Economic Feasibility of Second Generation Ethanol with and without indirect Greenhouse Gas Reduction Benefits

A simulation for Brazil

Report for the Dutch Ministry of Agriculture, Nature and Food Quality (LNV)

Authors: Fernando Lagares Tavora, Robert Bakker, Mladjan Stojanovic, Wolter Elbersen

LNV contactperson: Bart Vrolijk (LNV, Brasilia)

Report #

Colofon

Titel	Titel
Auteur(s)	Auteur
AFSG nummer	AFSG nummer
ISBN-nummer	ISBN nummer
Publicatiedatum	Publicatiedatum
Vertrouwelijk	Nee/ja + expiratiedatum
OPD-code	OPD-code
Goedgekeurd door	Rene van Ree

Agrotechnology and Food Sciences Group
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 475 024
E-mail: info.afsg@wur.nl
Internet: www.afsg.wur.nl

Abstract

The aim of this study is to determine the economic feasibility of second generation ethanol from sugar cane, whereby traditional ethanol production is combined with the use of lignocellulosic biomass for ethanol production. By applying cost-benefit analysis, this study evaluated the viability of the second generation ethanol technology as an alternative to conventional sugarcane-to-ethanol, both in terms of processing technology, and of land use impacts. Furthermore, an attempt is made to analyze impacts on CO_2 mitigation and land use in economic. The research results indicate that: i) from an economic point of view, the first generation plant is clearly preferable. With IRR of 18.7%, Minimum selling price of US$ 0.31 per liter, and NPV of US$ 213.0 million, first generation ethanol production from sugar cane has a large economic advantage compared to the second generation plant (IRR of 13.5%, Minimum selling price of US$ 0.40 per liter and NPV of US$ 78.5 million). ii) from an environmental point of view, a second generation biofuel that makes use of lignocellulosic biomass plant is clearly preferable. The second generation plant uses 49.6% less land and avoids a CO_2 debt average of 942,282 ton per year throughout the life of the project. iii) Productivity gains improve profitability (IRR) and reduce biofuel prices (Minimum selling prices). Increasing the yearlt Ethanol and sugar cane productivity's growth rate from 0.5% to 4.0% leads to a range of IRR from 17.5% to 21.5%, and of price from 0.29 US$/l to 0.32 US$/l for first generation plant, and from 13.2% to 14.2% and of price from 0.39 US$/l to 0.40 US$/l for second generation plant. iv) Process improvement shows little economic impact but matters on environmental side because less land is needed. Up to 10% more land can be saved compared to least advanced technology. v) Energy conversion development can improve income of the plant, especially for the first generation plant. Each 5% improvement can lead to 0.6% change in IRR project, and a reduction of 1.1% in the Minimum selling price. vi) Equipment investment is the most sensitive parameter to alter biofuel prices and profitability. The conventional plant is more sensitive to equipment investment, land prices and trash costs in this order while second generation plant is sensitive to equipment investment and almost insensitive to land prices and trash costs changes. vii) Assuming an average payment of US$ 29.43 or higher per ton CO_2 debt, the second generation plant may become a competing alternative to conventional, first generation plant. On average, the technology could be paid at reasonable cost (Revenue average of US$ 27.7 million). viii) Productivity gains reduce the repayment time of CO_2 debt, with ethanol productivity having a stronger contribution. Besides, from a growth rate of ethanol and sugar cane productivity from 0.5% to 4.0% per year, the repayment time changes from 11.8 years to a range between 6.5 years and 5.5 years and 13 and 9.5, respectively. In conclusion, the appraisal model represents a useful tool for analyzing many issues related with the dilemmas involved in biofuel production. And even having in mind that the model developed during the course of this study is a simplification of reality, the obtained results are consistent with studied literature and economic theory.

Table of Contents

Table of Figures

List of Tables

List of abbreviations

CO_2: Carbon dioxide
EtOH: Ethanol
GHG: Greenhouse gases
CEI: Chemical Engineering Plant Cost Index
PB: Payback time
NPV: Net present value
IRR: Internal rate of return
IBT: Income before tax
MACRS: Modified accelerated cost recovery system
TJLP: Brazilian long term run interest rate
SELIC: Brazilian bond reference rate (Special System of Clearance and Custody rate)
Conab: National Supply Company
EPE: Brazilian Electricity Research Company
IEA: Agricultural Economics Institute
A&F: Agrotechnology and Food Innovations, B.V.
WUR: Wageningen University and Research Centre

1 Introduction

The foreseeable scarcity of fossil fuel for the coming years is represented by limited stocks, the energy demand increase due to world growth and the concern about pollution and global warming effects have led countries to develop new sources of energy. One of the most successful initiatives, recognized at worldwide level, is the production of ethanol in Brazil.

However, riots in many countries from Latin America to Asia, passing through Africa, after the recent skyrocketing costs of staple food highlighted an ongoing global food crisis[1]. Droughts, more frequent flooding, patterns of rainfall change and other natural disasters compound this crisis. Regardless of these many specialists blame the transfer of land use from food to biofuel production as main reason (CNN, 2008-B). The increase of the oil price is also a major reason. In May 2008, the oil price reached US$140 per barrel.

This clear dichotomy between energy and food has demanded prompt answers from ethanol producers and international institutions around the world. As a consequence, developing fuels that can meet the environmental requirement and at same time being socially fair for poor countries can be indicated as a way to dealt with this issue.

In this context, renewable energy sources can play an important role, especially biomass from agricultural residues, namely lignocellulosic biomass. It can be used to produce energy without land use increase and to reduce greenhouse gases (GHG) emission, while CO_2 from biomass combustion can be re-absorbed by photosynthesis (Maas, 2008).

The product of the process that uses lignocellulosic biomass to produce ethanol (EtOH) is often referenced to a second generation biofuel. Explaining fermentation process is out of this research's scope. For a mini-review of the state of art's fermentation process, an overview is presented by Claassen et al. (1999)[2].

---

[1] *For a deep vision about the impact on world food crisis, see CNN (2008-A).*
[2] *For an example of a process' analysis of bioethanol production using wheat, see Maas (2008).*

Analyzing next generation biofuels, David L. Anton of DuPont Biofuels pointed out the following items as basic requirements for a successful biofuel commercialization: i) feedstocks must be in adequate supply; ii) the product must be compatible with existing infrastructure; and iii) biofuel must not compromise fuel performance (Licht, 2008).

Christoph Berg of F.O. Licht, in turn, presented his doubt about the long-term biofuel sustainability as follows: i) the cost of producing biofuels; ii) the perceived threat for food security; and iii) the greenhouse gas and energy balances (Licht, 2008).

Last but not least, Erich Nagele of European Union Comission presented the three pillars for next generation biofuel according to European demand: i) security of supply; ii) sustainability; and iii) competitiveness (Licht, 2008).

Many companies have already shown interest in starting next generation biofuel production soon (Licht, 2008). For instance, Brazilian Crystalsev and American Amyris announced a joint venture for starting in 2010 a new kind of fuel production in Brazil (e.g. biodiesel made of sugar cane). Their goal is to produce 4 billion-liter-fuel until 2015 (Gazeta Mercantil, 2008).

Brazil is notably a special case in biofuel production. Today, Brazil obtains three times much energy from biomass as the world average and five times more than the most European countries (Knight, 2007). Sugar cane is the feedstock for biofuel production in the country. This feedstock has a huge potential to produce much biomass, in other words, for each ton about 56% stand for bagasse, tips and leaves (Finguerut, 2006).

Brazil started its experiences in this field in the 1920's and created its biofuel program in 1975. It has a long tradition in developing solutions in biofuel area, such as flex fuel cars.

Moreover, Brazil complies with Anton's three basic requirements. Firstly, sugar cane production is cropped in sufficient quantity nowadays. For season 2007/2008, the Brazil's production can reach 580 million tones (Conab, 2008-A). The 1,038 million tones forecast for season 2020/2021 is also very noteworthy (Zuurbier, 2008).

Secondly, Brazilian biofuel is compatible with existing infrastructure in the country and abroad. Annually, Brazil exports biofuel to more than 50 countries, amongst them US, EU, Japan and India (Carvalho, 2005).

Thirdly, Brazilian biofuel does not compromise fuel performance. Ethanol stands for 40% of fuel used to power Brazil's fleet (Knight, 2007). According to Maas (2008), flex fuel cars whose engines can use ethanol or gasoline at any percentage stands for 60% of all cars in the country.

It is equally important to mention that Brazil's biofuel can dismiss Berg's doubt and fulfill EU's three pillars properly. First of all, the cost of producing biofuels in Brazil is the lowest in the world (Zuurbier, 2008) and the ethanol productivity (reaching up to 8,000 liter/hectare) is the highest amongst the producers (Knight, 2007). As a consequence, the supply can continue to be met without further difficulty, at least for some time to come.

Secondly, for Brazil's case the perceived threat for food security seems not to be a correct insight. Brazilian President and Foreign Minister defended that sugar cane for ethanol amounts to less than 1% of Brazilian territory and 3 percent of its farmland (CNN, 2008-C). Besides, there is still available land for agriculture expansion in the country (Carvalho, 2005; Zuurbier, 2008).

Thirdly, the greenhouse effect's gas emission balance for ethanol use is favorable in Brazil when considered the feedstock growing, the refinery process and fuel burning. The anhydrous (fuel that is added to gasoline) and hydrous (fuel to run cars) ethanols avoid on average emissions of 2.6 ton CO_2/m^3 eq. and 1.7 ton CO_2/m^3 eq., respectively (Macedo et al., 2004).

However, some specialists claim that the expansion of feedstock area to biofuel production even when made on degraded pasture may induce deforestation of new areas to grain production. In this condition, the traditional emission balance misses the carbon emissions that happen when new cropland is developed in forest area. For instance, Searchinger et al. (2008) affirm that ethanol from Brazilian sugar cane could pay back the upfront carbon emissions due to land change in 4 years if the displaced area is only grazing land. Nevertheless if the displaced ranchers convert rainforest to pasture, the payback period could rise to 45 years.

Fargione et al. (2008) affirm that sugarcane ethanol produced on c*errado*[3] would take about 17 years to repay the biofuel carbon debt. According to these authors, biofuel produced on converted land could be greater net emitters than fossil fuels during a long period of time.

In this context, Searchinger et al. (2008) highlight the importance of using bagasse and trash to produce biofuel because they can avoid land use and its associated emissions. In the chapter 2, this discussion is expanded to build a methodology that considers the environmental costs of CO_2 emissions.

Considering that i) Brazil is very efficient in biofuel production; ii) lignocellulosic biomass is present in ethanol production and its use contribute to decrease CO_2 emission; iii) the biofuel world demand tends to increase sharply in coming years; iv) a global food crisis demands actions for increasing land to food production; v) the carbon emission balance tends to become more and more important, an important question arises: could second generation biofuel to be produced nowadays in Brazil efficiently under economic point of view?

This discussion is very timely and brings up serious technological implications for biofuel and food production in Brazil for the near future. On the one hand, it is notably known that the country has land abundance and that capital has been scarcer. On the other, it is also known that land change may lead to an undesired deficit in Brazilian biofuel carbon balance. Furthermore, Latin America must contribute more significantly to feed people in Africa and Asia in the coming years. Thus, this debate is not only about economic matter now, but also about land restriction in the future and sustainable environmental production system.

The primary goal of this study is to assess the viability of the second generation biofuel production as an alternative to produce additional first generation biofuel via land expansion.

To tackle these issues, the following objectives are formulated in this project:

[3] a hot climate, semi-humid vast tropical savanna in Brazil with a pronounced seasonality marked by a dry winter season from May through October.

i) To collect data on biofuel production and price, land and energy's price for Brazil as well as on costs for building a conventional and second generation biofuel plant and their operation costs;

ii) To build a methodology for appraising whether a second generation biofuel plant is feasible when compared with the option of producing additional first generation biofuel via land expansion.

iii) To evaluate the environmental costs by taking into consideration revenues for CO_2 avoidance when second generation biofuel plant is used.

iv) To assess the effectiveness of this methodology to make decision on second generation biofuel plant construction versus biofuel land expansion at current technology level, considering economic efficiency.

In Chapter 2, a data set is constructed. It serves as an input for investment projects simulations and the appraisal methodology used in this research. In chapter 3, simulations are performed with the developed methodology and the results are presented. In chapter 4, main findings are discussed and limitation on own analysis is presented. Finally, in the last chapter the conclusions are presented and possible ways forward are discussed.

2 Data and Methodology

This Chapter presents the dataset (see section 2.1) that serves as an input for the applied methodology. Section 2.2 presents theoretical framework. Finally, Section 2.3 presents the appraisal methodology based on cost benefit analysis.

