing the liquidity of light oil in other country import fronts. By making the LLS more competitive against other international chains, would likely appreciation of its relative price.

The US regulation combined with increased production of tight oil worked in favor of refining margins and export of US products for the Atlantic Basin countries, highlighting the challenges of substitute fuels such as ethanol in Brazil.

## 3. Ethanol competitiveness drop in the Brazilian market

Brazil had been the greatest world ethanol producer until 2005. From 2006, U.S. assumed the leadership and, since then, their production has been detached from the Brazilian one [35]. Even though both countries have been producers of liquid biofuel since the 1970s, two elements in the North American energy policy were

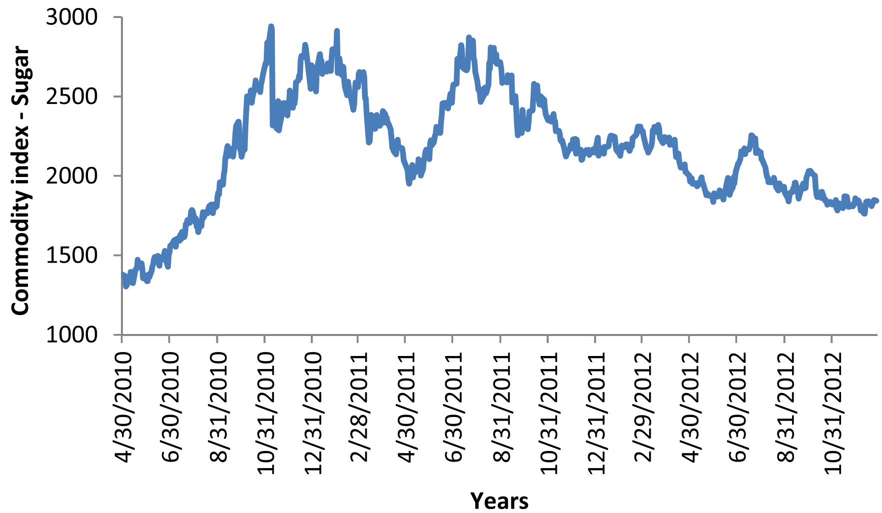


**Fig. 5.** Evolution of sugar price in the international market (Commodity Index CMCI Components Sugar #11 NYBOT USD Price Index 3 Month). Source: New York Board of Trade – NYBOT (BLOOMBERG, 2014) extracted from a Bloomberg terminal at Petrobras.

**Table 2**
Brent average price and gasoline 'A' average price in Brazil (2009–2012).

| Annual average (US$/bbl – Nominal) | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|
| Brent Price (US$/bbl) | 62 | 78 | 111 | 112 |
| Brent Price (US$/litrer) | 0.39 | 0.49 | 0.69 | 0.70 |
| Accumulated Variation % 2009 Basis | – | 26% | 79% | 81% |
| Gasoline A Price (US$/liter) | 0.77 | 0.87 | 0.93 | 0.78 |
| Accumulated variation% 2009 Basis | – | 13% | 20% | 1% |

Source: [1,2].

determinant to the U.S. supply ethanol push: The MTBE[10] banishment [7] and the biofuel edicts defined in the Renewable Fuel Standard (RFS), in accordance with The Energy Independence and Security Act[11] (EISA) de 2007.

Even though Brazil had lost the ground for the U.S. as the main global player in ethanol production, the country's sugarcane-based ethanol productivity has been much higher than the corn-based ethanol produced in U.S [43]. The costs of ethanol production in Brazil have always been significantly lower than the U.S. ones [7]. Indeed, in a sample analyzed with 2005 data, the Brazilian production costs were 39% lower than the U.S. ones [3].

Moreover, the advent of the flex fuel vehicles in Brazil, from 2003 on, has led to a greater cross-price elasticity between ethanol and gasoline (PINTO et al., 2011). According to Moura [29]; a positive variation of 1.0% in Brazil's gasoline resale price would cause an increase of 0.8% of the ethanol resale price, at the same month, *ceteris paribus*. Then, the gasoline price at the pump became the cap reference for hydrous ethanol in Brazil.

Nevertheless, between 2009 and 2012, gasoline prices in Brazil were detached from the behavior of crude oil marker prices. One of the consequences of the discretionary rule of fossil fuel pricing in Brazil was the profitability deterioration of ethanol production [5].

