Journal of Environmental Science and Engineering A 8 (2019) 113-129
doi:10.17265/2162-5298/2019.03.004

DAVID PUBLISHING

The Weight of Environment Aspect in the Choice of Vinasse Processing with New Technology through Economic Assessment

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Abstract: Vinasse improper disposal can cause damages to the environment. Fertigation, concentration and digestion aerobic or anaerobic generating fuel gas are the main technologies for vinasse use. Such alternatives present different impact on the environment; however, the weight of environment aspect in the decision remains under discussion. In this paper, authors present a discussion and valuations of environmental aspects about the main technologies of vinasse treatments. First, authors elaborated questionnaires, consulting specialists about the environmental and economical aspect of decision for changing to more environmentally friend technologies. The answers strongly suggest that the decisions of companies are mainly motivates by economics issue, and changing the current technology would be possible only if IRR (Internal Rate of Return) remains around 25%-30%. Then, authors proposed and performed calculations for inserting environmental aspects in the economical evaluation of technologies. The environmental resources performed considering carbon credit, economy with mineral fertilizers and the cost avoided with environmental fines. Scenarios and sensitivity cases performed, presenting discussions about the weight of environmental aspect in technology choice. It is possible to propose government policies that can economically value environmental benefits, such as tax reductions for people using vehicles to RGN (Renewable Gas Natural) or the implementation of a green label for companies that use biogas or RGN in their production processes (green label can be a differential or an extra score for company in future public bids, for example). The results showed that environmental aspect impacts directly the NPV (Net Present Value) of each technology, which can lead even to positive financial returns to companies; however, depending on valuation of environmental resources. Considering the environmental feature in economic impacts, the best option is the use of anaerobic digestion to produce energy that reduces carbon dioxide emissions or anaerobic digestion to produce gas if considering environmental scenario with the government policy of exemption from the tax on the ownership of motor vehicles. From the point of view of the land and water, it is possible to value economically in qualitative aspects through sectoral governmental policies.

Key words: Vinasse, sugarcane and biogas.

1. Introduction

In plants of ethanol from sugarcane, the vinasse is obtained in the distillation of wort, in a ratio around 10-15 liters of vinasse per liter of ethanol [1]. Since it is rich in organic components, nitrogen, phosphorus and potassium, among others, vinasse is used as fertilizers in agriculture [2].

Fertigation (disposing vinasse in soil concentrated or *in natura*) is the most common employed technology. Other technologies still have little use due to the options of better approval of the vinasse to have a high financial cost.

Several studies concern about technical, environmental and/or economic aspects of vinasse treatment. Next, some studies present summarizing impacts of the main two technologies employed nowadays, fertigation and biogas generation (with and

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without energy production).

Fig. 1 illustrates the possible environmental damage to steps of vinasse treatment, fertigation and digestion.

Studies support different interpretations about the impact of vinasse in air, water bodies and soils [3, 4].

Regard to air pollution, vinasse application can influence the amount of GHG (Greenhouse Gases) released on field. The lack of knowledge about greenhouse gas generation is hindrance to quantify the impact of sugar cane crops on the environment [5]. Emissions of CH_4 have been observed from in-open channels of vinasse storing and distribution [6, 7], however, can be significantly reduced (620 times) in closed tanks and pipes [8]. Some works quantified the release of CO_2 and/or N_2O under application of vinasse on soil, showing that vinasse used leads to greater amount of such gases compared to the use of urea [9-12]. However, such fluxes can be reduced by the vinasse pretreatment, like anaerobic digestion, although other fluxes like ammonia can increase [13]. Fertigation impacts air pollution also in the consumption of diesel of trucks for transport and application, nonetheless, studies show that it is less polluting than the emissions with the use of mineral fertilizers [14].

Regarding the impact in water bodies, the direct disposal of vinasse in water leads to great toxicity for aquatic life [15]. Even vinasse is never applied directly on water, the disposal in soils affects water bodies. Although it depends on soil, studies have shown the high capacity of soils to retain contamination of vinasse, where the percolated liquid presented significant lower values of BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), TDS (Total Dissolved Solids) and CE (Electrical Conductivity) compared to pure vinasse [16, 17]. Nonetheless, groundwater may present changes in the TDS, BOD, COD, CE, Cl^-, K^+, Ca^{2+} and Mg^{2+} [18, 19], making some groundwater bodies inadequate for irrigation under the risk of soil salinization [17].

