An Integrated Supply Chain Perspective Evaluation for Biodiesel Production in Brazil

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Abstract

Biodiesel has been highlighted as an important source of energy worldwide, but there is still a lack of research focused on Brazil, a major biofuel producer. Within this context, this paper analyzes the biodiesel supply chain developed from oil plants in Brazil and evaluates its feasibility. To achieve this goal, visits *in loco* and interviews with 42 participants were conducted across different links in the supply chain, from the farming of oil plants (agricultural production) to the extraction of oil and the production of biodiesel, up to its distribution (logistics) and commercialization. The paper also develops an economic evaluation model that generated 204 scenarios for the complete supply chain analysis for biodiesel produced from soybean, palm, castor, and cotton. Despite the many price fluctuations observed since the beginning of this research (end of 2005), for instance the petroleum diesel and oil plant prices, the conclusion of this work is that biofuel can be a feasible fuel alternative in Brazil. However, further studies should be conducted to address pending issues like the possible competition of the biodiesel supply chain with food chains and the expansion of crop cultivation areas into the native flora in Brazil.

Keywords: supply chain, biodiesel, economic evaluation model, Brazil

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Introduction

Biodiesel is a biodegradable fuel derived from renewable sources. It can be produced from vegetable oils, animal fat, residual oils, and fats. Conventionally, biodiesel is produced through a transesterification reaction of a natural oil triglyceride (animal fat or vegetable oil) with a short chain alcohol (methanol or ethanol) in the presence of a catalyst, usually sodium or potassium hydroxide (Fernando et al., 2007). Glycerine and cakes are significant and valuable co-products in its production (Raneses et al., 1999; Rozakis and Sourie, 2005; Dorado et al., 2006).

In recent years, the literature has continuously highlighted the importance of biodiesel (see Zhang, 2003; Demirbas, 2003; Carraretto et al., 2004; Mohibbe Azam, 2005; Marchetti et al., 2007; Sarin, 2007) because of its special characteristics. Specifically, biodiesel can replace petroleum diesel in internal combustion engines without requiring major adjustments, its impact on engine performance is small, it releases fewer sulfates (almost zero emissions), and has a small net contribution of CO_2 if its whole life-cycle is considered (cultivation, production of oil and conversion to biodiesel). For these reasons, there have been several campaigns designed to introduce and promote the use of biodiesel in many countries (Carraretto et al., 2004).

Although these characteristics are promising, an economic evaluation is still necessary to demonstrate the potential of biodiesel as a complete or partial substitute for petroleum diesel. Many studies have stressed the high economic cost of producing biodiesel as compared to petroleum diesel. According to results published by the Italian National Agency for New Technologies, Energy and the Environment (ENEA) in 1999, the average cost of biodiesel in Italy is about 2–3 times higher than that of petroleum diesel before the excise tax and Value Added Tax – VAT (Carraretto et al., 2004). Bender (1999) reviewed 12 economic feasibility studies and concluded that biodiesel is not economically feasible in the US and in many European countries. The author further notes that more research is needed to determine the economic feasibility of biodiesel. More recently, the United States Department of Agriculture – USDA (2003) — and Agarwal (2007) concluded that the production of biodiesel in Europe is not profitable without governmental fiscal incentives. Hofman (2003) demonstrated that biodiesel production costs are higher than those of petroleum diesel in the United States. Other authors also corroborate these findings, among them Stevens et al. (2004), Demirbas and Balat (2006), and Bozbas (2008).

However, the above-mentioned studies are from the US and the European viewpoints only. None of them address Brazil, which is the major producer of biofuels worldwide, according to the Organization for Economic Co-operation and Development – OECD (2006). Therefore, studies that address other world regions, especially Brazil, are needed. This work fills that gap.