In addition, as a major fraction of Brazil's ethanol supply comes from mixed plants (with productive capacity for ethanol and sugar), there is a partial substitution between sugar and ethanol. During the second semester of 2010 and along the year of 2011, the elevation of *commodities sugar* prices was observed as well as the price increase lag of gasoline in Brazil in relation to international price parity [1,2]. This dynamics increased the sugar production attractiveness related to ethanol (Fig. 5).

In addition, recent studies points to a reversion of the competitiveness of Brazilian ethanol, in relation to the U.S. corn-based ethanol, from 2011 on [1,2], due to the elevation of production costs in Brazil. Actually, the Brazilian ethanol loss of competitiveness was registered in the contracts of sales from Brazil to the North American market at a price of US$ 0.79/liter in 2011. This was 12.6% greater than the corn-based ethanol, quoted at US$ 0.69/liter (EWING, 2012). In addition, the competitiveness of sugarcane-based ethanol, in Brazil's Otto fuel market, has also been contested in the last three years, in favor of gasoline.

In fact, the valorization of sugar price in the commodities foreign market, the crop failure of 2011, the lack of investment on either new units or the expansion of the existent capacity [37], and, above all, the gasoline price lag in Brazil in relation to the international price parity explain most of the ethanol market loss in Brazil, from the second semester of 2008 on.

For instance, Table 2 shows the recent evolution of Brent crude oil Dated price, in dissonance with the price behavior of Brazil's refinery base gasoline (gasoline A),[12] which resulted in an unfavorable environment to investments on the country's ethanol production.

Therefore, even not considering the costs associated to the internalization of imported oil products in Brazil, the gasoline price in the country presented an increasing lag in relation to the prices of this fuel in the USGC (GoM), where the fuel exported to Brazil is priced. – Fig. 6.

This lag compromised the recent Brazil's ethanol

[10] Methyl tert-butyl ether, also known as MTBE, is almost exclusively used as a fuel component in fuel for gasoline engines, used as an oxygenate to raise the octane number. MTBE is a chemical compound that is manufacture [17].

[11] EISA defined the expansion goals for renewables in the consumption of fuels of the country (advanced biofuels included), aiming to reach the objectives of reducing emissions of greenhouse gases [42].

[12] This is the gasoline produced in refineries which is blended with anhydrous ethanol (20–30% volume basis) to form gasoline C, or a gasohol, which is the country's resale motor gasoline [6].

**Table 3**
Econometric analysis of the regression parameters.

| Estimation statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| R multiple | | | | | | | | 0.986858657 |
| R-Square | | | | | | | | 0.973890009 |
| Adusted R-Square | | | | | | | | 0.960835013 |
| Stand Deviation | | | | | | | | 0.024900975 |
| Sample | | | | | | | | 4 |
| | Coefficientes | Stand deviation | Stat t | P-value | 95% lower | 95% highers | Lower 95.0% | Higher 95.0% |
| Intersection | 0.936183268 | 0.023943539 | 39.09962031 | 0.000653475 | 0.833162536 | 1.039204 | 0.833162536 | 1.039204 |
| Variable X 1 | −1.15459971 | 0.133679513 | −8.637072976 | 0.013141343 | −1.729776232 | −0.579423188 | −1.729776232 | −0.579423188 |

Source: Data used on utilization plants and gasoline prices in Brazil were collected from [32]. Data used on gasoline prices was collected from Energy Information Administration [11].