Concerning impact on soil, literature report approaches associated to possible vinasse impacts, besides experimental investigations about short and long time of vinasse application. Negative impacts are generally associated to risk of salinization and nutrients leaching [20, 21]. This study presented potential negative effects of vinasse in the environment, thought the analysis of vinasse samples and compared with reported risks in the soil effect, pointing out to the high risk of salinization and organic overloading soil. In short time application studies, Macedo [22] applied vinasse in 0 to 350 $m^3 \cdot ha^{-1}$ with four repetitions for each test, observing a reduction in the infiltration rate of soil with vinasse dose, which increased the risk of soil erosion. Even so, soil erosion for sugar cane crops is typically less critical than other cultures, like corn or soybean [20, 23].

Camilotti, et al. [24] investigated different types of soils under application of crude vinasse and treated vinasse, concluding that crude vinasse application increased the risk of soil salinization by ions Zn^{2+} and Mn^{2+}. This work [25] investigated the risk of soil

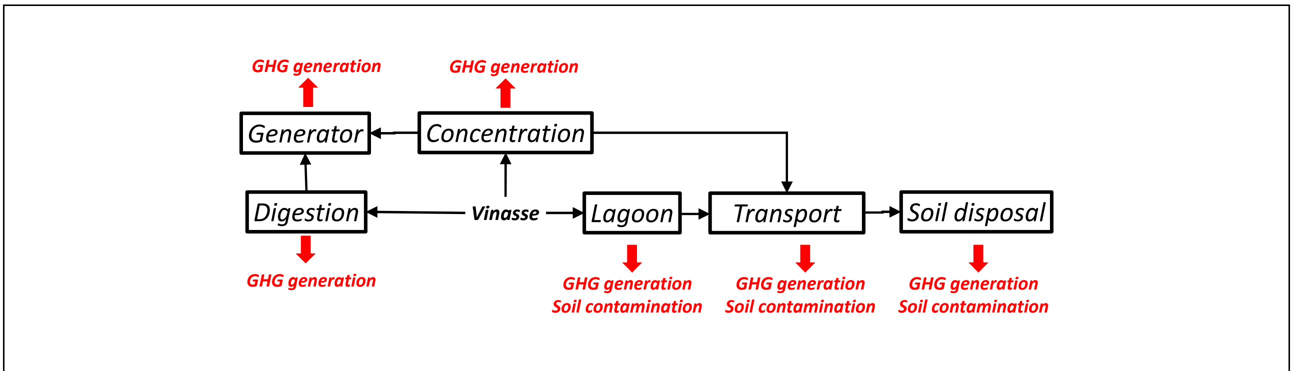

Fig. 1 Possible environmental damage from vinasse treatments (water bodies contamination comes from indirect effect of soil contamination).

contamination of the compounds Cd, Cr, Ni and Pb during the applications of vinasse with sewage sludge in the time of three years, to supply the 100% and 200% of soil need of N and K, concluding that species concentrations did not change during this time. The investigated the concentrations of the heavy metals Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn in fertigation soils, comparing concentrations with previous values obtained in 1995; the authors observed a significant increase only in Zn concentration of soils [25].

Canellas, et al. [26] investigated the effects of different treatments in soils during 2-3 years, with application of vinasse in water up to 105 $t \cdot ha^{-1} \cdot yr^{-1}$, observing an increase in K^+ concentration, besides no other significant negative effect was observed by authors. In long time investigating studies, compared with Rosabal, et al. [27] the soil compositions receiving 120 $m^3 \cdot ha^{-1}$ during 35 years and other areas without receiving vinasse, under same conditions of farming conditions during the same time, observed an increase of carbon, macro and micro nutrients in soil with vinasse addition, improving soil fertility. Nicochelli, et al. [28] performed investigation in a long-term soil fertigation, comparing soils fertigation during forty years without fertigation soils; observing negative impact on micro nutrient concentrations.

Some authors [23, 26, 29] affirm that contamination of groundwater and nutrients leaching is not significant below 300 $m^3 \cdot ha^{-1} \cdot yr^{-1}$. However, it depends on the characteristics of the soil, like ion CTC (Exchange Capacity), infiltration rate, storing capacity of nutrients, besides distance from water bodies [30].