2.1 Data

The best available data are collected and an explanation of choices is given. Section 2.1.1 describes the calculation of the ethanol and energy prices. Next, Section 2.1.2 presents the Brazilian sugar cane productivity. Then, Section 2.1.3 describes the calculation of Brazilian ethanol production average. Finally, section 2.1.4 presents the main investments and running costs to build a first and second generation biofuel plant.

2.1.1 Ethanol and energy prices

Ethanol prices are extracted from the Price Statistics of the World Ethanol & Biofuels Report (Licht, 2008). These prices were collected in February 2008 and weighted according to kind of Brazilian biofuel share (Conab, 2008-B) to determine the average price that is reference for biofuel price in simulations performed with applied methodology built in chapter 2. The average price is given in Table 2.1.

Table 2. 1: Ethanol Average Price

Ethanol	**Share**	Prices, US$/m^3
Anhydrous	40.30%	477.15
Hydrous	59.60%	426.08
Non-fuel Hydrous	0.10%	475.78
Average Price		446.71

Source: Conab (2008-B) and (Licht, 2008), own elaboration

Energy price is extracted from the statistical report of the Brazilian Electricity Research Company (EPE). To construct the data used in Section 2.3's methodology, average fare (129.13 R$/MWh) was taken and divided by exchange rate of 1US$ = R$ 1.9516, which is the period average for the year 2007 (FXHISTORY, 2008). The result is an electricity cost of 66.17 US$/MWh.

2.1.2 *Brazilian sugar cane productivity*

Sugar cane productivity, measured in fresh ton/hectare, are from the brand-new study about profile of Brazilian sugar and ethanol sector of National Supply Company (Conab, 2008-B). The productivity average from the season 2007/08 is presented in Table 2.2.

Table 2.2: Brazilian productivity average

Region	Productivity, t/ha
Center-South	84.3
North-Northeast	65.8
Brazil	81.4

Source: Conab (2008-B), own elaboration

2.1.3 *Brazilian ethanol productivity*

Ethanol average productivity (kilogram/liter) is also collected from Conab (2008-B) for the season 2007/08. To produce 1 liter of anhydrous ethanol 12.5 kg sugar cane is used. Following this principle, the ethanol average for Center-South region is weighted according to the kind of biofuel share to determine the ethanol average. Finally, to standardize this average into liter of ethanol per ton, the average in kg/l is inverted and multiplied by 1000, for which the final value (82.4 l/ton sugar cane) is found. Table 2.3 presents this procedure.

Table 2.3: Brazilian productivity average for Center-South Region

Ethanol	Share (%)	Sugar cane need (kg/lEtOH)
Anhydrous	40.30%	12.5
Hydrous	59.60%	11.9
Non-fuel Hydrous	0.10%	11.9
Average Productivity (kg/l EtOH)		12.14
Average Productivity (l/ton sugar cane)		82.4

Source: Conab (2008-B), own elaboration

2.1.4 *Investment costs*

In this study, multiple sources are used. The investment costs are specified as: i) Plant costs; ii) Machines costs, for agricultural purpose; iii) other running costs, which include a) labor, b) insurance, taxes and other costs, c) other operation costs; and iv) land costs; v) trash costs.

For Plant and Machine costs, measured in US$/ton and US$/ha, are used data provided by Cunha (2006). As these data are for a distillery to produce sugar and ethanol with capacity of processing 2 million sugar cane per season (164,720 M^3), they are scaled up according with scaling factor of 0.6: Updated costs = basic costs * (new capacity/old capacity)^0.6.

Other running costs were collected from a recent study presented by Goldemberg (2008). The original values were in €/100 l[4]. To transform these values into US$/l was used the following exchange rate: 1€ equals 1.205 US$ (FXHISTORY, 2008) because it simulates the exchange rate of as the data were produced. Finally all values are referenced to 2007 using Chemical Engineering Plant Cost Index (CEI). Table 2.4 presents these costs.

Table 2. 4: Investment cost for the first generation biofuel production

Item	Unit	Value
Plant Cost 1st Generation	US$/ton sc	53.50
Machines	US$/ha	1,307
Other running costs	US$/l	47.57
Labor	US$/l	7.45
Insurance, taxes and other costs	US$/l	6.88
Other operation costs	US$/l	33.24

Source: Cunha (2006), Goldemberg (2008), own elaboration

For the second generation plant investment costs, an estimate was provided by research of Mladjan Stojanovic from Agrotechnology and Food Innovations BV in July 2008. It will be detailed in Section 2.3.

[4] *In the article was written €/1000 l. However, the number was considered too small. After checking the original source mentioned by author, it was assumed that the correct value is €/100 l.*

Land prices were retrieved pasture land prices from database of Agricultural Economics Institute for some São Paulo state's regions (IEA, 2008). A land price average for a typical production area in Center-South region (10,588.85 R$/ha) was collected. Because the average considers only the prices but not the size of traded land, seventy per cent of this value was considered and divided by exchange rate of 1US$ = R$ 1.9516. The result is a price of 3,798.01 US$/ha. Finally, trash costs were collected from Finguerut (2006): 13.70 US$/ton in 2006 values. Considering the material with 50% humidity and value referenced to 2007, the trash costs equal 7.24 US$/ton.

2.2 Theoretical Methodology

To deal with the choice of building a new plant using second generation biofuel technology or expanding a biofuel production using conventional plant and more land, the following standard methods for the financial appraisal for long-term projects will be applied: i) Payback time (PB), ii) Net present value (NPV), and iii) Internal rate of return (IRR)[5].

2.2.1 Payback (PB)

Payback is the time needed for a project to recover the original investment in future cash flows. For instance, if a four-year project has an initial investment of US$ 600, an estimated net cash inflow of US$ 200 yearly (vide Table 2.5), the payback is calculated as follows.

Table 2. 5: Cash flow of a 4-year investment

Year	Initial Investment (US$)	Net cash flow (US$)
0	600	-
1	-	200
2	-	200
3	-	200
4	-	200

$$PB = 200+200+200 = 1^{st}+2^{nd}+3^{rd} = 3 \text{ years}$$

[5] *This framework is overwhelmingly known in financial management and is based on Van Horne (1992), Diacogiannis (1993), Pinches (1994), Broadbent and Cullen (2004), and Gardebroek and Peerlings (2006).*

Thus, the payback would be 3 years. However, looking only at this concept, it is not possible to know if the project is good or not. The concept only says when the nominal initial investment can be recuperated.[6]

2.2.2 Net Present Value (NPV)

Payback is a limited parameter because it ignores the time value of the money concept, which means that US$ 1 today differs US$ 1 in the future. To consider this, the present value of future benefits and costs need to be taken into account.

To reach this aim, the cash flow should be discounted back to its net present value (NPV) using the rate of return that can be earned on an investment in the financial market with similar risk. Each discounted cash inflow and outflow should be summed. Thus:

$$NPV = -C_0 - \sum_{t=1}^{N} C_t/(1+r)^t + \sum_{t=1}^{N} B_t/(1+r)^t \quad (1)$$

Or in short:

$$NPV = -\sum_{t=0}^{N} C_t/(1+r)^t + \sum_{t=0}^{N} B_t/(1+r)^t = \sum_{t=0}^{N} (B_t - C_t)/(1+r)^t \quad (2)$$

Taking the net yield (Y_t):

$$Y_t = B_t - C_t \quad (3)$$

Plugging equation 3 in equation 2, we have:

$$NPV = \sum_{t=0}^{N} Y_t/(1+r)^t \quad (4)$$

Where:

[6] *For other basic appraisal techniques' examples, vide Broadbent and Cullen (2004).*

C_0 - initial investment C_t - cost at time t B_t - benefit at time t
Y_t - yield at time t t - time of the cash flow N - life time of the project
r - discount rate

Some assets, namely perpetuity, give a constant cash flow stream that goes forever[7]. The present value of perpetuity with first payment starting in one period from now is equal to constant cash flow stream divided by discount rate, as follows[8].

$$NPV = \sum_{t=1}^{t\to\infty} S_t/(1+r)^t = S_t/r \qquad (5)$$

Where:
S_t - annual cash flow
r - discount rate

Using equations 4 and 5, cash flows' net present value can be determined. This method considers the value of the money concept and for this reason it can be used for taking financial project decisions. The decision rule for NPV is as follows: i) if NPV is positive, the project is acceptable; ii) if NPV is zero, the investor is indifferent; iii) if NPV is negative, the project should be rejected. Finally, the bigger NPV, the better the investment.

2.2.3 Internal Rate of Return (IRR)

The IRR stands for the economic yield on the investment. In other words, this is the effective return rate (profitability) which can be earned on the invested capital. Therefore, the equation 4 should be equaled to zero:

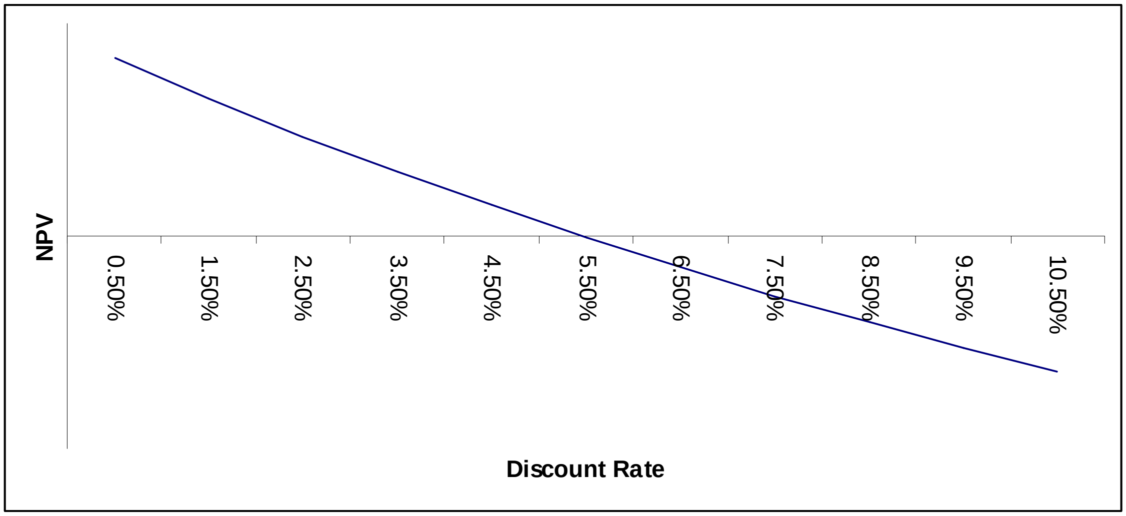
$$NPV = \sum_{t=0}^{N} Y_t/(1+IRR)^t = 0 \qquad (6)$$

Graphically IRR is the point at which the NPV intersects the horizontal axis (NPV equals to zero). Vide Figure 2.1 for an example in which the IRR is 5.5%.

---

[7] Gardebroek and Peerlings (2006) apply perpetuity for valuation of land.
[8] See Pinches (1994) for a demonstration of this formula.

Figure 2.1: Project's NPV against Discount Rate



The decision rule for IRR is as follows: i) if IRR is greater than the cost of capital, the project is acceptable; ii) if IRR is equal to the cost of capital, the investor is indifferent; iii) if IRR is smaller than the cost of capital, the project should be rejected. Finally, for the situation in which multiple IRR happens, NPV is a preferred tool[9]. Finally, the bigger IRR, the better the investment.

2.3 Appraisal Methodology: a cost benefit analysis

In the next section a cost benefit analysis is performed utilizing similar framework used for Curry and Weiss (1993), Zerbe Jr. and Dively (1994) and Perkins (1994). Some adaptations were needed to apply this tool to a biofuel plant options.

The appraisal methodology considers that a first generation plant produces biofuels in the conventional way using only the sugar cane juice and that second generation plant produces biofuels integrating the conventional production and also production from lignocellulosic biomass (bagasse and trash). Both plants produce 200,000 M^3. Furthermore, the integrated plant shares investment and part of its operation cost.

[9] *For a complete debate about multiple* IRR, *see Van Horne (1992), Pinches (1994), Broadbent and Cullen (2004).*

Thus, based on concepts presented in the previous section, the appraisal methodology performs a cost benefit analysis using following items (see Table 2.6).