The main goal of this paper is to analyze the biodiesel supply chain and evaluate its feasibility for Brazil. Since the cost of biodiesel depends on variables such as the crop growth area, farming techniques, processing technologies, and intermediate processes used to obtain biodiesel (Carraretto et al., 2004), this research develops an integrated analysis of the biodiesel chain in Brazil, from the farming of oil plants to the distribution and commercialization of biofuels. In doing so, the paper addresses the processes of oil extraction, biodiesel production, and related logistics.

This feasibility analysis was difficult to conduct due to the price fluctuation of the many variables included in the evaluation model. For instance, since the end of 2005 (starting point of this research) the price for soybean oil has varied almost 50%, nearly the same percentage of change for the auction prices for biodiesel in Brazil. The other vegetable oils, plants, and petroleum diesel have also experienced significant price fluctuations in the last 3 years. These price fluctuations were a challenge addressed in this research and additional effort was required to conduct a detailed evaluation in this dynamic market. However, the study is not without limitations. The restricted focus on an economic analysis limits the extent to which the findings can be generalized across a wider range of parameters that address other relevant areas. Notwithstanding, this is a first and necessary step to a more general analysis of the Biodiesel Supply Chain. The exploratory nature of the evaluation justifies the approach. Further studies need to address pending issues like the possible competition of the biodiesel supply chain with food chains and the expansion of crops cultivation areas into the native flora in Brazil.

The next sections of this paper presents a literature review of biodiesel, the research methods used in the study, results and discussion, and the conclusions.

Literature Review

Renewable energies are considered important resources in many countries around the world. However, on a global scale, less than 15% of the primary energy supply comes from renewables (Lund, 2007). Renewable energy technologies range from biomass, hydro energy, and geothermal energy to solar and wind power. Countries have chosen different approaches to the development and use of these many forms of renewable energy. This choice is influenced by natural conditions (types of resources, crops, and climate), the structure of the energy system, and the specific political priorities established for the agricultural and forestry sectors by each country (Faaij, 2006).

Biomass is the most common form of renewable energy (McKendry, 2002), and among renewable forms of energy, is the major source of primary energy supply. Biomass accounts for about 10% of the world's energy consumption (Anselmo Filho and Badr, 2004) and can be converted to other usable forms of energy such as biofuels. Biofuels can be produced from crops or waste material accumulated during agricultural production and processing (Henke et al., 2005) and can potentially replace fossil fuels. Brazil, the United States, and Europe have the largest programs to promote biofuels worldwide (Demirbas and Balat, 2006). The main types of biofuels include alcohols, biogas, and biodiesel. The paper next presents an overview of the global status of biofuel production and the specific status of its production in Brazil.

Global status of biodiesel production

The acceptance and market share of biodiesel have been growing in many developed countries, for instance, Europe and the United States (Demirbas and Balat, 2006), as well as in emerging countries like Brazil. It can be used in its pure form or blended with petroleum diesel fuel (petrodiesel) in different proportions. ''Neat'' biodiesel or B-100 refers to 100 % biodiesel. B-2 refers to a blend with 2% biodiesel and B-5 refers to a blend with 5% biodiesel (Wassell Jr. and Dittmer, 2006). The use of biodiesel in the automotive industry has continuously increased in recent years, especially in France, where blends with petroleum diesel are widely used, and Germany, where many engines are fuelled with pure biodiesel (Carraretto et al., 2004).

In 2004, the International Energy Agency reported that the world biodiesel production capacity rose approximately 300% from 1998 to 2003 (Demirbas and Balat, 2006). Steenblik (2006) estimated a growth of more than 300% from 2003 to 2008. Most biodiesel production is in Europe, where regional production has been largely boosted in response to positive signals from the European Commission (EC), such as tax deductions and exemptions (Faaij, 2006; Frondel and Peters, 2007). At the moment, biodiesel is by far the most representative and important biofuel produced in the European Union (Demirbas and Balat, 2006; Bozbas, 2008). According to the European Biodiesel Board (EBB, 2007), in 2006 there were approximately 120 plants in the EU producing up to 6,100,000 tons of biodiesel annually, which is three times more than in 2003. Germany is the largest European biodiesel producer, accounting for nearly 40% of the EU (European Union) capacity. Italy and France also have a significant production capacity. Biodiesel production has also increased rapidly in the US and in Brazil (Wright, 2006).