Several studies point out possible benefits of fertigation. It can improve soils degradation for burns [31] or contaminated soils improving yield in agriculture [32]. Fertigation can also supply part of the necessary water volume required to implement subsurface drip irrigation, which is specially beneficial in regions where water availability is a problem [33], among other effects. Harihastuti and Marlena [34] through an LCA (Life Cycle Assessment) study, concluded that the substitution of chemical fertilizers by vinasse led to environment benefits, concluding that it reduces the demand for non-renewable energy sources, besides climate change, terrestrial acidification and human toxicity.

Technologies that improve of anaerobic digestion [35, 36] and are mature with extensive development of the operation and maintenance market and stresses that vinasse contained high carbohydrate generations, such as, VFAs (Volatile Fatty Acids), high COD and it is possible to produce biogas that can be used as renewable energy.

According to many papers [37, 38], it is possible to emphasize that fundamental items such as modeling process aspects (performance, two- and single-phase systems, type of biodigester, operation and maintenance, among others) must be analyzed for realization of environmental and economic feasibility studies.

Studies about digestion [39, 40] enhancement and many pre-treatments of several technologies and types of waste can process inputs, such as, landfill waste, vinasse and animal waste. This study about the advantages of anaerobic digestion for minimize the emission of greenhouse gas in many scenarios and combined technologies.

Many papers [41, 42] said that anaerobic digestion reduced twenty-five environmental impacts of GHG. Papers [37, 43] present that based on LCA, anaerobic digestion power plants can reduce the total impact by 77%, showing to be the best option for vinasse treatment. This study presents exergy efficiencies up to 46% for anaerobic digestion power plants, being that 24% of the exergy of vinasse can be converted into renewable energy.

This paper presents LCA methodology [43]. LCA has many limitations, such as:

- LCA accuracy is related if data are available for your research and analysis;
- Classic LCA does not bring the accuracy of

which product or process is most economically feasible by analyzing the scenarios in a holistic and integrated way (environmental, technical and economy aspects);

- LCA does not quantify any new impacts, for example, legal risks from the vinasse spill in the aquatic.

Vinasse has been used principally on fertigation on practices, for utilizing it as a liquid fertilizer for crops [44]. Fertigation usually has negative effects on soil and ground waters and air in the long time [45]. Actually, in the world, have many uses of vinasse in large-scale operations, for example, vinasse recycling to fermentation streams [41, 42], energy production [44, 46], animal feed production [46], concentration vinasse with economy analysis and incineration of vinasse [47].

Many works [47, 48] realized economic analysis about this area. All the works conclude that the use of technologies for the best use of vinasse in Brazil through vinasse biodigestion or concentration is feasible. Other studies propose scenarios with the combination of technologies, such as, Costa, et al. [49] propose combination of concentration and anaerobic biodigestion for best use of vinasse.

Ceres [50] propose many scenario combinations and designed much objective optimization in virtual biorefinery. The modeling involving the production of first and second generation ethanol besides the energy generation through vinasse. Finally, Table 1 presents technologies for best use of vinasse [51].

Biofertilizer can be generated both in concentration technologies and in biogas production. Besides this characteristic, advantages and drawbacks of the main technologies are summarized in Table 2.

Particularly, biogas generation from vinasse allows the production of energy from the combustion of biogas, allowing reducing the emission of methane in atmosphere [47].

Several authors have investigated technologies for vinasse treatment only based on technical and economic aspects without considering the environmental aspects quantified in the cash flow of the project. Many authors [30, 48, 49] address the environmental aspects of the best technological option but in a qualitative only way and considering only economic aspects for its analysis. This work needs additional studies of economic feasibility of these treatments considering the environmental aspects and others scenarios.

Table 1 Technologies in the field of vinasse.

Technology	Characteristics
ScbcsZld	It is sugarcane business case sustainability with zero liquid discharge with recovery of water for reuse in the production process.
Biofom	Evaporates vinasse with high heat transfer mass and production of biofertlizers.
Meri System	Production of biogas and biofertilizers through vinasse in UASB (Upflow Anaerobic Reactor System), which can produce electric, thermal and/or vehicular energy.
Compress	System of evaporation for this vinasse of sugarcane plant and possibility fertigation is farthest from the sugarcane plant.

Table 2 Technologies and vinasse applications.