Table 2. 6: Appraisal Methodology

2.3.1) Fixed costs
Plant Cost (1st generation costs **or** 2nd generation costs)
Machines
Land
2.3.2) Working capital
2.3.3) Operating Costs
Ethanol operating costs
Royalties (only for second generation costs)
2.3.4) Total Revenue
Ethanol revenue plus Energy revenue
2.3.5) Tax = Tax Rate * Income before Tax (IBT)
Tax Rate
Income before tax (IBT)
2.3.6) Net cash flow: Total revenue - Fixed costs - Operating costs (including Royalties for 2nd generation plant) – Tax
2.3.7) Project Appraisal (NPV, IRR, Payback time)
2.3.8) Price Simulation
Minimum selling price

2.3.1 Fixed costs

For the purpose of this research, fixed costs stand for plant, machine and land costs.

Plant costs

Once that for first plus second generation plant is necessary to integrate the cost, the calculation of the plant costs has different assumptions as follows.

1St generation methodology: Plant costs are collected in a presentation by Cunha (2006) based on 164,720 m^3 plant that produces sugar and ethanol. In this work the capacity is 200,000 M^3. Therefore, total costs are scaled up. As a consequence, the following formula applies for the conventional plant:

1st generation plant investment = plant cost per ton * ton per year

Resulting a total investment for the 1st generation plant of **US$114.0 million**.

2nd generation methodology: For the second generation plant investment costs, an estimate was provided by the research of Mladjan Stojanovic from Agrotechnology and Food Innovations BV. Second generation sugarcane ethanol plant cost was estimated using literature data (Cardona Alzate & Sánchez Toro, 2006 and Eggeman & Elander, 2005) that assumes dilute acid pretreatment of lignocellulose. However, as this project considers that only one plant will work using both system producing 200,000 M^3, the costs were scaled down[10] considering the share of conventional and second generation systems. The total volume is reached under the condition that all bagasse and trash produced at the field are used for EtOH production, while extra trash is purchased to burn for plant power requirements. The total investment for the integrated plant is therefore **US$ 188.3 million** (vide Table 2.7).

Table 2.7: Estimate of investment cost for second generation plant

	Separate plants	
	1st gen	**2nd gen**
Total capacity, Ml	**200**	**200**
Base cost, MUS$ (2007)	**150**	**227.25**
Present Capacity, Ml	100.78	99.22
Present Cost, MUS$ (2007)	99.43	149.22
	Integrated plant, MUS$	
Total Cost, MUS$ (2007)	**188.32**	

[10] *Using the same formula used previously: Updated costs = basic costs * (new capacity/old capacity)^0.6.*

Machines

Machine costs are collected in a presentation by Cunha (2006), standardized for 2007 using CEI and scaled up to 200,000 M^3.

Machines costs = machines cost per ha * amount of land

For conventional plant, machines cost represents **US$ 30.1 million**, while for integrated plant this is **US$ 15.2 million**.

Therefore, the total equipment investment that is sum of the plant and machines investment is as follows:

1st gen plant: **US$ 144.1 million** 2nd gen. plant t**: US$ 203.5 million.**

Land costs

According to Conab (2008-B), 65% of added land used for sugar cane crop is former grazing area. Thus pasture land is the proxy for land price in Brazil. To construct this parameter, prices were collected in Instituto de Economia Agrícola database. Furthermore, it is assumed that 70% of average pasture land price represents the land price because the land price average is not weighted by the total amount of land sold. The result is a price of 3,798.01 US$/ha.

Land costs = land cost per ha * amount of land

2.3.2 Working capital

As the model does not treat in detail stocks of materials, biofuel stocks and the work in process, it was considered that a share of 6% equipment investment is used as working capital, having in mind 18 years project life. See Perkins (1994) for further discussion on working capital.

Working capital = total plant investment * 6%

2.3.3 Operating costs

For both plants the operating costs are determined. Only for the second generation biofuel plant royalties are paid.

Ethanol operating costs

The volume of 200,000 M^3 times the cost per liter. Ethanol costs per liter based on Goldemberg (2008) were transformed in US$ and referenced to 2007 using CEI.

Ethanol operating costs: volume * ethanol cost/liter

Royalties

5% of ethanol revenue produced with second generation will paid as a compensation for technology use.

Royalties = 2^{nd} generation biofuel production * 5%

2.3.4 Total Revenue

Total revenue is the sum of ethanol and energy revenues. Ethanol Price is the weighted price provided by Licht (2008) as in the Table 2.1. Electrical Energy Price is the price average of 66.17 US$/MWh provided by EPE (2007). Coefficients 1 and 2 stand for the possibility of not full operation (less than full-time). It was adopted as being 95%. Coefficient 3 is the trade energy share that can be sold to public grid. As a new plant is being built, it was considered 100%.

Total revenue = Ethanol revenue + Energy revenue

Ethanol revenue = volume * ethanol price * coefficient 1

Energy revenue = amount of energy sold to the public grid * energy price * coefficient 2 * coefficient 3

2.3.5 Tax

Stands for the tax rate times the income before tax (**Tax:** Tax rate * Income Before Tax).

Tax rate

Load Tax in Brazil is above of 40%. There are many taxes and a complex tax system exist. At moment, personal income tax has two ranges 16.5% and 27.5%. Van Horne (1992) applies 40% for some simulations. The appropriate tax rate depends on the tax system and it varies a lot from country to country. For the purpose of this simulation a **tax rate of 35%** is adopted.

Income Before Tax (IBT): stand for total revenue minus operating costs including royalties for the second generation plant, minus interest payment, minus depreciation. Revenue and operating costs are shown above. Interest payment and depreciation are shown as follows.

IBT: **Total revenue – Operating costs (including Royalties only for the 2nd generation plant) – Interest payment – Depreciation**

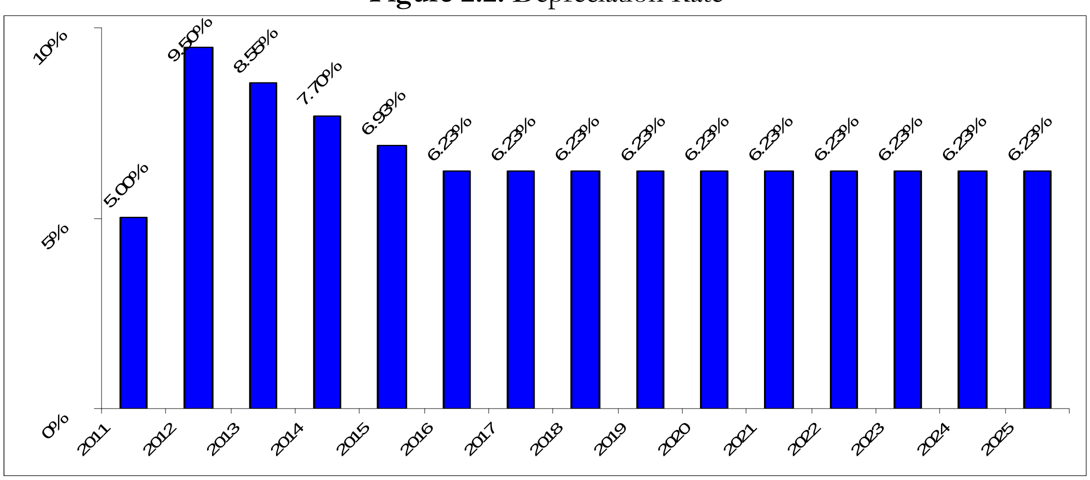
Interest Payment: Debt * interest rate

For tax treatment, debt control is performed and the interest payment is considered to determine the taxable income. A constant amortization system is used with three years waiting period for interest payment. During this period, the owed interest is aggregated to debt.

Depreciation

It is adapted a Modified Accelerated Cost Recovery System (MACRS) to a 15 year asset. According to Pinches (1994), industrial steam and electric-generation equipments are 15 year class asset. One-half of MACRS' depreciation in the first year and MACRS' depreciation rates (declining balance method[11]) were taken up to class life. As the project has only 15 year life span, then it is applied straight line depreciation until the rest of the depreciation period. The following graph shows the depreciation rate behavior.

Figure 2.2: Depreciation Rate



[11] *Declining balance method = M * (1/N), Where: M (multiplier): 150% for a 15 year asset and N (normal recovery Period): 15 year class asset.*

2.3.6 Net cash flow

Finally, the financial project cash flow is determined considering costs and benefits that are generated over economic life span investment. The following equation summarizes the methodology's net cash flow.

Net cash flow: Total revenue - Fixed costs – Working capital - Operating costs (including Royalties for 2nd gen.) - Tax

2.3.7 Project Appraisal

Using the theoretical methodology developed in section 2.2, Payback, NPV, IRR for conventional and second generation plant are determined. The input for this calculation is the net cash flow based on cost benefit analysis.

2.3.8 Price Simulation

Minimum price that the biofuel can be sold to guarantee an internal rate of return at 10%, which is the baseline, is calculated for both plants. Other assumptions and hypothesis are presented as follows.

Investment interest rate

An estimate interest rate of 10% per year is used. In April 2008 the bond reference rate (SELIC rate) in Brazil was 11.25% per year and Long term run interest rate (TJLP) was 6.25% per year. Private rate, in general higher, also applies. Most cases, an interest rate mix is made in which own capital is used to favor better financing conditions.

Productivity growth rate

Considering a growth rate of 1.5% per year, from 2008 until 2025, the Brazilian sugar cane productivity average will grow from 81.4 ton/ha to 104.8 ton/ha. For the purpose of this work, the average of **92.66 ton per ha** is used. This procedure is taken to avoid the need of reducing crop area every year. The idea behind of this action is to avoid that the model can be an agent speculative in land use. Similar idea applies for ethanol productivity average that will grow from 82.4 l/ha to 106.1 l/ha, with consolidated average of **93.75 liter per ton of sugar cane**.

Price growth rate

A yearly growth rate of biofuel and energy price of 3% is considered based on rough calculation of biofuel price in dollar from 2000 and 2006 in Brazil.

Land Appreciation

The ratio between first class land and pasture land in Brazil from 1980 to 2001 varied from 1.5 to 2.5 according to Rezende (2002). Taking this in terms of land appreciation rate, the value of 2.46% a year comes out (land appreciation rate = (2.5/1.5)^(1/21) -1 = 2.46%). This is used in this work to simulate the land valorization.

Residual value of the investment

The salvage value of 5% is considered for machine and plant. Furthermore, all land is sold at the end of life span project in 2025.

2.4 CO_2 assessment: a first attempt

First, it is assumed that the extra land used for the first generation represents the land saved for the second generation and that for this reason a revenue may compensate second generation investors. In other words, it is ignored that the second generation plant indeed repays the CO_2 debt quicker once it produces more ethanol per ton sugar cane and only the economic aspect is considered. This hypothesis will be relaxed in section 2.4.1 where the repayment time is studied. For this purpose, the repayment is divided into carbon storage, ethanol displacement and transportation emission.

2.4.1 Minimum price per ton CO_2 debt

Minimum price per ton CO_2 stands for the price that equals the investments between conventional and second generation plants. This value represents the money amount that makes both investments economically equal considering revenue for CO_2 avoidance to second generation plant. The CO_2 revenue stream is discounted and compared with the difference between net present value of 1st and 2nd generation plant as follows.

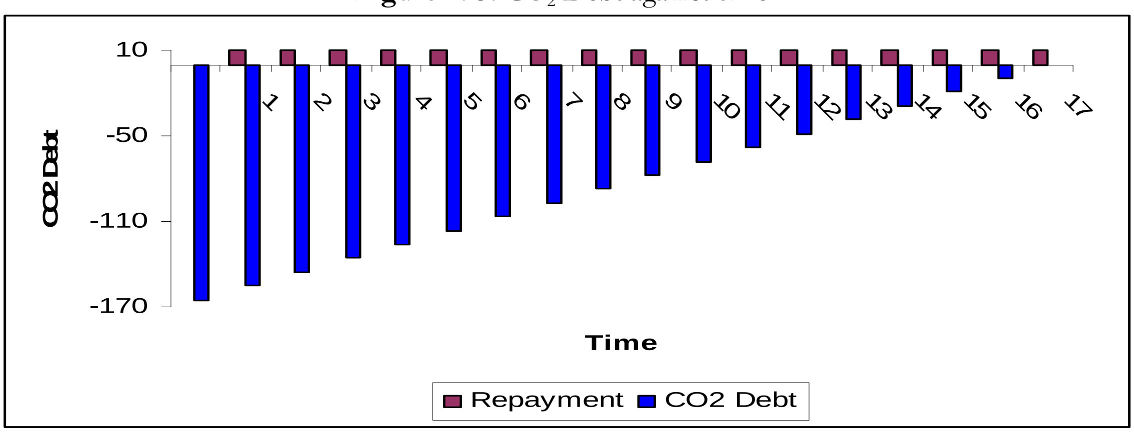
NPV (CO_2 Debt avoided * Price CO_2 per ton) = ΔNPV

CO_2 Debt avoided stands for the amount that is avoided because less land is used once that second generation technology is being applied. The scenario reference is a conversion of Brazilian *Cerrado* in a wooded ecosystem into sugar cane (sc) biofuel production (Fargione et al., 2008). The revenue payment is considered annually according with the existing CO_2 debt. Initial carbon debt and CO_2 repayment are 165 ton CO_2 per hectare and 9.8 ton CO_2 per year per hectare, respectively (Fargione et al., 2008). Thus, this CO_2 debt goes down yearly up to zero with annual payment after 17 years[12] (See Figure 2.3).