Brazilian technical biodiesel development program – probiodiesel

Costa (2004), Anselmo Filho and Badr (2004), and Mathews (2007) and Pousa et al. (2007) have noted the vast potential of biofuels in Brazil. Although they are largely renewable and environmentally friendly, they need to be evaluated on a case-by-case basis for their advantages, disadvantages, and specific applications (Agarwal, 2007).

In the second half of the 1970s, as a result of soaring world oil prices, the Brazilian government decided to encourage the use of national sources of energy for transportation. Biofuels were among them. Initially, two possible oil substitutes were studied and analyzed in Brazil, one to replace gasoline – ethanol – and the other to replace petroleum diesel – vegetable oils (Costa, 2004). While a well-developed program to make alcohol a substitute for gasoline took place in the country, the use of vegetable oils as fuels was left for future development.

The Brazilian Alcohol Program (PROALCOOL) was established in 1975 as an answer to the first "oil crisis" and a solution to the fluctuating sugar prices in the international market (Wheals et al., 1999). In the early stages of this program, the use of ethanol became available for everyday consumers because of the price-incentive policy developed for the fuel sector in Brazil. As the efficiency and cost competitiveness of ethanol production evolved over time, these incentives were no longer needed and ceased to exist. There are currently no subsidies for ethanol production.

The well-planned Brazilian Alcohol Program paved the way to a stable ethanol production market, with low investment risks. This led to the production of bioethanol at low-cost and surplus capacity available for export. In addition, when compared to other countries like the US, Brazil has a significant cost advantage in the production of ethanol for two main reasons: its large-scale, commercial production of ethanol and the favorable existing conditions for the cultivation of sugarcane (Ryan, 2006). In the first half of 2008, ethanol accounted for 17.5% of motor vehicle fuel usage in Brazil (ANP, 2008).

After developing and consolidating ethanol fuel technology in the last thirty years, Brazil now faces a new strategic technology challenge: the development of biodiesel from biomass. This type of biofuel is produced from vegetable oils and can be made from new or used vegetable oils and animal fats, which are non-toxic, biodegradable, renewable resources (Demirbas and Balat, 2006). The emerging geopolitical crisis over the control of oil reserves and global efforts to reduce greenhouse gas emissions, based on the Kyoto Protocol, constitute the motivations to further push biodiesel research in Brazil (Aliske, 2007).

The Brazilian Biodiesel Program was launched in 2004. In January 13, 2005, the Brazilian government enacted the federal law number 11,097 (MCT, 2005) regulating the addition of biodiesel to petroleum diesel in the Brazilian Energy Matrix. According to this law, the addition of 2% biodiesel to petroleum diesel has been compulsory since the beginning of 2008 (B-2 blend) and shall increase to 5% (B-5 blend) in 2013 (MCT, 2005). This law should open a market niche for approximately 1 million cubic meters of biodiesel per year after 2008 and 2.4 million cubic meters after 2013 (Gomide, 2006). Recently, the addition of 3% biodiesel to the diesel consumed in Brazil (B-3 blend) has been mandated by the Brazilian Federal Government, starting in July of 2008.

To structure the biodiesel market in Brazil, the Brazilian Government created public auctions that ensure minimum prices and guarantee sales by producers of biodiesel. From 2006 to 2008, eleven auctions took place. They negotiated a total volume of 1.69 million cubic meters of biodiesel, at an average price of US$ 1.04 to US$ 1.11 per liter until 2007 and from US$ 1.56 to US$ 1.61 per liter in 2008, according to the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP, 2008). These values refer to FOB prices (Free on Board). They do not include transportation costs or regional taxes, which vary from 17 to 18%. However, they do include federal taxes applied to the biodiesel sector.