Technology	Advantages	Attention points
Fertigation	Easy-to-apply, mature method with supply of goods and services of supplies and workers suitable for professional activity	Economically feasible up to 15 km of displacement, risk of contamination of soil and groundwater, besides accidents with dams and transport.
Vinasse concentration and fertigation	Reduces the amount of fresh vinasse through the soil: Reducing transport costs of several plants in operation, possible reuse of water reducing the amount of fresh water in sugarcane process.	The same of the fertigation.
Biogas generation	Allows increasing the supply of energy and RGN (Renewable Gas Natural).	Few plants in operation (however, with a tendency to rise).

Finally, Renovabio is the federal policy (law 13.576-2017), for the biofuels sector was announced with many objectives, such as, contributing to an adequate energy efficiency and GHG emission reduction ratio in the production, marketing and use of biofuels, including LCA mechanisms. It stressed that government policies interconnect with the monetization and economic valuation of environmental, social aspects, among others.

The evaluation of the best technology depends on the valuation of environmental resource. EVER (Economic Value of the Environmental Resource) classified aspects of environmental valuation. EVER is composed by the sum of VU (Value of Use) and VNU (Value of Non-Use), each of these can be divided in other terms, as shown in Eq. (1) [50]:

$$EVER = \underbrace{(DUV + IUV + OV)}_{VU} + \underbrace{EV}_{VNU} \quad (1)$$

where:

DUV = Direct Use Value, value that individuals attribute to an environmental resource due to direct consumption.

IUV = Indirect Use Value, value that individuals attribute to an environmental resource when the benefit of their use derives from ecosystem functions.

OV = Option Value, the amount that individuals are willing to pay to maintain the option of one day to use, directly or indirectly.

EV = Existence Value, the value that derives from a moral, cultural or altruistic position.

With regard to vinasse, it is common the following application of EVER presents in Table 3 with valuation methods for vinasse.

Of all these options presented, it was possible to study in this work:

fertilizer economy (Opportunity Costs);

economy with environmental fines (Avoided Costs);

Carbon credit (Marginal Productivity).

Several authors have investigated technologies for vinasse disposal considering environmental aspect but without a monetary valuation, but only present in this work technical and economy aspects of this vinasse [47-49].

Motta [50] presents in summary form the benefits of the use of better technologies for the development of vinasse without economic studies and without monetizing the environmental aspects.

Curran [51] presents methodology for economic valuation of environmental resources. However, the work does not connect with the internalization of this valuation to the cash flow of a project. Lakatos and Marconi [52] present the environmental life cycle but do not connect with the economical valuation of environmental resources in a cash flow of project.

Cruz, et al. [3] resent a feasibility study for the use of vinasse in the sugarcane only of São Paulo State addressing the environmental aspects of vinasse use (water, air and land) and comment the need to include the economic valuation of the environmental impacts on the cash flow of the next ventures of the sector.

In resume, this work said that the biodigestion and concentration, these technologies presented several gains against use in nature, being the first responsible for the mitigation of GEE's (*Greenhouse* Gas Emissions) and the second by a more rational application of vinasse and by a better equation of the high volumes of water used by the mills and distilleries [3].

This paper [47] analyzed some environmental impacts (GHG for example) of the use of vinasse but did not carry out the internalization of the valuation of the environmental resources in the economic evaluation of the project of improvement of vinasse utilization through available and feasible technologies used.

Finally, this work presents economy and environmental analysis of possible technological option for best use of vinasse, considering the economic valuation of environmental aspects, such as: carbon credits, avoided costs of soil pollution through possible environmental fines and the economy with the purchase

Table 3 Valuation methods for vinasse.

Valuation methods			Use Value		Use not value	
			Use Value direct	Use Value Indirect	Option Value	Enterprise value
Indirect methods	Marginal productivity		Carbon credit		NA	NA
	Replacement goods market	Avoided costs	Administrative or judicial environmental fines		NA	NA
		Control costs	Technologies for the best use and destination of vinasse		NA	NA
		Replacement costs	Costs for repairing of groundwater with the wrong application of soil vinasse		NA	NA
		Opportunity costs	Economy with the production of biofertilizers		NA	NA
Direct methods	Real market	Travel cost	Inadequate disposal of vinasse near tourist attractions		NA	NA
		Hedonic prices	A sugarcane mill that reduces pollution can raise the value of its soil and nearby areas			NA
	Hypothetical market	Contingent evaluation	Renovabio and other forms of hypothetical markets for the use of vinasse			

NA: not applicable.

of mineral fertilizers. The results discussed are based on questionnaire answered from specialists.