CO_2 Debt avoided = Initial carbon debt – annual repayment
Land saved = difference between land required for conventional and second generation plants
Initial carbon debt = 165 ton CO_2 per hectare * land saved
Annual repayment = 9.8 ton CO_2 per year per hectare * land saved

Price CO_2 per ton is the unknown that will be found in the model. This price will grow at the same growth rate of prices (3% per year). The time life of revenue stream is 17 years.

Figure 2. 3: CO_2 Debt against time



12 *This value is presented in Table 2.8.*

ΔNPV stands for the difference between the net present values between conventional and second generation plant investments.

ΔNPV = NPV conventional plant – NPV second generation plant

2.4.2 *Repayment time*

First of all, Fargione et al. (2008) consider annual life-cycle GHG reduction from biofuels, including displaced fossil fuels and soil carbon storage. A first attempt is to separate soil carbon storage from the rest of GHG reduction from biofuels' contribution as follows.

Repayment = Net CO_2 avoidance's EtOH + Net CO_2 storage – Transport CO_2 emission

Net offset is 9.8 Mg CO_2/ha annual and Transport CO_2 emission is 0.195 Mg CO_2/ha (Fargione et al., 2008). An estimate for net CO_2 avoidance's EtOH is performed as follows.

Considering the chemical equation of ethanol combustion and the fact that CO_2 biomass combustion can be absorbed by growing plants:

$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_20$ (1 mol ethanol → 2 moles CO_2)

It is possible to realize that 1 mol of ethanol combusted corresponds to 2 mols of CO_2 emitted and that 1 ton ethanol can stock 1.91 ton CO_2. This is the amount of CO_2 that will be recycled. Taking Fargione et al. (2008)'s reference (Macedo et al., 2004), we have average of 68.7 t/ha.annum from season 1998/99 to 2002/03 and 86.0 l/ton sugar cane. Furthermore, the EtOH density is 0.789 kg/l.

To determine the EtOH production (l/ha), the following formula is applied.

Production (l EtOH/ha) = EtOH productivity (l/ton sc) * sc productivity (ton sc/ha)

The production in l EtOH/ha is multiplied by EtOH density to determine the production in kg EtOH/ha:

Production (kg EtOH/ha) = EtOH Production (l EtOH/ha) * EtOH density

Then the Net CO_2 avoidance's EtOH is determined:

Net CO_2 avoidance's EtOH (ton CO_2/ha) = Production (kg EtOH/ha) * CO_2 stocked tsc

Finally, the Net CO_2 storage (ton CO_2/ha) is found:

Net CO_2 storage = Net offset - Net CO_2 avoidance's EtOH – Transport CO_2 emission

Last but not least, the repayment time is determined:

Repayment time (years) = Carbon debt (t CO_2/ha)/ Repayment

In the next chapter, Net CO_2 storage and Transport CO_2 emission are fixed (based on Fargione et al., 2008) and Net CO_2 avoidance's EtOH and Repayment are updated considering that sugar cane and ethanol productivity increase with the second generation plant use. Table 2.8 shows the repayment time based on Fargione et al. (2008).

Table 2. 8: Repayment time Fargione et al.'s scenario (2008)

Carbon debt CO_2 , t/ha	165
Productivity, l/tsc	86.00
Productivity, tsc/ha	68.70
Production, EtOH l/ha	5,908
Density ETOH, kg/l	0.789
Production EtOH, kg/ha	4,662
tCO_2 captured/t EtOH	1.91
Net CO_2 avoidance' EtOH, tCO_2/ha	8.90
Transportation emission, tCO_2/ha	0.195
Net CO_2 storage, tCO_2/ha	1.09
Net offset, tCO_2/ha	9.80
Repayment time, years	**17**

Last, the summary of the appraisal methodology built in sections 2.3 and 2.4 can be found in Appendix. Using the model written in these spreadsheets[13], all simulations, scenarios, and sensitivity analysis of this project can be performed.

[13] *For more details about using spreadsheets on financial management, see Diacogiannis (1993).*

3 Results

This chapter presents the main results produced using methodology developed in chapter 2. Section 3.1 shows economic results, while section 3.2 deals with environmental ones.

3.1 Economic Assessment

3.1.1 Economic analyses

Applying the appraisal methodology developed in chapter 2, the following results are obtained. They provide the base for comparison of different scenarios to be simulated in the next sections. The economic comments can be seen at section 4.1.

Table 3. 1: 1st gen. plant – economic results

	years
Project life	**18**
Pay-back time	**8,4**
	MUS$ (2007)
Electricity revenue (**198,510 MWh**)	**13.6**
Internal rate of return (IRR)	**18.70%**
	MUS$ (2007)
NPV	**213,0**
	US$/l
Minimum Selling Price	**0.31**
	MUS$ (2007)
Plant Investment	114,0
Machines	30.1
Land Investment	87,4
Total investment	**231,5**

Table 3. 2: 2nd gen. plant – economic results

	years
Project life	**18**
Pay-back time	**8,1**
Electricity revenue (**0 MWh**)	**0**
Internal rate of return (IRR)	**13.50%**
	MUS$ (2007)
NPV	**78,5**
	US$/l
Minimum Selling Price	**0.40**
	MUS$ (2007)
Plant Investment	188.3
Machines	15.2
Land Investment	44,1
Total investment	**247,6**

3.1.2 Scenario 1: Productivity gains (S1)

This scenario simulates sugar cane and ethanol productivity increase. Brazilian agricultural productivity and ethanol productivity have grown considerably in the recent period and deserve special attention in this work. Thus, S1 varies the productivity growth rate from 0.5% to 4.0% per year and obtains the plant profitability (see Figures 3.1 and 3.2) considering the initial hypothesis (sugar cane productivity of 81.4 ton/ha and ethanol productivity of 82.4 l/ha).

Figure 3. 1: 1st gen. plant - IRR versus productivity growth and price

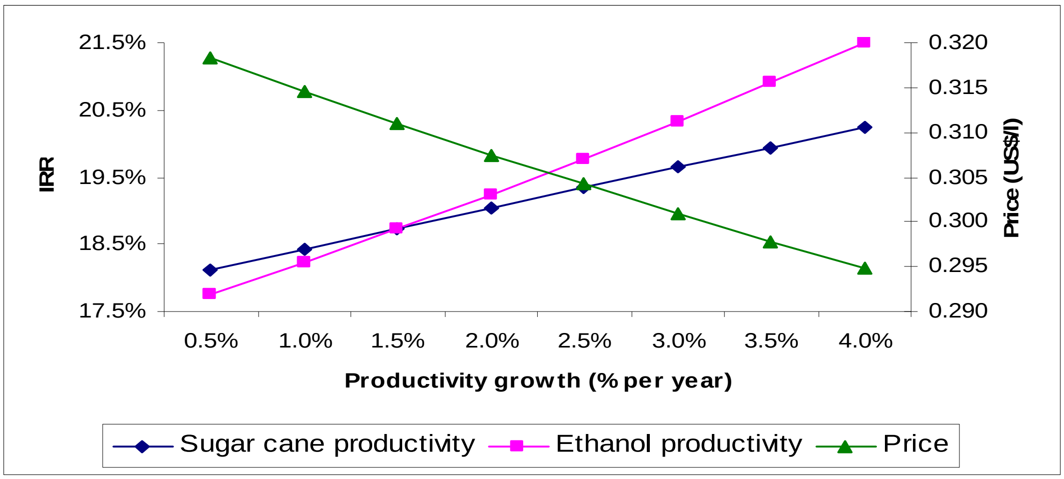
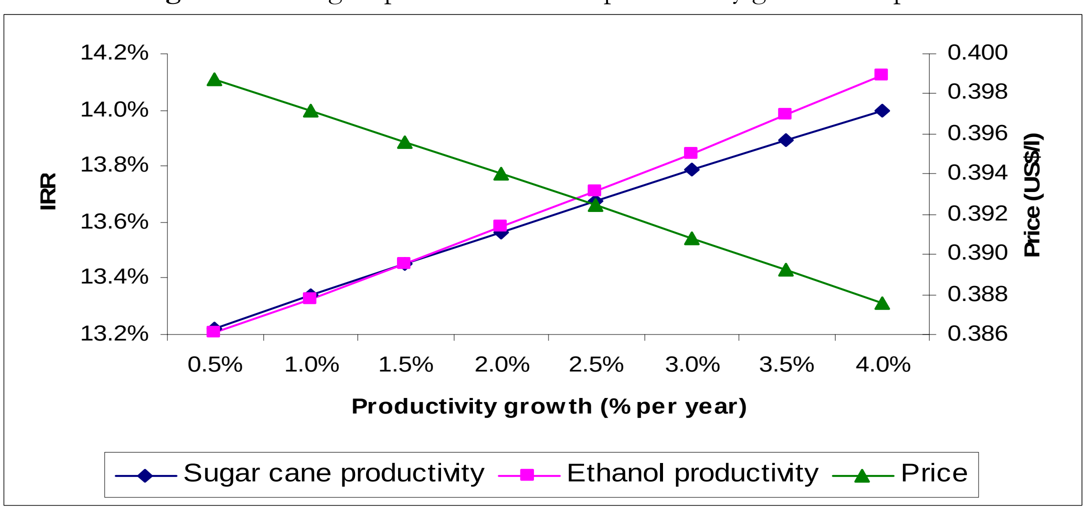


Figure 3. 2: 2nd gen. plant - IRR versus productivity growth and price



3.1.3 *Scenario 2: Process improvement (S2)*

Once that the best technology available is being considered not much space exists for drastic changes. However, in the carried discussion an important doubt rose up about ethanol yield fermentation. The baseline is that cellulose and hemicellulose will be converted in sugar at rate of 43%. In reality, this value can be a bit lower or higher. To eliminate this doubt, S2 simulates the ethanol yield fermentation range of 39% a 47% against profitability of second generation and selling price, once that this issue is applicable only for this kind of plant. The results are presented in the following table.

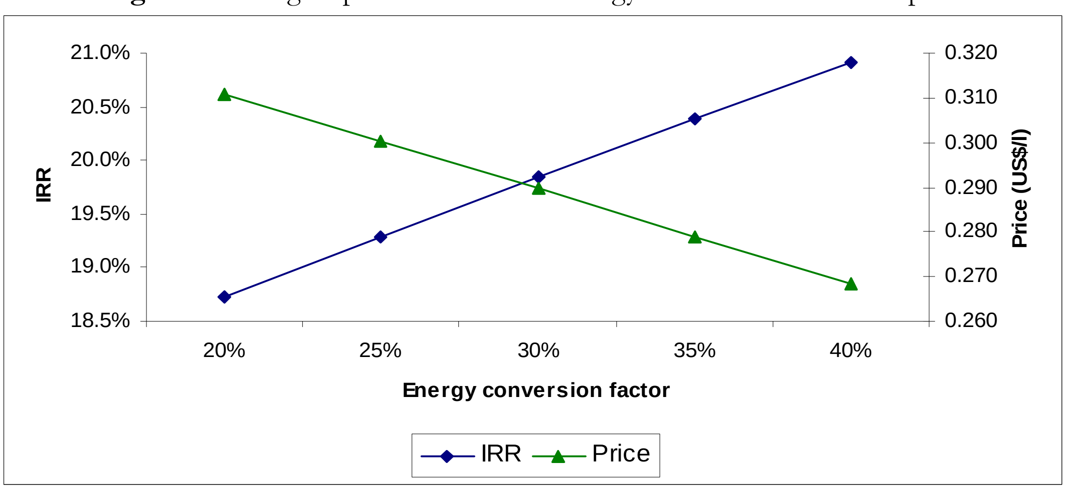
Table 3. 3: 2nd gen. plant: EtOH yield versus min. selling price, IRR and land saved

EtOH yield fermentation	Minimum Selling price	IRR	Land saved, ha
39%	0.40	13.5%	10,860
41%	0.40	13.5%	11,148
43%	0.40	13.5%	11,422
45%	0.40	13.5%	11,683
47%	0.40	13.5%	11,933

3.1.4 *Scenario 3: Energy conversion development (S3)*

Electricity is a source of revenue for the first generation plant. In our model, conventional plant sells electricity and second generation plant buys trash to produce energy to meet its internal demand. Besides, in baseline scenario, the conversion of steam into electricity is 20%. According to studied literature, this parameter can vary from 20% to 40%. So, S3 simulates this range against the profitability and ethanol price for the first generation plant (see Figure 3.3).