Until now, 58 Brazilian companies have been authorized by the ANP to produce biodiesel, yielding an annual capacity of almost 3 million cubic meters of biodiesel (ANP, 2008).

The taxation system in the biodiesel sector foresees federal tax rates that differ from those in the petroleum diesel sector. Consequently, tax deductions do apply to biodiesel produced from oil plants cultivated by family farming and to the biodiesel produced from castor and palm oils in North and Northeast Brazil.

Because of Brazil's agricultural industry and potential, biodiesel production in the country has been developed from oil plants. Several oil plants have been studied for this purpose, such as the jathropa and the sunflower. However, industrial ventures have concentrated major efforts on four oil plants: soybean, castor, palm, and cotton. They are the focus of this study. Even though there are many technical constrains for the use of biodiesel generated from castor oil for motor vehicle fuel (ANP, 2008), an economic analysis for this oil plant was conducted since it was considered the symbol of biodiesel production in Brazil for many years.

Brazil is the second largest world producer of soybean. The 2006/07 crop yielded 58.4 million tons of soybean, planted across 20.7 million hectares. These grains can produce more than 29 million cubic meters of biodiesel. The production of soybean has grown 30 times during the last three decades.

The production of other oil plants can also significantly increase to meet the demand for biodiesel-oriented oil production. According to Campos (2003), a farmable acreage of 70 million hectares has the conditions to improve the growing prospects of palm.

In the case of cotton, Brazil produced 1.27 millions of tons in the 2006/2007 cotton crop. This production placed the country among the world's largest cotton producers. Brazil currently accounts for 5.1% of the world's total cotton crop (CONAB, 2007).

Brazil ranks fifth among the producers of fresh fruit castor bunches. However, this production has historically been much larger: until the end of the 70's, Brazil was the major producer of castor, with crops that yielded up to 600 thousand tons/year. This output represented more than 50% of the total world production (FAOSTAT, 2007).

The above section addressed the potential for biodiesel production in Brazil. The research methods used to study its technical and economic feasibility are now presented.

Research Methods

The continental territorial extension of Brazil necessitates a detailed evaluation of the biodiesel chain for specific regions of the country. Therefore, an in-depth case study of one of the most promising region of Brazil, the State of Bahia (Northeast Brazil) was performed. In doing so, the agricultural potential and the existing logistic resources of Bahia were addressed. The State of Bahia is a leader in the production of biomass. It occupies an area greater than France, ranks first in the production of castor and second in the production of cotton and palm among the Brazilian states. Furthermore, Bahia is the new agricultural frontier for soybean. In addition to its agricultural potential, the state of Bahia's biodiesel supply chain has also been structured by three biofuel production plants.

The methodology used to analyze the biodiesel supply chain was drawn from Yin (2005), who proposed a method of data triangulation based on three dimensions: interviewing, observation, and document analysis. This triangulation allowed us to converge data from our sources as well as from the direct contraposition of primary and secondary research, as described below.

Primary research consisted of fact-finding field trips to companies that are part of the biodiesel productive chain in Bahia (at least two major companies of each link in the production chain were visited) and to governmental offices involved with the field. It also consisted of a structured questionnaire administered to entrepreneurs (engineers, production managements, area coordinators, and directors), researchers, and governmental representatives who work in the field, based on their role in the biodiesel production chain. Overall, 42 participants were interviewed across links in the production chain. They were distributed as follows:

- Ten who work in agricultural production: three from the soybean chain, three from the palm chain, two from the castor chain, and two from the cotton chain. Some of the major agribusiness enterprises from the region were involved;
- Thirteen in oil extraction: four from the soybean chain, three from the palm chain, three from the castor chain, and three from the cotton chain. The biggest oil producers from the region were involved;
- Twelve in biodiesel production. Engineers and managers of companies that were implementing biodiesel plants in Bahia were interviewed;
- Seven in logistics and commercialization. This included major companies dealing with petroleum diesel and biodiesel.