2. Material and Methods

Questionnaires are an instrument of data collection, containing a logical order of questions, which in this work were answered by a contracted system of company and site "Survey Monkey" and without the presence of the researcher, according to the studies about methodology for the application of questionnaires [53].

In general, the questionnaires fulfill two objectives that are to describe the characteristics and measure certain variables of a group of professionals of a given sector, being, in essence, a highly structured and segmented interview [54].

In this sense, the questionnaires represent a more rigid and rich form of information exchange [55-57]. In this sense, the questionnaires represent a more rigid and rich form of information exchange [56]. In this paper, it is possible to map these technologies with the best using of vinasse and what the internal return rate necessary for motivating this investing and market of suppliers.

Many papers [56, 57] show the importance of working with questionnaires to measure the market opinion about a particular technology to be used and qualitative analysis on a certain subject, as for example, the qualitative analysis of which the percentage of economic feasibility motivates the change of use of one technology.

Brinkmann [54] showed many and mutual contributions between the two approaches, indicating that qualitative methods can support quantitative research in the following ways:

Using questionnaires and observation techniques as tools to aid in the formulation of problem throughout the planning phase of the research;

Using questionnaires, interviews, observations and group discussions in order to enrich the data collection process; and

Using questionnaires and other qualitative techniques in this paper and relation respective with quantitative methods.

In this work [57], quantitative and qualitative approaches are not discrepant or mutually exclusive, but on opposite, they are complementary. Many qualitative researches have provided statistical techniques for the treatment and quantification of part of the data collected. It is possible to make the connection between quantitative and qualitative vision in search of integrated solution for better use of vinasse in Brazil.

The questionnaire was applied to three hundred people and answered by thirty-nine people who are professionals in the field and specialists in the sector.

The followings are the questions asked to the respondents of this questionnaire:

(1) What is the professional sector?

(2) Technology used at Brazil?

(3) IRR for changing technology?

(4) Anaerobic biodigestion is more economical process than fertigation?

(5) Concentration is more economical process than fertigation?

(6) Environmental technologies versus financial advantages?

(7) Does the government offer little incentive for technologies for better use of vinasse?

(8) Is it necessary to create a national program to encourage the best use of vinasse in Brazil?

At second moment, after verification through questionnaire responses and definition of which technologies are feasible for implementation and large scale, this paper determined the values of technologies obtained from manufactures, together with annual costs for maintenance. These values are present for a sugar plant with 200 m³ by hour of vinasse. Table 4 present standards values of investment of different technologies.

NPV (Net Present Value) [58, 59] is used to determine the present value of an investment by the discounted sum of all cash flows received from the project.

Eq. (2) presents NPV, calculated as:

$$NPV = Investiment - \sum_{n=1}^{10} \frac{Income_n}{(1 + MRA)^n} \quad (2)$$

where MARR is minimum attractiveness rate return, typical in investment analysis. MARR calculates the rate that motivated to invest in a project or business.

Eq. (3) presents income at a year n, which can be calculated as:

$$Income_n = \binom{Energy}{sells}_n + \binom{RNG}{sells}_n + \underbrace{\binom{Environmental}{Economy}_n}_{\substack{carbon\ credit,\\ avoided\ costs\ with\ fines}} - AnTecCosts_n \quad (3)$$

Eq. (4) presents energy sells that can be calculated as:

$$\binom{Energy}{sells} = \left(\frac{kWh}{ton\ of\ vinasse}\right) \cdot \left(\frac{R\$}{kWh}\right) \cdot \binom{\text{Vinasse production}}{\text{per year}} \quad (4)$$

Eq. (5) presents RGN sells that can be calculated as:

$$\binom{RNG}{sells}_n = \left(\frac{m^3 of\ RNG}{ton\ of\ vinasse}\right) \cdot \left(\frac{R\$}{m^3}\right) \cdot \binom{\text{Vinasse production}}{\text{per year}} \quad (5)$$

Eq. (6) presents Renewable Energy Calculating, that is:

$$\text{REC} = \binom{\text{Energy of}}{\text{vinasse}} \cdot \underbrace{\left(0.451 \frac{\text{ton } CO_2}{\text{MWh of vinasse}}\right)}_{\substack{\text{Tones of CO2}\\ \text{equivalent per energy}\\ \text{unit of vinasse}}} \cdot \underbrace{\left(20.74 \frac{\$}{\text{ton } CO_2}\right)}_{\substack{\text{Carbon credit}\\ \text{market value}}} \cdot \binom{\text{Vinasse production}}{\text{per year}} \quad (6)$$

Table 4 Values of investment of different technologies.