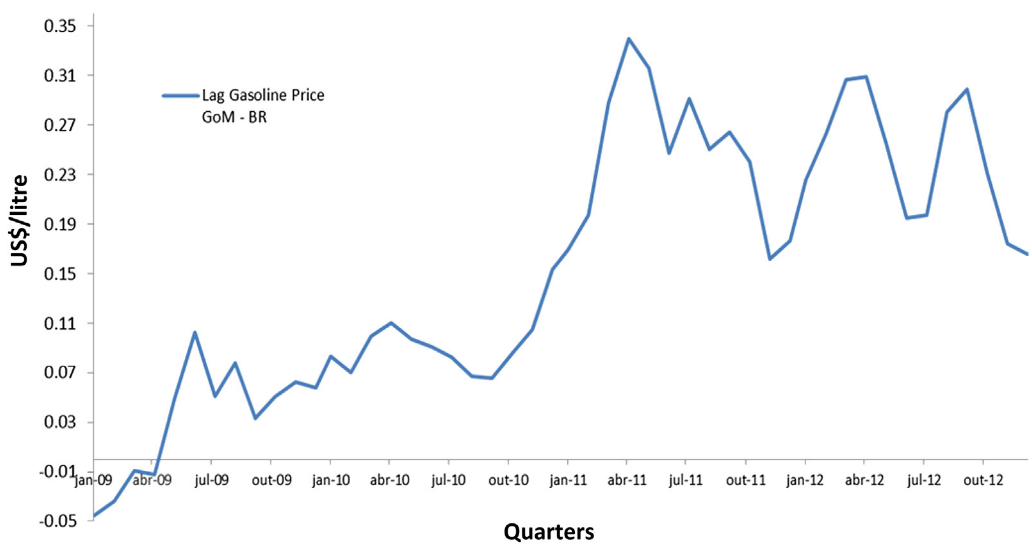


**Fig. 6.** Evolution of lag realization price of gasoline in Brazil in relation to the GoM between 2009 and 2012 (US$/liter). Source: [15] and [1,2].

competitiveness loss (Fig. 7), favoring gasoline consumption.

The increase of the gasoline price lag in Brazil in relation to the international market in 2011/2012 led to an ethanol consumption drop in favor of gasoline. Insofar as ethanol lost market, more gasoline was imported to cater the oil products demand in Brazil. Brazil's refineries also increased their gasoline production, by altering their campaign from distillates to naphtha. However, this products' flexibility is limited in Brazilian refineries, due to their hardware that was increasingly modified to optimize diesel production (Barros and Szklo, 2014).

From the sugarcane industry perspective, the substitution of ethanol for gasoline contributed to the drop in installed capacity utilization of ethanol plants [1,2], as the next sections of this paper will show.

## 4. Entailments to investment on ethanol distillaries in Brazil

### 4.1. Methodological procedure

This section aims to quantify the impact of low gasoline prices on the profitability of the Brazilian ethanol industry, in order to prove the qualitative analyses done so far. The methodological procedure is based on two stages:

1 Firstly, the magnitude of the impact of low gasoline price scenarios on the Brazilian ethanol profitability was quantified.[13] In addition, this analysis evaluated the flow of new ethanol plants entrance from 2005, aiming to demonstrate the existence of a rupture in the investments trajectory, when the lag period over gasoline price starts in Brazil.

2 Secondly, the marginal refining scheme in GoM was identified. The purpose was to check if the present context of USGC (GoM) refineries profitability is sustained for different crude oil price scenarios.[14] Therefore, this tests if the gasoline exports from GoM, at decreasing gasoline price trends in the Atlantic Basin, may keep its pressure on Brazil's ethanol supply competitiveness, even under a new pricing rule in Brazil that follows international price parity.

At this point, it is important to clarify the marginal refining

[13] An econometric analysis was undertaken, in which the endogenous variable (ethanol plants utilization rates) was estimated through the gasoline lag level in the Brazilian market (exogenous variable), from 2009 to 2012.

[14] It aimed particularly to clarify if the USGC refineries profit margins are impacted by low crude oil prices or, in other words, if USGC refineries gasoline oversupply can vanished in the following years.