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Secondary research consisted of a survey of academic and technical literature and of information from the sector, available in annual books and other publications from Brazilian and international agencies/offices. Table 1 outlines details of the secondary research data.

Inputs to the Economic Evaluation Model

The feedstock (seeds, fertilizers, alcohol, catalysts, crops and vegetable oil) and co-products prices (cakes, brans, shells and glycerins, among others) are inputs to the problem. They were analyzed by applying statistics and regression analysis to the historical price series used in the Brazilian and international markets.

The analysis also takes into consideration other information relevant for biodiesel production: idle capacity and the degree of oil extraction in the biodiesel production plants; route of production (methylic or ethylic); technical coefficients in the production process; investment in assets (among them equipment and land); variable production and transformation costs; capital cost; logistic costs (among them transport and storage); commercialization margins; tax rates; the origin of the oil plant since the type

Table 1 – Secondary research data.

Offices	References
Brazilian offices	
Brazilian Ministry of Science and Technology – MCT	MCT (2005)
National Agency for Petroleum, Natural Gas and Biofuels – ANP	ANP (2008)
Brazilian Institute of Geography and Statistics – IBGE	IBGE (2007)
Company of Energy Research – EPE	EPE (2007)
Brazilian Company of Agricultural and Livestock Research – EMPRABA	EMBRAPA (2006)
Superintendency of the Manaus Free-Trade Zone – SUFRAMA	SUFRAMA and FGV (2003)
Getúlio Vargas Foundation – FGV	
National Supply Company – CONAB	CONAB (2007) AQUINO (2006) MACÊDO (2006) RUAS (2006)
Brazilian Association for the Plant Oil Industry – ABIOVE	ABIOVE (2007)
International Trade Secretary – SECEX	SECEX (2007)
Company for the Agricultural Development of the State of Bahia – EBDA	CARVALHO (2005)
Secretaria de Agricultura, Irrigação e Reforma Agrária da Bahia – SEAGRI-BA	SEAGRI – BA (2005)
Brazilian National Oil Company – PETROBRAS	PETROBRAS (2007)
International offices	
Organization for Economic Co-operation and Development – OECD	OECD (2006) STEENBLIK (2006)
Food and Agriculture Organization of the United Nations – FAOSTAT	FAOSTAT (2007)
Union for the Promotion of Oil and Protein Plants – UFOP	UFOP (2007)
Economic Research Service – ERS	ERS (2007)
Energy Management Institute – EMI	EMI (2007)

of farming system (family farming or intensive agriculture) determines if tax deductions apply. The values for every input to the problem were obtained by primary and secondary research. Primary data were gathered through 42 interviews with experts in the area and were compared and validated with the various secondary data (see Table 1).

Economic evaluation model

An economic evaluation model was developed to evaluate the integrated chain of biodiesel production technically and economically. This model evaluates the economic feasibility of biodiesel production based on the following economic indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Return over Investment (ROI), Average Net Profit and Profit Margins. The model encompasses every link of the production chain (agricultural production, extraction of vegetable oil, biodiesel production, distribution and commercialization), and allows the combination of every technical and economic variable mentioned earlier.

There are three possible situations for each link in the chain: worst, probable, and best. They are represented by different cash flows and were defined according to productivity and cost of production. That is, the worst situation bears the lowest productivity and highest cost, while the best one bears the highest productivity and lowest cost. The model allows an estimation of the cost of biodiesel as well as the combination of these different situations for links in the chain.

Several scenarios were generated for the complete biodiesel production chain, from the farming of oil plants to the extraction of oil and the production of biodiesel, up to its distribution. Table 2 shows the number of scenarios created for each of the oil plants used in this study.

Table 2 – Number of scenarios.

	Soybean	Oil	Castor	Cotton	Total
Number of scenarios	78	78	24	24	204

The number of scenarios was calculated based on the structure of the chain and the number of possible outcomes for each link of the chain. The chain can be structured as a totally integrated chain – where the entrepreneur has all the assets of the chain (agricultural production, extraction of vegetable oil, and biodiesel production links), a partially integrated chain (the entrepreneur buys the crops from the farmer to extract the vegetable oil and produce biodiesel), and a non-integrated chain (the entrepreneur buys vegetable oil to produce biodiesel).