Figure 3. 3: 1st gen. plant - IRR versus energy conversion factor and price



3.1.5 Economic sensitivity analysis

The robustness of the model and the sensitivity to some assumptions made are tested by sensitivity analyses. Economic sensitivity analysis for the first and second generation plants is carried out to assess the impact of equipment investment, land prices and trash costs on the minimum selling price and profitability. The equipment investment (plant plus machines costs), land prices and trash costs vary from -75% to +100% and the minimum selling price and IRR are determined for the first generation plant (see Figures 3.4 and 3.5) and for second generation plant (see Figures 3.6 and 3.7).

Figure 3. 4: 1st gen. plant – Min. selling price versus equipment investment, land prices, trash costs change

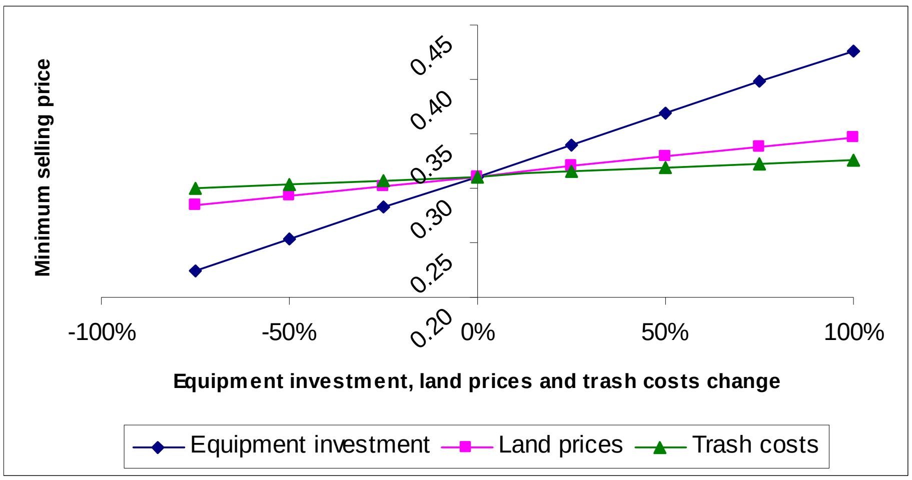


Figure 3. 5: 1st gen. plant - IRR versus equipment investment, land prices, trash costs change

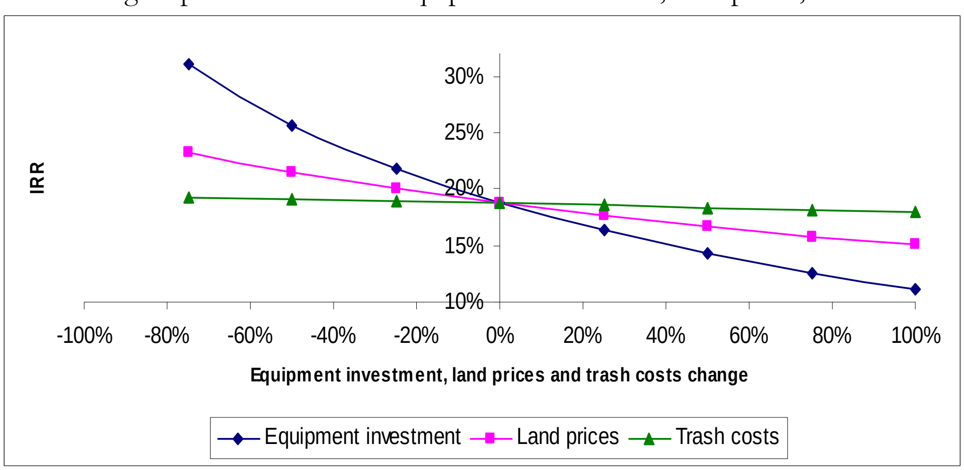


Figure 3. 6: 2nd gen. plant –Min. selling price versus equipment investment, land prices, trash costs change

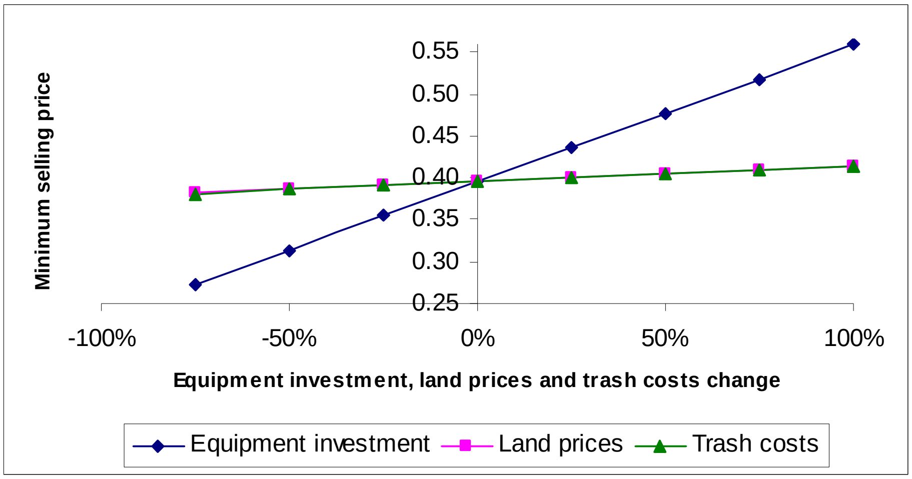
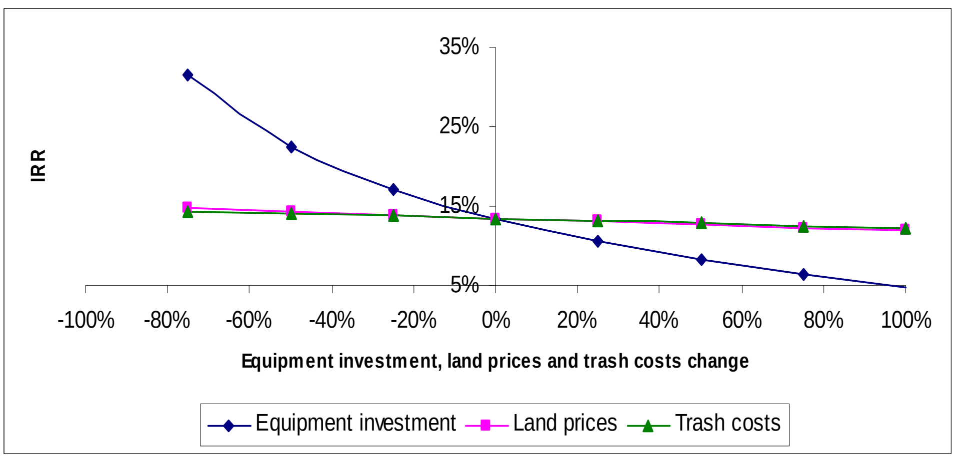


Figure 3. 7: 2nd gen. plant -IRR versus equipment investment, land prices, trash costs change



3.2 Environmental analyses

3.2.1 Price per ton CO_2

Using the methodology developed in Section 2.4.1 to the baseline scenario, the following results come out.

Table 3. 4: Calculation of CO_2 price

Land used in conventional plant, ha	23,024
Land used in 2nd generation plant, ha	11,602
Land saved, ha	**11,422**
CO_2 Debt, t/ha	165
Initial CO_2 debt, t	**1,884,564**
Annual repayment, t/ha	9.8
Annual repayment, t	**110,857**
NPV conventional, MUS$	213,0
NPV 2nd generation, MUS$	78,5
NPV Difference, MUS$	**134,5**
Price US$/t$CO_2$	**11.62**

3.2.2 Repayment time

Using the methodology developed in Section 2.4.2 to the baseline scenario, the following results are determined.

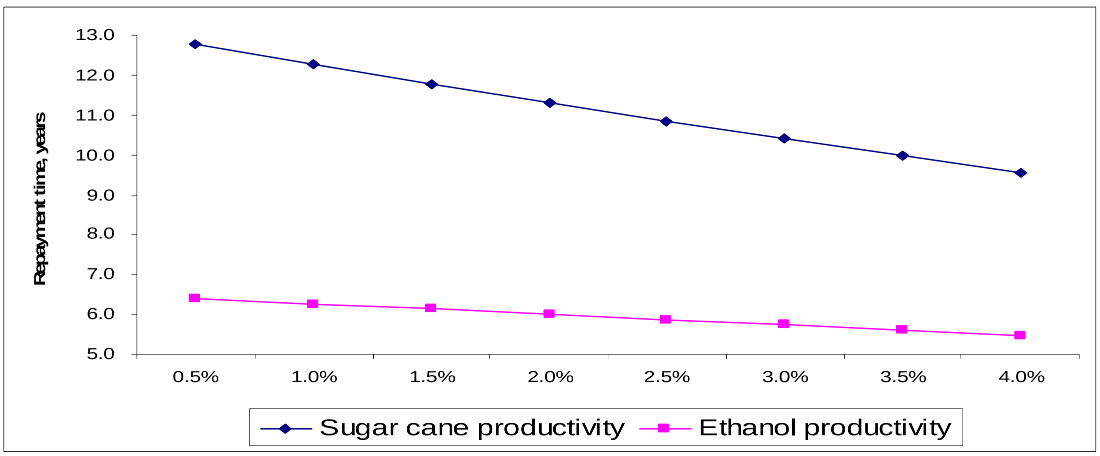
Table 3. 5: Repayment time for baseline scenario

Carbon debt CO_2 , t/ha	165
Productivity, l/tsc	**93.75**
Productivity, tsc/ha	**92.66**
Production, EtOH l/ha	8,687
Density ETOH, kg/l	0.789
Production EtOH, kg/ha	6,854
tCO_2 captured/t EtOH	1.91
Net CO_2 avoidance' EtOH, tCO_2/ha	13.09
Transportation emission, tCO_2/ha	0.195
Net CO_2 storage, tCO_2/ha	1.09
Net offset, tCO_2/ha	13.99
Repayment time, years	**11.8**

3.2.3 Environmental sensitivity analysis

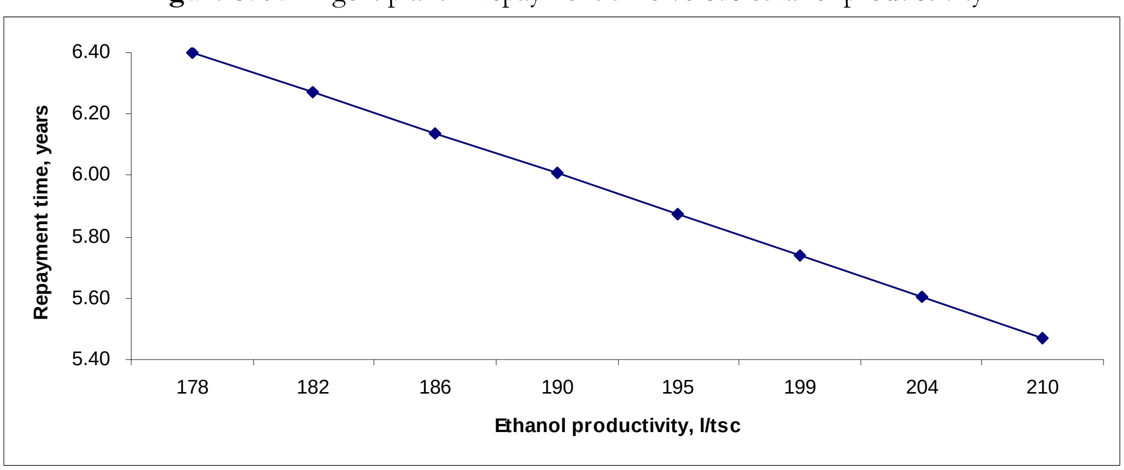
To find out how the repayment time changes when productivity increases, an environmental sensitivity analyses is carried out for second generation biofuel. Varying the ethanol productivity increase from 0,5% to 4% per year, time to repay biofuel carbon debt changes from 6,5 to 5,5 years. Similarly, varying the sugar cane productivity increase from 0,5% to 4%, the repayment time is between 13 and 9,5 years (See Figure 3.8).