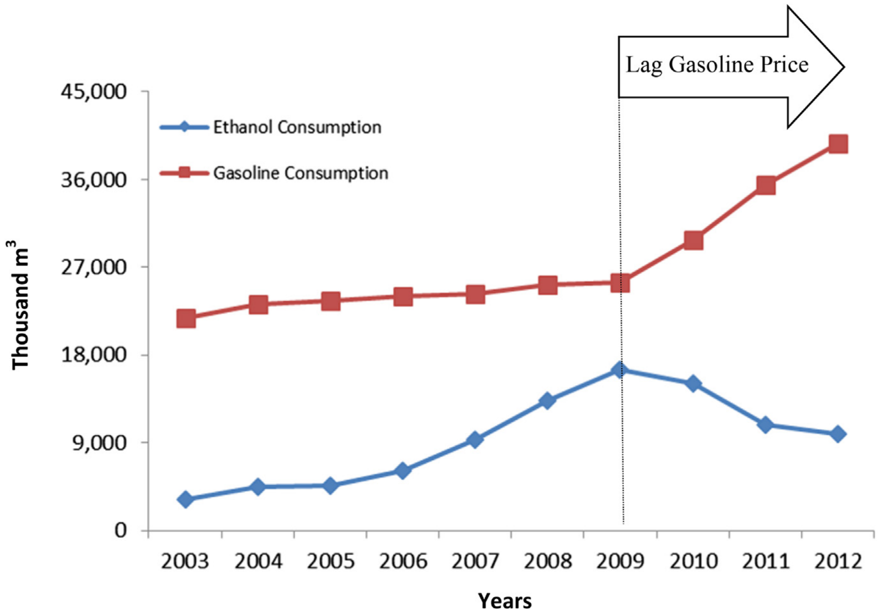


**Fig. 7.** Evolution of hydrous ethanol consumption and conventional gasoline consumption in Brazil between 2003 and 2012 (thousand $m^3$). Source: [1,2].

concept and the typical refining schemes in the USGC, which is an important part of the proposed methodology. It is possible to breakdown the USGC refining system into three typical refining schemes: 1- Hydroskimming,[15] 2 – Cracking,[16] and 3 – Coking.[17]

When a breakeven[18] points out a given refining scheme, this scheme must be classified as the marginal refining scheme. Therefore, the identification and analysis of the marginal refining scheme responses to oil price scenarios indicate if the USGC refining system can keep operating at high utilization rates under more adverse conditions. For example, when USGC marginal refining scheme is a hydroskimming one, it means that a refinery which operates with this configuration perceives a breakeven (null margin), while other more complex schemes obtain positive margins. In a stylized form, Fig. 8 represents this hypothetic situation, aiming to demonstrate that the hydroskimming refining scheme needs higher oil products prices than other configurations, in order to operate as the breakeven.

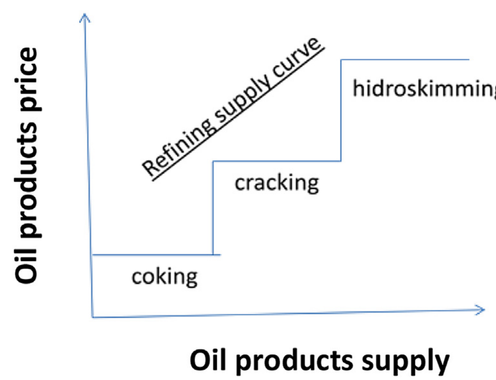


**Fig. 8.** Hypothetical Supply Curve of a refining hub of oil products. Source: [1,2].

It is important, thus, to analyze if U.S. would keep an important role in the supply of oil products in the Atlantic Basin, even under different crude oil price scenarios. The way to test how the USGC refining system would react under lower and higher crude oil prices will be based on the typical revenues of a hydroskimming refinery.[19]

Through the oil products prices and the typical products revenues for a hydroskimming configuration, it is possible to obtain the Gross Product Worth (GPW[20]). After finding the GPW of a hydroskiming refinery, a regression analysis was performed, aiming to verify to what extent Brent prices (exogenous variable) explains GPW (endogenous variable), during 2012 and 2013. This analysis tries to prove that the dated-Brent price variation is a good proxy to estimate the GPW of the marginal refinery scheme in GoM.

[15] Hidroskimming scheme consists in a unit of oil fractions separation, named atmospheric distillation (AD) and oil products specification and quality units, as, for instance, the catalytic reform unit (CR), which aims to transform low octane molecules (paraffinic and naphthenic) in high octane molecules (aromatic).Note that, even a high complexity level refinery can operate with a hydroskimming, after saturating the capacity of its conversion units.

[16] Cracking scheme presents an important complexity increase. Its basic characteristic is to convert heavy fractions, as the Vacuum Gas Oil (VGO), into light streams, as cracked gasoline and cracked gas oil (LCO), through the Fluid Catalytic Cracking (FCC) unit. Other additional units are: Vacuum Distillation (VD), and Alkylation. This refining scheme focuses on the gasoline maximization. The refinery with a hydrocracking unit (HCC), instead of a FCC, can also be considered as a cracking scheme, although its cracking process (through hydrogen and other catalysts and types of reactors) is different. Other difference refers to the output unit, as HCC can maximize either gasoline or diesel production.