The number of scenarios is calculated using the following Equation 1:

$$\text{Number of scenarios} = (\text{possible outcomes})^{n}, \quad (1)$$

where:

- number of possible outcomes = 3 (worst, probable, and best); and
- n = number of links in the chain (n = 3 for the totally integrated chain, = 2 for the partially integrated chain, = 1 for the non-integrated chain).

For soybean and palm, scenarios were generated for the three possible structures of the chain (total, partial, and non-integrated chains), so there were 39 total scenarios ($3^3 + 3^2 + 3$).

In the case of castor and cotton, scenarios were not generated for the totally integrated chain due to the fact that the chain of castor beans is based completely on small farmers, without the participation of large-scale agribusinesses, which results in a low productivity. For cotton, agricultural producers aim at the production of cotton fiber, which is the main product. Cotton seeds are co-products with lower added value. As a result, only 12 scenarios ($3^2 + 3$) were generated for the partially and non-integrated chains of castor and cotton.

Since the research was conducted for two different production routes (methylic or ethylic), these scenarios were duplicated, totaling 78 scenarios for soybean and palm and 24 scenarios for cotton and castor.

Results and Discussion

Figure 1 summarizes the results of 204 scenarios on the cost of biodiesel production in US$ per liter. For every oil plant (soybean, palm, castor, and cotton), the minimum (Min.), average (Avg.), and maximum (Max.) production costs after taxes are presented for the scenarios created in this study. Figure 1 also illustrates the average petroleum

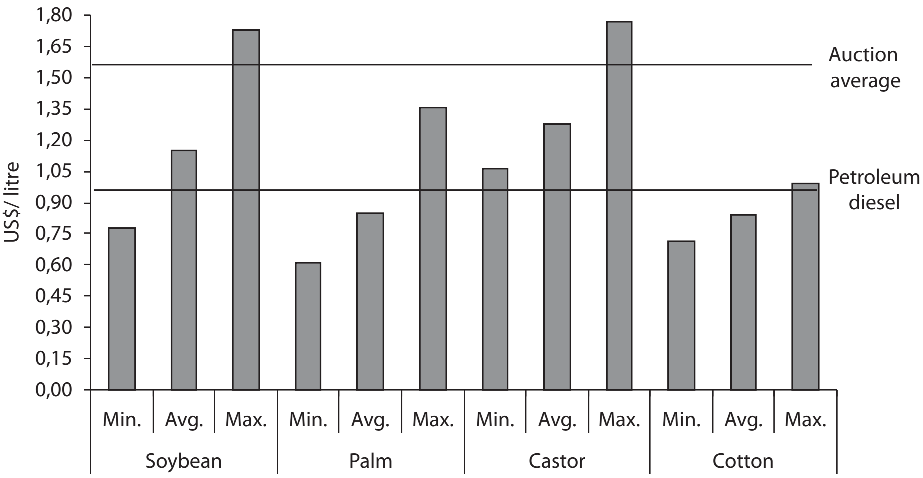

Figure 1 – Summary of the results for cost of biodiesel production.

diesel price per liter (US$ 0.97) after taxes in the State of Bahia for the first half of 2008, and the average bidding price in the last four biodiesel auctions conducted in Brazil (US$ 1.59). These last auctions occurred in 2008 and the price varied from US$ 1.56 to US$ 1.61, and shows a stabilization of the price around US$ 1.59. This number indicates a change in the average price compared to the other 7 auctions that occurred in 2005, 2006, and 2007, in which prices varied from US$ 1.04 to US$ 1.14.