Figure 3. 8: 2nd gen. plant - Repayment time versus productivity growth



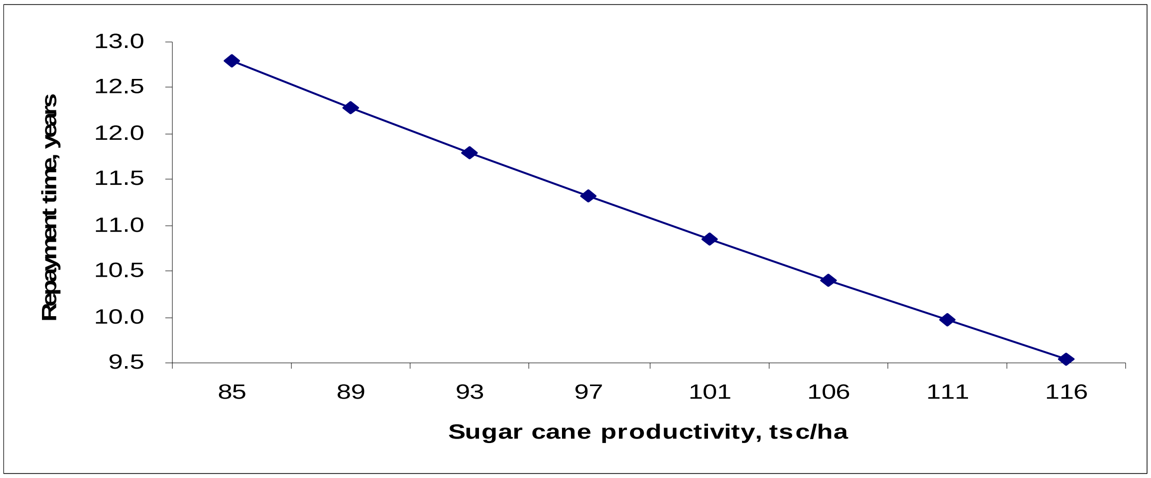
The same information can be obtained in terms of ethanol and sugar cane productivity. From 0.5% to 4.0% ethanol productivity growth per year, the productivity ranges between 178.0 and 210.0 l per sc ton (see Figure 3.9).

Figure 3. 9: 2nd gen. plant - Repayment time versus ethanol productivity



For the same growth interval, the sugar cane productivity varies from 85.0 to 116 ton sc per hectare (see Figure 3.10).

Figure 3. 10: 2nd gen. plant - Repayment time versus sugar cane productivity



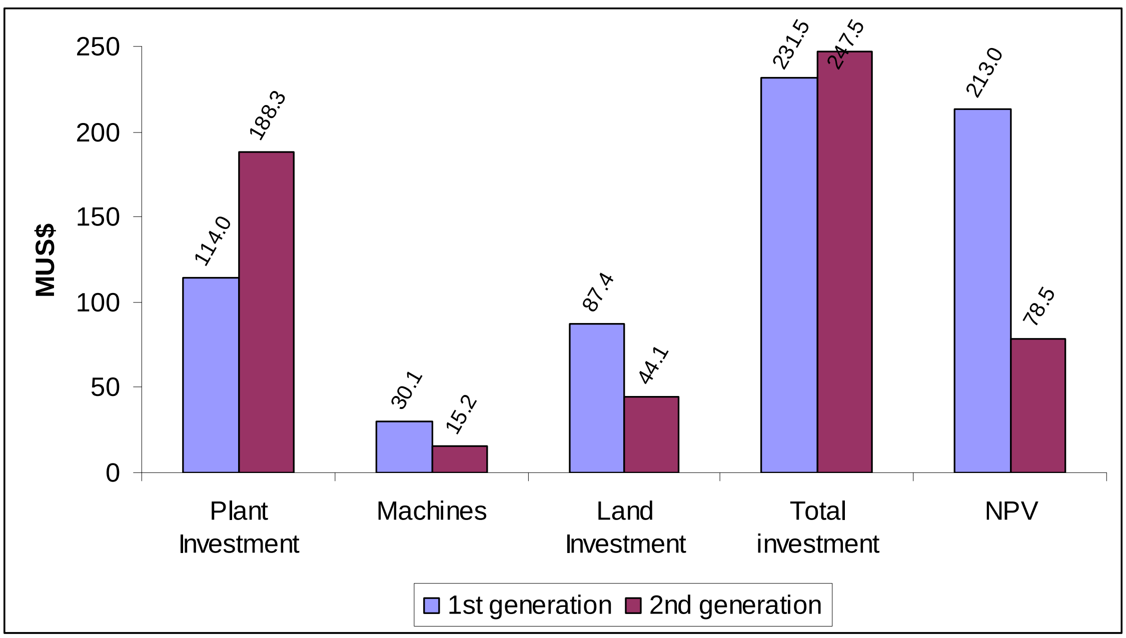
4 Discussion

This chapter presents the discussion on economic and environmental issues (sections 4.1 and 4.2) based on the analysis presented in previous chapters. Moreover, section 4.3 presents some limitations on our analysis.

4.1 Economic discussion

Under economic point of view (see Tables 3.1 and 3.2), first generation plant is preferable to the second generation plant. With IRR of 18.7% and NPV of US$ 213.0 million, it has a large economic advantage against the second generation (IRR of 13.5% and NPV of US$ 78.5 million). The greater the IRR and NPV, the better the investment (see argumentation on sections 2.2.2 and 2.2.3). Both plants have similar payback, which is between 8 and 9 years (conventional plant: 8.4 years and second generation plant: 8.1 years, including the waiting period of 3 years). See figures 4.1 and 4.2 for a summary.

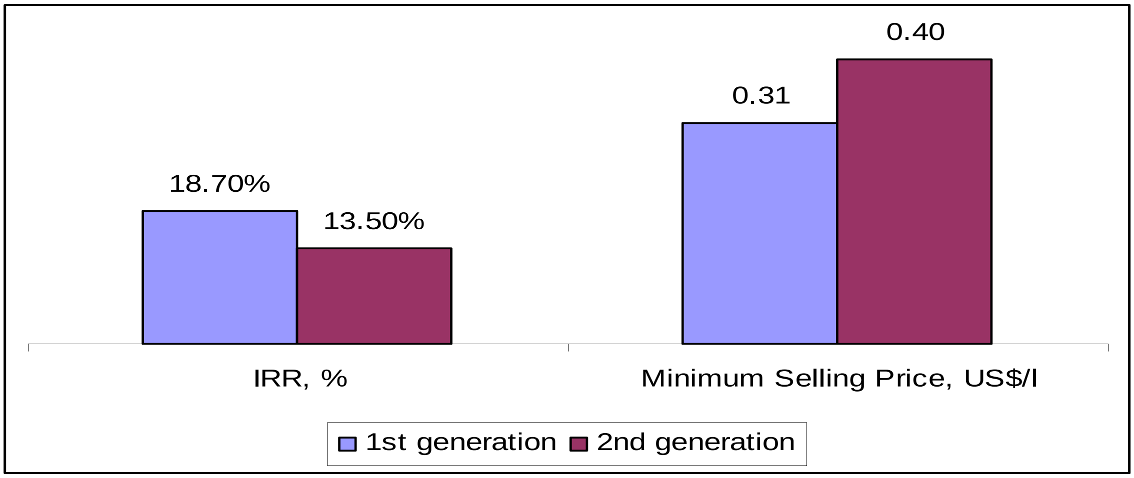
Figure 4. 1: Investments costs and NPV



The conventional plant costs US$ 114.0 million while second generation plant costs US$ 188.3 million. On the other hand, conventional plant needs 23,024 hectares (US$ 87.4 million) while second plant needs 11,602 (US$ 42.1 million). This fact has important consequences for environmental issue, which is discussed in the next section. Comparing machine costs, one can observe that conventional plant project needs to spend almost the double of the second generation investment. However, adding up all costs, as a total initial investment, first generation plant costs 6.5% less (US$ 231.5 million against US$ 246.6 million). Finally, the conventional plant is able to offer ethanol at much lower cost and at higher profitability (0.31 US$/l against

0.40 US$/l and IRR of 18.7% against 13.5%, see Figure 4.2). In other words, the first generation plant has about 37% higher profitability and can sell the biofuel for about 23% less.

Figure 4. 2: IRR and Minimum selling price



Under S1, a range of ethanol and sugar cane productivity growth rate from 0.5% to 4.0% per year leads to a range of IRR from 17.5% to 21.5%, and of price from 0.29 US$/l to 0.32 US$/l for first generation plant (see Figure 3.1), and from 13.2% to 14.2% and of price from 0.39 US$/l to 0.40 US$/l for second generation plant (see Figure 3.2). From a growth rate of 1.5% on, ethanol productivity growth rate increases the profitability more than sugar cane productivity growth rate. Below 1.5%, the opposite happens.

For S2, ethanol yield fermentation changes were not able to change both minimum selling price (0.40 US$/l) and IRR (13.5%). This factor does not play an important role in the economic side. However, it reduces the land area. Up to 10% more land can be saved compared with the worst fermentation process. Therefore, it contributes to the CO2 balance (see Table 3.3) decreasing the carbon pay-off period.

In S3 simulation, varying from 20% to 40% energy conversion efficiency from steam to electricity, IRR changes from 18.5% to 21.5% and prices changes from 0.31 US$/l to 0.27 US$/l (see Figure 3.3). This changes directly the electricity revenue. Each 5% improvement led to about 0.6% change in IRR and reduction in 1.1% in the minimum selling price. This finding is consistent with the general economic theory because technological improvement can increase sensibly the efficiency of the plant and consequently the profitability.

The economic sensitivity analysis indicates that with equipment investment, land prices and trash costs changes from -75% to 100%, the minimum selling price and IRR varies:

i) from 0.22 US$/l to 0.43 US$/l and from 31% to 11%, respectively for the first generation (see Figures 3.4 and 3.5);
ii) from 0.27 US$/l to 0.56 US$/l and from 32% to 4.7%, respectively for the second generation (see Figures 3.6 and 3.7);

Furthermore, the conventional plant is more sensitive to equipment investment, land prices and trash costs in this order while second generation plant is sensitive to equipment investment and almost insensitive to land prices and trash costs changes. The bigger the line slope, the more sensitive the plant is (see Figures 3.5 and 3.7).

As a final observation, it is highlighted that the conventional plant is profitable for all economic changes, being that its minimum IRR of 11% is superior to baseline interest rate of 10%.

4.2 Environmental discussion

Under environmental point of view (see section 3.2), the second generation plant is preferable to conventional plant. Taking a pure economic comparison, the value of US$ 11.62 per ton CO_2 debt could make both investments equal (both value paid per CO_2 and debts vary through the project). The logic behind is that second plant investor could receive an extra revenue for the CO_2 avoidance. This kind of approach depends on the government budget and, for sure, of political interest.

Just to give an example of that this technology can be pushed off if political interest grows, average values were calculated as follows (see Table 4.1). The CO_2 debt and price evolution can be found at appendix. The price average grows at baseline interest rate.

Table 4. 1: Annual revenue to CO_2 emission

	years
Project life, years	**18**
CO_2 Debt average, t	**942,282**
Price average US$/t CO_2	**29.43**
	MUS$ (2007)
Annual revenue average to be paid	**27.74**

Under this hypothesis, a CO_2 debt average of 942,282 ton and a price average of US$ 29.43 per ton CO_2 are found. According to this figures, the annual revenue average of US$ 27.7 million should be paid to second generation investor to equalize his profitability to first generation plant investment.

A quick calculation for a typical car use in the Netherlands that has an average mileage of 15,000 km per year, emitting 0.180 kg CO2 per km (average sized gasoline car) show that the cost to be paid to correct the CO2 emission could be low. A total emission of 2.7 ton CO2 is calculated and the total cost of US$ 79.50 is determined (See Table 4.2). Therefore, the Dutch drivers could pay about US$ 80 per year to have a second generation fuel that accounts for the emission effects.

Table 4. 2: Dutch car cost average for CO_2 emission

Distance, km	**15,000**
CO_2 emission in kgCO_2/km	**0.180**
Total emission tCO_2	**2.7**
Price average, US$/t$CO_2$	**29.44**
Cost average, US$	**79.50**

The sugar cane productivity can also strengthen the CO_2 balance. When second generation is used, the repayment is even done quicker. Much less land is used: almost 50% less (see Table 3.4). Revisiting the parameters by Fargione et al. (2008) with the methodology developed in Section 2.4.2, an estimated decrease of the repayment time could be lowered from 17 to 11.8 years (see Tables 2.6 and 3.5).