[17] Coking scheme adds to all the previous units delayed cocking capacity (DC) as well. The DC utilization allows the refiner the possibility of eliminating fuel oil production, by converting vacuum residue fractions into intermediate light and medium oil products. The most complex refineries (e.g.: coking) have a higher operating cost, but they have a higher income to higher valued products. On the other hand, less complex refineries or refineries operating as simple refineries (e.g.: hydroskimming) have low operational costs and capture a larger share of their revenue based on less valued products, as the fuel oil.

[18] The competitive mechanisms in the USGC lead to the equality between the gross revenue obtained through oil products sale and refineries' production costs. The production cost includes mainly the feedstock cost (crude oil) and the refinery variable costs. This equilibrium condition can be classified as a breakeven situation.

[19] According to the Handbook of Petroleum Refining Yields [19], and on the Platts oil products prices, in 2012 and 2013.

[20] Gross Product Worth (GPW) is the weighted average value of all refined product components (less an allowance for refinery fuel and loss) of a barrel of the marker crude. GPW is computed by multiplying the spot price of each product by its percentage share in the yield of the total barrel of crude [23].

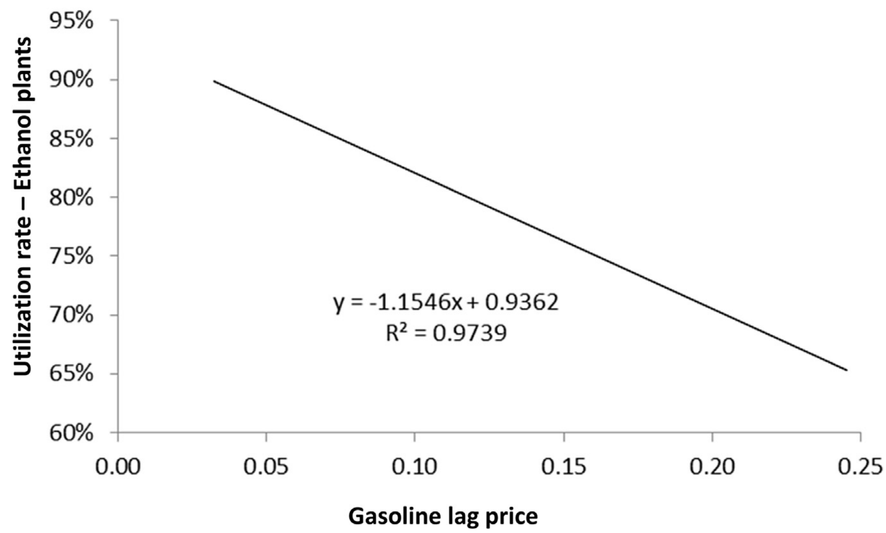


**Fig. 9.** Brazilian ethanol plants' utilization rates versus gasoline lag, between 2009 and 2012. Notes: The Diagram was elaborated using the equation estimated on Table 3. It shows the negative relation between variables – Utilization rate of ethanol plants & Gasoline lag price.


**Fig. 10.** Evolution in number of new ethanol production units in the Center-South region of Brazil. Source: [37].

However, since the hydroskimming refining in the GoM uses the Light Louisiana Sweet (LLS[21]) as the crude marker, while the GPW is estimated by the Brent price, the developed methodology to represent the marginal refining current frame was to ascertain the GPW through the Brent and the cost of the oil through the LLS. Therefore, a new regression analysis was performed in order to examine the existence of a correlation between Brent and LLS.

### *4.2. Impacts of gasoline pricing policy on ethanol distilleries utilization rate*

The logic of the ethanol industry in Brazil is equivalent to the logic of the corn-based biofuel producers in the U.S. The ethanol supply will be higher, should the crude oil price in the international market increases. That is, relatively high crude oil prices result in more attractive ethanol prices and, therefore, greater gains for producers [42].

Therefore, under a scenario of increased gasoline supply in the GoM, leading to decreasing price trends, the attractiveness of new ethanol plants is challenged. Furthermore, the risks of renewing the sugar cane crop in 2020 timeframe may become higher.