The costs of palm and cotton biodiesel production obtained for all the analyzed scenarios were lower than the average price for the biodiesel auctions. The average costs for the biodiesel produced from these two oil plants were also lower than for petroleum diesel, a result that was not obtained in other studies covering the US and Europe (Carraretto et al., 2004; Bender, 1999; Agarwal, 2007; Hofman, 2003; Stevens et al., 2004; Demirbas and Balat, 2006; and Bozbas, 2008). This fact highlights the economic feasibility of biodiesel production from these two oil plants. The average cost of castor biodiesel (US$ 1.28) and the soybean biodiesel (US$ 1.15) were higher than the price of petroleum diesel, but were lower than the average auction price. In order to get a broader understanding of biodiesel production from these results, Table 3 outlines the number of scenarios for which the cost of biodiesel production is less than both the average bidding price in auctions and the petroleum diesel price.

Table 3 – Number of feasible scenarios in Brazil's market.

	Auction avearge	**Petroleum diesel**	**Total**
Soybean	70 (90%)	28 (36%)	78
Palm	78 (100%)	68 (87%)	78
Castor	18 (75%)	0 (0%)	24
Cotton	24 (100%)	22 (92%)	24
Total	190 (93%)	93 (75%)	204

Twenty eight out of 78 soybean scenarios (36%), 68 out of 78 palm scenarios (87%), and 22 out of 24 cotton scenarios (92%) showed costs less than those of petroleum diesel. In addition, biodiesel produced from these three oil plants is economically feasible when compared to Brazilian market prices in biodiesel auctions. This makes biodiesel a feasible alternative fuel in Brazil, even considering the fact that there was significant growth in the supply chain costs in 2008. Table 4 provides a comparison between the costs obtained in the research for the biodiesel production in 2007 with those obtained in 2008. Costs rose significantly for all oils plants, especially for the

Table 4 – Biodiesel cost growth between 2007 and 2008.

Soybean			**Palm**			**Castor**			**Cotton**		
Min.	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**
+23,0%	+35,6%	+45,5%	+11,7%	+14,8%	+27,6%	+34,0%	+26,5%	+31,0%	+13,1%	+9,6%	+11,5%

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soybean biodiesel supply chain, which shows how dynamic this market is in Brazil. This price elevation was followed by the auction prices of biodiesel in Brazil (35% increase in the same period).

Based on the 2008 results, palm biodiesel rendered a better competitive cost than the soybean biodiesel and has high potential farmable land. However, because of its long maturation cycle (5 years), it ranks as a medium range alternative for biodiesel production. The palm and soybean options are aligned with global numbers, since their oils are notable not only for their competitive prices, but also for their world large supply (39 and 36 million metric tons respectively – ERS, 2007). Both oil plants account for 60% of the global vegetable oil production. Therefore, as functions of price and raw-material supply, they are potential raw materials for biodiesel production *par excellence,* worldwide.

Furthermore, although cotton yielded the lowest biodiesel production costs in Brazil, its use will depend on the demand for fiber by the textile sector, since cotton seeds, the input for biodiesel production, are only a co-product of the process.

The production of castor oil biodiesel yielded the highest production costs among the analyzed oil plants. If the high costs were associated with the need to increase the amount of farmed land and productivity (there is a need for improved farming conditions and genetic advances toward increased productivity) and the need to surpass the technical aspects that compromise the use of the castor biodiesel for a motor-vehicle fuel, it can be concluded that the feasibility of castor oil biodiesel is at the moment restricted. This conclusion is also supported by the high castor oil prices currently in effect (castor oil biodiesel has novel applications, for instance, the cosmetic and automotive industries). However, the castor oil plant plays a relevant social role. Besides generating jobs and income in needy communities across Brazil, it has a minor impact to the environment, since farming normally occurs in degraded lands. Moreover, castor does not compete with the food chain, but even promotes it, given that it can be farmed with vegetables such as beans and cotton in an integrated, mixed farming system. castor, then, is an interesting option to generate biodiesel once the above-mentioned constraints are solved; this will likely not happen in the short term.