An environmental sensitivity analysis is performed in Section 3.2.3. From a growth rate of ethanol and sugar cane productivity from 0.5% to 4.0% per year, following conclusions can be made:

i) from 178 l to 210 l of EtOH produced per ton sugar cane, the repayment time varies from 6.5 years to 5.5 years (see Figure 3.9);
ii) from 85 to 116 ton sugar cane produced per hectare, the repayment time varies from 13 years to 9.5 years (see Figure 3.10);

For both situations, an average repayment time is lower than in the baseline scenarios (11.8 years). Besides, the best practices show clearer advantage in the reduction of repayment time with second generation plant.

4.3 Drawback on the results

Some adopted information merits further considerations. The biofuel and electricity prices should be considered carefully and come first. The oil price increase can make the biofuel price grow sharply. On the other hand, the price of electricity can have a different behavior. The last auction for new energy in Brazil registered a price of R$ 78.87 (US$ 40.41) per MWh. However, it is not recommended to use this value in our analyses once that it is the reference to new large plant capacity built in northern Brazil. Therefore, the adopted electricity price average is R$ 129.13 (US$ 66.17) per MWh. Depending on the plant's geographic location, the received price can be even higher!

Investment and operational costs are, in turn, not available in the complete extension that is desirable. Besides, in many cases, new distilleries are not completely built, but an expansion is carried out. In other cases, mills for sugar and ethanol are installed making the costs segregation more difficult. For our analyses, the focus was a distillery that produces only ethanol. Further research on this topic may compromise the quality of the analysis.

A real estimate for working capital and royalties should be included, that could replace the rough values used here and make these items more reliable. Besides, technological parameters are ongoing development and can modify our assumptions. For instance, a quick look in the S3 shows that first generation plant can still benefit an increase in its revenue with energy conversion systems development.

Recently the land prices increased a lot mainly in São Paulo state and this deserves special attention too. From 2001 to 2006, the land average price had an increase of 113.6% in São Paulo state (Agência Estado, 2008). According to specialists interviewed by the same source, the land valorization has not considered the ethanol effect yet, once that until 2012/13 more 31 mills will be built and consequently more sugar cane will be required. Although Center-South region is considered the ideal place for a new plant, this cost can induce a direction change on this issue.

Last but not least, Brazilian ethanol and sugar cane productivity can have a huge impact on the results of this model. The economic and environmental sensitivity analysis could show this clearly. Besides, Brazil continues improving its productivity and applying very developed technology. As a consequence, these parameters should be revisited any time a new simulation is performed.

5 Conclusion

A comparison between conventional biofuel plant, which uses only the sugar cane juice to produce biofuel, and second generation plant, which combines traditional production with lignocellulosic biomass use to produce ethanol, was studied. Applying cost benefit analysis, the option of building a second generation biofuel plant was compared with the option of producing biofuel via land expansion with the conventional technology use. An attempt of analyzing CO_2 impact was also performed.

The best available data on biofuel production and price, land and electricity's price for Brazil as well as on costs for building a conventional and second generation biofuel plant and their operation costs were collected (see Section 2.1).

A methodology for appraising the alternatives to produce biofuel in Brazil was built (see Section 2.3) and an attempt of evaluating the environmental costs by taking into consideration revenues for CO_2 avoidance for second generation biofuel plant is developed (see Section 2.4).

Applying this framework, economic assessment and environmental analyses were performed (see sections 3.1 and 3.2) as well as a discussion of this results and limitations (see Chapter 4).

Exploring the economic and environmental results, some selected scenarios simulation, and the sensitivity analysis the following results arise:

i. From an economic view point, the first generation plant is clearly preferable. With IRR of 18.7%, Minimum selling price of US$ 0.31 per liter, and NPV of US$ 213.0 million, it has a large economic advantage compared to the second generation plant (IRR of 13.5%, Minimum selling price of US$ 0.40 per liter and NPV of US$ 78.5 million, see Tables 3.1 and 3.2).
ii. From an environmental view point, second generation biofuel plant is preferable. It uses 49.6% less land and avoids a CO_2 debt average of 942,282 ton per year through the life project (see Table 3.4 and Section 4.2).
iii. Productivity gains improve profitability (IRR) and reduce biofuel prices (minimum selling prices). Ethanol and sugar cane productivity's growth rate from 0.5% to 4.0% leads to a range of IRR from 17.5% to 21.5%, and of price from 0.29 US$/l to 0.32 US$/l for first generation plant, and from 13.2% to 14.2% and of price from 0.39 US$/l to 0.40 US$/l for second generation plant (see Figures 3.1 and 3.2).
iv. Process improvement shows little economic impact but matters on environmental side because less land is needed. Up to 10% more land can be saved compared (see Table 3.3).

v. Energy conversion development can improve income especially for conventional plant. Each 5% improvement lead to about 0.6% change in IRR project and reduction of 1.1% in the minimum selling price for conventional plant (see Figure 3.3).

vi. Equipment investment is the most sensitive parameter to alter biofuel prices and profitability. The conventional plant is more sensitive to equipment investment, land prices and trash costs in this order (see Figures 3.4 and 3.5) while second generation plant is sensitive to equipment investment and almost insensitive to land prices and trash costs changes (see Figures 3.6 and 3.7).

vii. with a payment average of US$ 29.43 or higher per ton CO_2 debt, second generation plant is a competing alternative to conventional plant (Revenue average of US$ 27.7 million, see Table 4.1). On average the technology could be paid at reasonable cost. For instance, on average a Dutch car user could pay for its CO_2 emission compensating the second generation plant investor at cost of about US$ 80 per year (see assumption at Section 4.2).

viii. Productivity gains reduce the repayment time of CO_2 debt, being that ethanol productivity has a stronger contribution. Besides, from a growth rate of ethanol and sugar cane productivity from 0.5% to 4.0% per year, the repayment time changes from 11.8 years to a range between 6.5 years and 5.5 years and 13 and 9.5, respectively (See Figures 3.8, 3.9 and 3.10).

Tackling the economic feasibility of the second generation biofuel plant in Brazil, this studies concludes that under the adopted hypothesis (a chased IRR of 10%), the plant could be considered viable (IRR 13.5%). However, when it is compared with conventional plant (IRR 18.7%), the economic difference is large (5.2%) in favor of the latter. In addition, if an investor demands an IRR higher for second generation plant due to the risk involved in this new technology (for instance, 4% or 5% more), it could be viable only with reduction of investment costs about 15% (see Figure 3.7).

But, on the other hand, the second generation plant can produce much more biofuel using less land. Besides, if some revenue is attributed to CO_2 avoidance this option can become tenable under economic point of view in relative terms as well. Furthermore, this alternative could relieve the food crisis once that less land to biofuel production could increase the land availability for food production. Last, the CO_2 repayment could be done in a reasonable period of time. Therefore, a decision about the best choice is multifold and has a broad variety of issues to be considered, especially in the political arena.

Finally, the appraisal model represents a useful tool for analyzing many issues related with the dilemma involved in the alternatives for biofuel production. And even having in mind that this built model is a simplification of reality, the obtained results are consistent with studied literature and economic theory.

Bibliography

AGÊNCIA ESTADO. (2008) Em 5 anos, preço da terra em SP subiu mais de 100%. http://noticias.br.msn.com/economia/artigo.aspx?cp-documentid=4889387 Retrieved on May 21st, 2008.

Broadbent, M. and Cullen, A. (2004) *Managing Financial Resources*, Elsevier Butterworth-Heinemann, Oxford and Burlington.

Cardona Alzate, C.A. and Sánchez Toro, O.J. (2006) Energy consumption analysis of integrated flowsheets for production of fuel ethanol from lignocellulosic biomass. *Energy, 2006*. 31(13): p. 2447-2459.

Carvalho, E. P. de (2005). Industrial perspective on expansion of ethanol production capacity for export in Brazil. Presentation of Sugar Cane Industry Association (UNICA), Campinas, Brazil, unpublished document.

Classen, P. A. M., Lier, J. B van, Lopez Contreras, A. M., Niel, E. W. J. Van, Sijtsma, L., Stams, A. J. M., Vries, S. S. De, Weusthuis, R. A. (1999). Utilisation of biomass for the supply of energy carriers. *Appl Microbiol Biothecnol, (1999)52, 741 - 755*.

CNN (2008-A) Global food Crisis. http://edition.cnn.com/SPECIALS/2008/news/food.crisis/. April, 2008.

CNN (2008-B). Riots, instability spread as food prices skyrocket. http://edition.cnn.com/2008/WORLD/americas/04/14/world.food.crisis/index.html#cnnSTCText. Retrieved April 14, 2008.

CNN (2008-C). Brazil leader denies biofuels hiking food prices. http://edition.cnn.com/2008/WORLD/americas/04/10/brazil.biofuel.ap/index.html Retrieved April 21, 2008.

Companhia Nacional de Abastecimento – Conab (2008-A). Acompanhamento da safra brasileira de cana-de-açúcar safra 2007/2008, Brasília, Brazil, April 2008.

Conab (2008-B). Perfil do setor do Açúcar e do Álcool no Brasil, Brasília, Brazil, April 2008.

Curry, S., Weiss J. (1993) *Project analysis in developing countries*, The Macmillan Press, London.

Diacogiannis, G. P. (1993) *Financial Management: a modeling approach using spreadsheets*, MacGraw-Hill International, London.

Eggeman, T. and Elander, R.T. (2005) Process and economic analysis of pretreatment technologies. *Bioresource Technology,* 2005. 96(18): p. 2019-2025.

Empresa de Pesquisa Energética – EPE (2007). Monitoramento, acompanhamento e Análise do Mercado de Energia. Brasília, Brazil, December 2007.

Fargione, J., Hill, J., Tilman, D., Polansky, S., Hawthorne, P. (2008) Land Clearing and the Biofuel Carbon Debt, *Science 319, 1157*.

Finguerut, J. (2006). Etanol production from sugar cane: using the sugar and the bagasse. Presentation of Brazilian Cane Technology Center, São Paulo, unpublished document.

FXHISTORY (2008): Historical Currency Exchange Rate. http://www.oanda.com/convert/fxhistory. Retrieved June 6, 2008.

Gardebroek, C. and Peerlings, J.H.M. (2006). Economics of Agribusiness, Reader 2006/07, Wageningen.

Gazeta Mercantil (2008). Diesel de cana chega até 2010. http://www.agrolink.com.br/clipping/jr.aspx?cn=113740&ul=136238&cid=10753&rt=1&cnd=0&tv=1. Report published on April 24, 2008.

Goldemberg, J. (2008). The Brazilian biofuels industry. *Biotechnology for biofuels 2008, 1:6*.

Instituto de Economia Aplicada - IEA (2008). Valor da Terra Nua. http://www.iea.sp.gov.br/out/banco/menu.php. Retrieved June 4, 2008.

Knight, P. (2007). Energy crops have begun a revolution for agribusiness in Brazil. *World Ethanol & Biofuels Report, F. O. Licht, 05 (12), 243 - 248*.

Licht, F. O. (2008). Next Generation Biofuels. *World Ethanol & Biofuels Report, F. O. Licht, 06 (12), 219 - 224*.

Maas, R. H. W. (2008). Microbial Conversion of Lignocellulose-Derived Carbohydrates into Bioethanol and Latic Acid, PhD thesis, Wagenigen University.

Macedo, I. C, Leal, M. R. L. V., Silva, J. E. A. R. da (2004). Balanço das emissões de gases do efeito estufa na produção e no uso do etanol no Brasil, São Paulo, Brazil, Abril, 2004.

Perkins, F. (1994) *Practical cost benefit analysis*, The Macmillan Education Australia, Melbourne.

Pinches, G. E. (1994) *Financial Management*, Haper Collins College Publishers, New York.

Rezende, G. C. Ocupação agrícola e estrutura agrária no cerrado: o papel do preço da terra, dos recursos naturais e da tecnologia. *Texto para Discussão* nº 913, IPEA, 2002.

Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J. Tokgoz, S., Hayes, D. Yu, T. (2008) Use of US Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change, *Science 319, 1238*.

Van Horne, J. C.. (1992) *Financial Management and Policy*, Prentice-Hall International, London.

World Bank (2007) *World Development Indicators* http://library.wur.nl/citrix/wur/World-Development-Indicators.ICA. Retrieved June 4, 2008.

Zerbe Jr., R. O., Dively, D. D. (1994) *Benefit-cost analysis: in theory and practice*, HarperCollins College Publishers, New York.

Zuurbier, J. P. (2008). Feedstock for bioethanol: the Brazilian case. Presentation of 6th European Motor - BioFuels Forum, Rotterdam, The Netherlands, 9-10 January 2008: http://conference.europoint.eu/biofuels2008/. Retrieved April 18, 2008.