For example, recently, due to the government pricing control policy of oil products in the Brazilian market, low gasoline prices have severely affected the ethanol supply. Fig. 9 presents the estimation result of the relation between the ethanol plants utilization rates and the price lag of gasoline in Brazil, for the recent period (2009–2012). The price lag of gasoline represents the difference between the Ex-Refinery Price in Brazil in relation to the international market, which was based on Gulf Coast (GoM) Regular Conventional Gasoline Prices. The method for estimating the parameters in this linear regression model was the ordinary least squares (OLS) [9].

The data sample reflects the annual averages of VARIABLE X1 (INDEPENDENT): price lag of gasoline in Brazil in relation to GoM,

[21] Light Louisiana Sweet – crude oil produced in Louisiana State, in the GoM.

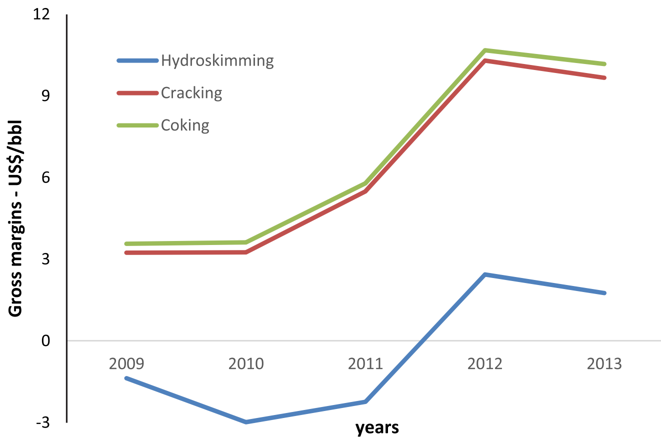


**Fig. 11.** Evolution of gross margins by refining type in the GoM from 2009 to 2013 (US$/bbl). Source: Adaptation based on Platts crude oil and oil products prices [33].

in the United States, and of DEPENDENT VARIABLE: ethanol plants utilization rates. As observed in the analysis of the linear regression [32,11], results show with 95% confidence that there is evidence[22] of the existence of a correlation between the two variables. This means that increases in the gasoline price lag (VARIABLE X1) explain in 98% the decline in the use of ethanol plants in Brazil during the period assessed. In other words, between 2009 and 2012, the increase in lag led to deterioration in the ethanol profitability business, which resulted in further decrease of its production.

Since the environment for the ethanol producer was less attractive and more risky, there was also a reduction of investments projected in recent years [1,2]. This vicious dynamics resulted in contracting the supply and deepening the loss of ethanol competitiveness compared to gasoline. In Fig. 10, the contraction in investment is shown through the inflow of new ethanol plants. After a cycle of high investments to expand production between 2005 and 2008, it is observed, from 2009, a sharp drop in new plants, portraying the need for restructuring the sector as a way to respond to the deteriorating business environment.

Assuming the continuity in the regulatory framework of the U.S., regarding the restriction on exports of crude oil, the only form to monetize the produced oil is by refining it and exporting oil products. So, high utilization rates of refineries in the GOM should be maintained, which contribute to the deterioration of the general price level of gasoline in the Atlantic Basin. As seen before, low gasoline price levels pose risks to ethanol production in Brazil. These risks are larger due to the country's gasoline pricing policy that does not follow international price parity.

### 4.3. Impacts of the refining activity on ethanol distileries profitability

Recently US has become vital on supplying oil products to all the Atlantic Basin countries, including Brazil. The exported gasoline from U.S. becomes cheaper than in other regions of the country. Larger is the price differential, more competitive the gasoline produced in the GoM becomes, regarding the ethanol market in Brazil. As the liquids supply increases inside the U.S., the greater is the pressure on the logistic infrastructure for oil flow [13].

Fig. 11 shows the evolution of the gross margin[23] from 2009 to 2013. From 2012, the hydroskimming refineries start to perceive positive margins, which corroborate the hypothesis of a utilization rate increase in the refining system as a whole. As described before, in the methodological section (4.1), Fig. 11 indicates that, from 2012, the hydroskimming scheme became the marginal refining configuration (breakeven) of the GoM refinery system.