Agricultural acreage

According to the Brazilian legislation (law number 11,097 – MCT, 2005), there will be a firm market for about 2.4 million cubic meters after 2013. Table 4 shows the necessary acreage for the farming of the oil plants under analysis, if full demand for B-5 blends is met by one single oil plant.

If the current farmed acreage in Brazil is considered, the supply of soybean is the highest among the four oil plants. The farmed acreage is more than 20 million hectares, which is sufficient to meet the current Brazilian demand for the B-5 blend four times over. Therefore, soybean is an excellent option for the production of biodiesel in the short term. Its production costs are low and a large acreage is available for its cultivation.

The results also highlight the small acreage necessary to crop oil palms when compared to the other oil plants. This is because the productivity of oil palms is much higher than that of the other oil plants under analysis. To expand the cultivated acreage of oil palm, Brazil has 70 million hectares in good growing conditions; they are mainly located in the Amazon Region and east of the State of Bahia. Despite of its lower production costs and the large acreage available for farming, oil palm is as an option for the medium term, given that it takes 5 years to bear fruits.

Finally, the feasibility of castor oil biodiesel is very limited considering its high production costs and its farmed acreage in Brazil. The cultivated area needs to increase more than 50 times to meet the domestic demand for the B-5 blend, as Table 5 illustrates.

Table 5 – Current and necessary acreage to meet the biodiesel demand.

Oil Plant	Current		Necessary
	Bahia	Brazil	B-5
Soybean	0.85 million hectares	20.69 million hectares	4.70 million hectares
Oil Palm	0.04 million hectares	0.09 million hectares	0.50 million hectares
Castor bean	0.12 million hectares	0.15 million hectares	7.70 million hectares
Cotton	0.29 million hectares	1.10 million hectares	6.28 million hectares

Conclusion

This study analyzes the economic feasibility of the biodiesel supply chain based on the use of four oil plants (soybean, palm, castor, and cotton), from plant cultivation to the distribution of the biofuel. Oil extraction and biodiesel production processes that lie in-between these two phases are also considered.

According to the results, it can be concluded that biodiesel produced from oil plants are a feasible alternative for fuels in Brazil. Among the 204 scenarios generated by the economic evaluation model developed in this work, 75% have a lower price than petroleum diesel and 93% have a lower price than the average value bid in the biodiesel auctions held in Brazil in 2008. The costs identified to produce biodiesel from the analyzed oil plants were significantly variable, and with the exception of the castor plant, all reached satisfactory results for biofuel generation. If the Brazilian acreage available for the farming of these four oil plants, their importance for the Brazilian economy, and their production cost are considered, soybean is the best option for biodiesel production in 2007 for the short term with an average production cost of US$ 0.74/liter. With the price fluctuation of the many variables involved, the production cost of biodiesel from soybean rose to US$ 1.15/liter in 2008 (35.6% higher); this gives

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an average price higher than petroleum diesel, but is still feasible as it is significantly lower than the bidding prices in all auctions in Brazil during 2008. This price increase was also observed in biodiesel produced with all the other oil plants in the same period and is included in the research (10% for cotton, 15% for palm, and 26% for castor – on average), which reveals the extremely dynamic market for this supply chain in Brazil.

Although Probiodiesel was launched in 2004 and is still very new compared to Proalcool (which is more than 30 years old), the findings from this study indicate the production of soybean and palm biodiesel are feasible in terms of costs and capacities along the supply chain (i.e., enough land and productivity output). Results should improve over time as demonstrated by Brazil's experience with ethanol: economies of scale and technological advances can increase the competitiveness of renewable energies.

Still, further studies are needed to address some pending issues to complement these results. For instance, the possible competition of the biodiesel production chain with the food chain; the case of soybean, which is a major source of animal protein; the fact that the biodiesel chain can create ecological problems in some instances, given that it may replace the native flora of Brazilian regions like large land expansions for the cultivation of oil palm in the Amazon without a sustainable policy. Since these issues are out of the scope of this paper, and it is recommended that they be addressed in future research.

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