Appendix

Entry data

Basic assumptions

	M3/a	
Ethanol Plant Capacity		200,000
Brazilian ethanol productivity	l/ton sugar cane	
		82.4
Sugar cane productivity	ton/ha	
		81.4
Ethanol productivity growth rate		1.50%
Sugar cane productivity growth rate		1.50%
Bagasse per ton sugar cane		28%
Trash per ton sugar cane		28%

Economic parameters

Trade energy share	100%
Expected ethanol revenue	95%
Energy revenue expectancy	95%
Investment interest rate	10%
Income tax	35%
Residual industry value	5%
Land appreciation	2.46%

Costs

1st gen Plant	US$/ton sugar cane	
		53.5
1st and 2nd gen plant (total investment)	M US$	
		188.3
Machines	US$/ha	
		1,307
Land	US$/ha	
		3,798
Other running costs	US$/M3	
		47.57
Labor	US$/M3	
		7.45
Insurance, taxes and other costs	US$/M3	
		6.88
Other operation costs	US$/M3	
		33.24
Trash costs	US$/ton trash	
		7.24
Working capital	% equip investment	
		6%
Royalties	% ethanol revenue	
		5%

Prices

	US$/l
Ethanol price	0.45
Electricity price	US$/MWh
	66.2
Price growth rate	3.00%

2nd generation technology

Bagasse and trash composition (dry matter)	
Cellulose	35%
Hemicellulose	25%
Lignin	25%
Ash	15%
Sugars yield hydrolisis	
Cellulose	90%
Hemicellulose	90%
EtOH Yield	43%
Fermentation	
Energy conversion efficiency	
Total Energy to Steam	80%
Steam to Electricity	20%

Data Calculation – Part I

	1st + 2nd gen plant					
		kta	m3/a	l/a		
	Plant capacity, EtOH	157.8	200000	**200000000**		
				200000000	Adjust	
		kta	kg	l		
1st gen	EtOH productivity	79.52	79518757.95	100784230.6		
	EtOH productivity per ton sugar cane		73.96906849	**93.75**		
	Total sugar cane to be harvested	**1,075**				
	EtOH productivity	78.28	78281242.05	99215769.39		
	EtOH productivity per ton sugar cane		72.81792	92.29140684		
2nd gen						
		kta	kg	l		
	Total bagasse produced	301.007606	301007606			
	Bagasse (50% wet) per ton sugar cane		280			
	Total trash produced	301.007606	301007606			
	Trash per ton sugar cane		280			
	Total EtOH productivity				Adjust all	
	Total EtOH productivity per ton sugar cane		146.7869885	186.0418105		
		t/ha	ha			
	Total area required for sugarcane	**92.66**	11,602			

1st gen plant				
	kta	m3/a	l/a	
Plant capacity, EtOH	157.8	200000	200000000	
	kta	kg	l	
EtOH productivity	157.8	157800000	200000000	
EtOH productivity per ton sugar cane		73.96906849	93.75	
Total sugar cane to be harvested	2,133			
	kta	kg	l	
Total bagasse produced	597.330761	597330761.4		
Bagasse (50% wet) per ton sugar cane		280		
Total trash produced	597.330761	597330761.4		
Trash per ton sugar cane		280		
	t/ha	ha		
Total area required for sugarcane	92.66	23,024		

1st gen plant - Energy produced total				
	MJ/kg	GJ	MW	MWh
Power potential total, bagasse and trash (50% wet)	9.42075	11254607.54	390.784984	
Power potential per ton of bagasse and trash used	9.42075	9.42075		
Steam potential total		9003686.032	312.6279872	
Steam potential per ton of bagasse and trash used		7.5366		
Electricity potential total		1800737.206	62.52559745	500204.7796
Electricity potential per ton of bagasse and trash used		1.50732		0.4187
		GJ	MW	MWh
Steam Demand for internal use		4537200	157.5416667	
Rest Energy - Steam		4466486.032	155.0863206	
Rest Energy - Steam per ton of bagasse and trash used		3.738704183		
Electricity sold to the grid		714637.7652	24.81381129	198,510.49
Electricity sold to the grid per ton of sugar cane		0.334987895		0.093052193

	years
Project life	18
	M$ (2007)
Plant Investment	114,028,963
Machines	30,082,555
Land Investment	87,444,409
Total capital investment	231,555,927
	$/l
Minimum Seling Price	0.31
	%
Internal rate of return (IRR)	18.7%
	years
Pay-back time	8/9

Data Calculation – Part II

Bagasse utilization for EtOH	100.00%
Trash utilization for EtOH	100.00%

		Sugars Yeild	EtOH Yield
2nd generation technology		Sugars Yeild	EtOH Yield
Bagasse and trash composition (dry matter)		Hydrolysis	Fermentation
Cellulose	**35.00%**	**90.00%**	
Hemicellulose	**25.00%**	**90.00%**	**43.00%**
Lignin	**25.00%**	0.00%	
Ash	**15.00%**	0.00%	
Total	100.00%		
Total Sugars		60.48%	26.006400%

Energy conversion efficiency		
Total Energy to Steam	**80.00%**	
Steam to Electricity	**20.00%**	(20%-old systems
Total Energy to Electricity	16.00%	,40% - new high pressure boilers)

		1st gen	2gen
Energy required to produce one liter EtOH (steam)	MJ/L		
Pretreatment and SSCF		0	4.23
Distillation and dehydration		21.14	26.42
Evaporation		0	0
Effluent treatment		0	0
Burned lignin		0	0
Feedstock handling		0.96	0
Transportation		0.59	0
Total		22.686	30.65

Integrated 1st + 2nd gen plant					
Energy produced	GJ		MW	MWh	kta
Lignin Available after hydrolysis (Bagasse + Trash)		1991767.329	69.15858781		75.2519
Unconverted residue available after hydrolysis		170143.0443	5.907744592		18.06046
Power potential total		2161910.373	75.0663324		
Power potential per ton of bagasse and trash used		3.5911225			
Steam potential total		1729528.299	60.05306592		
Steam potential per ton of bagasse and trash used		2.872898			
Electricity potential total		345905.6597	12.01061318	96084.90548	
Electricity potential per ton of bagasse and trash used				0.159605444	
Electricity sold to the grid				0	
Electricity sold to the grid per ton of sugar cane				0	
	GJ		MW	MWh	kta
Steam Demand for internal use		6130000	212.8472222		
Missing Energy - Steam		4400471.701	152.7941563		
Missing Energy - Steam per ton of bagasse and trash		7.30956895			
Trash demand for missing steam energy					**467.1042**

Project life		years	18
Plant Investment		M$ (2007)	188,322,091
Machines			15,159,236
Land Investment			44,065,087
Total capital investment			247,546,414
Minimum Seling Price		$/l	0.40
Internal rate of return (IRR)		%	13.5%
Pay-back time	8/9	years	

First Generation Biofuel Results – Part I

Parameter	Unit	Value	References	Conventional
Ethanol capacity	M^3	200,000	Data entry	
Brazilian ethanol average	l/ton sugar cane	82.4	Calculated, based on Conab (2008), p.45	
Sugar cane productivity	ton/ha	81.4	Calculated, based on Conab (2008), p.45	
Plant	US$/t	53.5	Cunha (2006) scaled up	
Machines	US$/ha	1,307	Cunha (2006) scaled up	
Land	US$/ha	3,798	IEA (2008) - 70% pasture price average	
Other running costs	US$/M3	47.57	Goldemberg (2008)	
Labor	US$/M3	7.45		
Insurance, taxes and other costs	US$/M3	6.88		
Other operation costs	US$/M3	33.24		
Trash costs	US$/ton trash	7.24	Finguerut (2006)	
Expected ethanol revenue	%	95%	Parameter for not full operation	
Energy revenue expectancy	%	95%	Parameter for not full operation	
Ethanol productivity growth rate	%	1.50%	Suggestion based on historical data	
SC productivity growth rate	%	1.50%	Suggestion based on historical data	
Ethanol price	US$/l	0.45	Licht (2008)	
Price growth rate	%	3.00%	Suggestion based on historical data	
Income tax	%	35%	adopted Brazil's average tax	
Investment interest rate	%	10%	Estimate (Selic = 11%, TJLP = 6.75%)	
Energy price	US$/MWh	66.2	EPE (2008)	
Trade Energy share	%	100%		
bagasse per ton sugar cane	%	28%		
trash per ton sugar cane	%	28%		
Residual industry value	%	5%	Suggestion for salvage value	
Land appreciation	%	2.46%	Suggestion based on Rezende (2002)	
Working capital	%	6%	Suggestion	

First Generation Biofuel Results – Part II

Results			
Average sugar cane productivity	ton/ha		92.66
Average ethanol productivity	l/ton sugar cane		93.75
Need sugar cane	thousand tons		2,133
Need land	ha		23,024
Investment			
Plant	US$		114,028,963
Machines	US$		30,082,555
Equipments' total	US$		**144,111,518**
Land	US$		87,444,409
Total Investment	US$		**231,555,927**
Other Costs			
Labor	US$		1,490,185
Insurance, taxes and other costs	US$		1,375,556
Other operation costs	US$		6,648,518
Total	US$		**9,514,259**
Working capital	US$		**8,646,691**
Project appraisal			
NPV	US$		213,001,923
IRR	%		18.7%
PB		1.43	8/9
Price simulation	Calculate		
NPV		-0.0	
Minimum selling biofuel price		0.31	
IRR		10.0%	

Second Generation Biofuel Results – Part I

Parameter	Unit	Value	References	Conv. + 2nd Gen.
Ethanol capacity	M^3	200,000	Data entry	
Brazilian ethanol average	l/ton sugar cane	82.4	Calculated, based on Conab (2008), p.45	
Sugar cane productivity	ton/ha	81.4	Calculated, based on Conab (2008), p.45	
Machines	US$/ha	1,307	Cunha (2006)	
Land	US$/ha	3,798	scaled up IEA (2008) - 70% pasture price average	
Other running costs	US$/M3	47.57	Goldemberg (2008)	
Labor	US$/M3	7.45		
Insurance, taxes and other adm. costs	US$/M3	6.88		
Other operation costs	US$/M3	33.24		
Trash costs	US$/ton trash	7.24	Finguerut (2006)	
Expected ethanol revenue	%	95%	Parameter for not full operation	
Energy revenue expectancy	%	95%	Parameter for not full operation	
Ethanol productivity growth rate	%	1.50%	Suggestion based on historical data	
SC productivity growth rate	%	1.50%	Suggestion based on historical data	
Ethanol price	US$/l	0.45	Licht (2008)	
Price growth rate	%	3.00%	Suggestion based on historical data	
Income tax	%	35%	adopted Brazil's average income tax	
Investment interest rate	%	10%	Estimate (Selic = 11%, TJLP = 6.75%)	
Energy price	US$/MWh	66.17	EPE (2008)	
Trade Energy share	%	100%		
bagasse per ton sugar cane	%	28.0%		
trash per ton sugar cane	%	28.0%		
Residual industry value	%	5%	Suggestion for salvage value	
Land appreciation	%	2.46%	Suggestion based on Rezende (2002)	
Royalties	%	5%	Suggestion	
Working capital	%	6%	Suggestion	

Second Generation Biofuel Results – Part II

Results		
1st gen ethanol production	M^3	100,784
2nd gen ethanol production	M^3	99,216
Average sugar cane productivity	ton/ha	92.66
Average ethanol productivity	l/ton sugar cane	93.75
Need sugar cane	thousand tons	1,075
Need land	ha	11,602
Investment		
1st gen. + 2nd gen. Plant	US$	**188,322,091**
Machines	US$	15,159,236
Equipments' total	US$	**203,481,327**
Land	US$	44,065,087
Total Investment	US$	**247,546,414**
Other Costs		
Labor	US$	1,490,185
Insurance, taxes and other costs	US$	1,375,556
Other operation costs	US$	6,648,518
Total	US$	**9,514,259**
Working capital	US$	**12,208,880**
Project appraisal		
NPV	US$	78,516,315
IRR	%	13.5%
PB	1.06	8/9
Price simulation	Calculate	
NPV	0	
Minimum selling biofuel price	0.40	
IRR	10%	

CO_2 debt and price evolution

Year	CO_2 Debt (ton)	Price US$ per ton CO_2
2008	1,884,564	11.62
2009	1,773,707	12.78
2010	1,662,851	14.06
2011	1,551,994	15.46
2012	1,441,137	17.01
2013	1,330,280	18.71
2014	1,219,424	20.58
2015	1,108,567	22.64
2016	997,710	24.90
2017	886,854	27.39
2018	775,997	30.13
2019	665,140	33.14
2020	554,284	36.46
2021	443,427	40.10
2022	332,570	44.11
2023	221,713	48.53
2024	110,857	53.38
2025	0	58.72
Average	**942,282**	**29.43**