It is also observed an increase in margins from 2011 on, while the hydroskimming refining scheme was effective recovered in 2012 and 2013. That is, even the less complex refining of the GoM, which represents less than 5% of the capacity in the region (Table 4), operated with positive margins. As such, the price level of oil products in the entire GoM refining system sustained margins above its breakeven. Such a fact led to high utilization rates, through the resumption of units that have been idle in the previous years, and promoted incremental investments in refining capacity GoM.

It remains, however, to test, according to the proposed methodology (section 4.1), the return on the hydroskimming refining scheme, under scenarios of significant changes in crude oil prices. This analysis involves the use of a typical feedstock of light oil (LLS) in the GoM, in a hydroskimming refinery. A refinery with these characteristics would obtain the following outputs[24] and outcomes [19] – see Table 5.

The equation that follows represents the value of oil LLS in the hydroskimming scheme of the GoM, measured by its netback pricing.[25]

Table 6 shows that even at prices above and below the average prices of 2012 and 2013 (US$ 111.9 and 108.8/bbl, respectively), a typical and simple GoM refinery would achieve gross margins in the range of its breakeven. For the Brent oil price level in 2015 and early 2016, in the range of US$ 50-30/bbl, the refining margins for the hydroskimming scheme becomes even better.

Hence, even assuming the discontinuity of the legal restriction regarding the U.S. crude oil exportation, it is observed that significant changes in the level of crude oil prices would not be enough to derail the profitability of the GoM hydroskimming refining, what would result in lower attractiveness for the production of ethanol.

By applying the regression equation presented in Fig. 2, when the Brent price equals $80/bbl, gasoline in the GoM is traded at $88/bbl. Interestingly, considering a location factor of gasoline (internalization costs) in the Brazilian market of approximately 12% over FOB price of gasoline in the U.S., the price of this fuel would reach around US$ 0.61 per liter, which is near the price currently practiced in Brazil for gasoline. In addition, a drop in the Brent price to around $50/bbl (the average crude oil[26] price in 2015) would keep the sign of economic infeasibility for the ethanol production expansion in Brazil, considering the price of imported gasoline from GoM close to US$ 0.42 per liter, and a domestic gasoline pricing policy aligned with the international parity.

[22] The small size of the sample limits a more robust econometric analysis. Nevertheless, results indicate a satisfactory correlation between variables.

[23] Gross margins do not consider productiveness gains and operational costs (fixed and variable), which oscillates between US$ 2 and 4/bbl. As a general rule, the higher the complexity the higher the operational costs are.

[24] The octane number measured is not an absolute number but rather a relative value based on accepted standards. The Octane Number denotes its resistance to detonation. Thc Research Octane Number (RON) simulates fuel performance under low severity engine operation. The Motor Octane Number (MON) simulates more severe operation that might be incurred at high speed or high load. In practice the octane of a gasoline is reported as the average of RON and MON or R + M/2 [21].

[25] GoM.LLS_Hydroskimming = 0.0023*GOM.C3 + 0.001*GOM.C4 + 0.0547*GOM.Mogas_87 + 0.111*GOM.Mogas_92 + 0.0881*GOM.Jet + 0.362*GOM.No2 + 0.345*GOM.LS_Resid - 1*GOM.LLS_CIF (USGC.LLS CIF represents the cost of freight to transport the LLS oil from the producing center to the refinery terminal).

[26] The Europe Brent spot price FOB in 2015 was US$ 52,32/bbl [16].

**Table 4**
Typical refining schemes in the GoM.

| Refining schemes | Hydroskimming | Cracking | Coking | Total |
|---|---|---|---|---|
| Number of Refineries (units) | 10 | 22 | 17 | 49 |
| Atmospheric Distillation Capacity (MM bpd) | 0.3 | 2.3 | 6.1 | 8.7 |

Source: Based on [31].

**Table 5**
Outputs and characteristics of products from hydroskimming, in USGC, based on LLS.

| Products outputs | Currents description | Main specification & quality |
|---|---|---|
| USGC.C3 | Propane | Specific Gravity 0.5077 |
| USGC.C4 | Butane | Specific Gravity 0.5077 |
| USGC.Mogas_87 | Regular Gasoline | Octane Number (RON[a] + MON)/2 minimum specification is 87 |
| USGC.Mogas_92 | Premium Gasoline | Octane Number (RON + MON)/2 minimum specification is 92 |
| Jet USGC.Jet | Jet Fuel | Smoke Point minimum 25.0 |
| USGC.No2 | Diesel Fuel, Heating Oil & Gas Oil | Cetane Number minimum 45 |
| USGC.LS_Resid | Low Sulfer Fuel Oil | Specific Gravity between 0.845 and 1.000 |

[a] The octane number measured is not an absolute number but rather a relative value based on accepted standards. The Octane Number denotes its resistance to detonation. Thc Research Octane Number (RON) simulates fuel performance under low severity engine operation. The Motor Octane Number (MON) simulates more severe operation that might be incurred at high speed or high load. In practice the octane of a gasoline is reported as the average of RON and MON or R + M/2.
Source: Adaptation based on the HPI Handbook data [19].

**Table 6**
Price sensitivity and impact on USGC marginal refining - Hydroskimming Proftability (US$/bbl).

| Brent (US$/bbl) | GPW $y = 0.906x + 11.65$ | LLS $y = 1.032x - 4.349$ | USGC margin (GPW − LLS) |
|---|---|---|---|
| 30 | 38.83 | 26.61 | 12,22 |
| 50 | 56.95 | 47.25 | 9,70 |
| 80 | 84.14 | 78.21 | 5.93 |
| 100 | 102.26 | 98.85 | 3.41 |
| 120 | 120.38 | 119.49 | 0.89 |

Source: [33] and [19].

## 5. Future opportunities and challenges for Brazil's ethanol industry

From 2003, ethanol consumption considerably increased in Brazil, due to the massive entry of flex vehicles and the strong consumer preference for this type of engine [25]. At the present Brazil is the world's largest producer of sugarcane and centrifugal sugar and, in 2005, the world's largest producer of ethanol. It is also a leading exporter of raw sugar and fuel ethanol. However, from 2010 on, the pricing policy of oil products in Brazil proved to be an impeller mechanism of the gasoline market in the country, reversing the trend observed over the past decade.

The ethanol consumption drop was accompanied by an increase in the demand for gasoline and imports of this oil product. The additional supply of gasoline in Brazil was provided mostly by the Gulf of Mexico region.

It was demonstrated that even the less complex refining of the GoM operated with positive margins. Even considering a lower or higher crude oil price level, the oil products in the entire GoM refining system sustained margins above its breakeven. On the other hand, a drop in the Brent price to under $80/bbl would keep the sign of economic infeasibility for the ethanol production expansion in Brazil, even under a gasoline pricing policy aligned with the international parity.

Considering this new oil price trend, it is worth studying carefully the forces that can act in opposite directions in the development of brasilian ethanol industry: the sharp fall in the Brent price on the international market concurrent to the slowdown of the Chinese economy and the removal of sanctions on Iran. In this case, the scenario of low gasoline price in the Atlantic Basin is strengthened even with the removal of the impediment export of crude from the US.

Countries across the globe committed to create a new international climate agreement by the conclusion of the U.N. Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP21) in Paris in December 2015. In preparation, countries have agreed to publicly outline what post-2020 climate actions they intend to take under a new international agreement, known as their Intended Nationally Determined Contributions (INDCs). The INDCs will largely determine whether the world achieves an ambitious 2015 agreement and is put on a path toward a low-carbon, climate-resilient future [45]. On the other hand, the current Brazilian INDC highlight the role of biomass, particularly the cane sugar products, in the care of climate change goals in Brazil. These phenomena are recent and only reinforce the need to maintain and deepen its study.

Proposals such as application of agriculture technologies might open a new path to ethanol production. Brazil can provide technology assistance to replicate the sugarcane growth in all river beds around the world and the technology for flex vehicle production can be exported from Brazil as well. Nevertheless the definition of a transparent pricing rule for oil products in Brazilian refineries, should be the agenda of discussions in International Forums of Sustainability.

Even though pricing policy in Brazil changes, the country's government should prepare the sugarcane industry to face a possible scenario of decreasing gasoline price trends in the Atlantic Basin. This should include inducing productivity gains but also promoting better light-duty vehicles and evaluating possible alternative uses for ethanol, for example flex vehicle technology may be extended to micro turbine concept for electrical power production and ethanol utilization may be extended to new areas like in urban buses with higher compression ratio engines dedicated to ethanol to replace mineral diesel and light trucks. This should be the focus of future studies.

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