Technology	Investiment ($)	Reference	$AnTecCosts$—Annual costs for each technology ($)	Reference
Fertigation	≈ 0	*	480,000	[12]
Vinasse concentration and fertigation	4,000,000	[4]	70,600	[4]
Anaerobic digestion (energy)	7,800,000	*	62,500	*
Anaerobic digestion (renewable gas)	8,134,000	*	77,720	*

* Values obtained from technology vendors for the plant capacity.

Eq. (7) presents avoided fines that calculated as:

$$\binom{\text{Avoided}}{\text{fines}} = \binom{\text{Number}}{\text{of incidents}} \cdot \underbrace{\left(25{,}000\ \frac{\$}{\text{incident}}\right)}_{\text{cost with one incident}} \quad (7)$$

Eq. (8) presents vinasse production in sugar cane.

$$\begin{aligned} \mathit{Vinasse\ production} &= \underbrace{200\,\frac{m^3}{hr}}_{\mathit{choped\ cane\ processing}} \cdot \underbrace{5040\,\frac{hr}{yr}}_{\mathit{hours\ of\ operatoin\ in\ one\ year}} \\ &\cdot \underbrace{0{,}070\,\frac{m^3}{ton}}_{\mathit{amount\ of\ ethanol\ per\ ton\ of\ cane}} \cdot \underbrace{12\,\frac{L}{L}}_{\mathit{liters\ of\ vinasse\ per\ liter\ of\ ethanol}} \quad (8) \\ &= 846.720\ \frac{m^3}{yr} \end{aligned}$$

A plant of 200 m^3 by hour of chopped cane (this number was defined by the author as being considered a standard sugarcane plant in Brazil), leads to the following amount of vinasse production per year.

Eq. (9) presents the amount of electric energy produced with biogas generation which can be calculated as:

$$\begin{aligned} Q\ biogas\ by\ year &= Biogas\ vol \\ &* (1 - leaked\ vol) \\ &* \text{calorific value below (CVB)} \end{aligned} \quad (9)$$

where:

Vol = volume;

CVB of biogas = 17.765 Kj by Nm^3;

Leaked Volume = 5%.

Eq. (10) presents energy production for paper in all options of technological and scenarios analysis.

$$\text{Energy} = Q\ biogas\ by\ year\ * \text{engine performance} \quad (10)$$

For valuation of environmental resources, considering Eqs. (11) and (12). Eq. (13) presents the values of environmental aspects raised as follows:

$$\text{REC} = \binom{\text{Energy of}}{\text{vinasse}} \cdot \underbrace{\left(0.451\,\frac{\text{ton } CO_2}{\text{MWh of vinasse}}\right)}_{\text{Tones of } CO_2 \text{ equivalent per energy unit of vinasse}} \cdot \underbrace{\left(20.74\,\frac{\$}{\text{ton } CO_2}\right)}_{\text{Carbon credit market value}} \quad (11)$$

Eq. (12) presents the economy with Biofertilizer (BO), that is calculated as follows:

$$\text{BO} = \underbrace{80\%}_{\text{percentage of fertilizer replaced by biofertilizers}} \cdot \underbrace{\left(350\ \frac{\$}{\text{ton fertilizer}}\right)}_{\text{price of mineral fertlizer}} \cdot \left(\begin{array}{c}\text{Anual demand}\\ \text{of fertilizer for the}\\ \text{plant capacity}\end{array}\right) \quad (12)$$

Eq. (13) presents the possibility of two-evite costs estimated as:

$$\text{EC} = \underbrace{\text{x incidents}}_{\text{number of incidents in 10 years}} \cdot \underbrace{\left(25{,}000\ \frac{\$}{\text{incident}}\right)}_{\text{cost with one incident}} \quad (13)$$

Eq. (14), presents the annual value of environmental resources for each year k, i.e. $AnValEnvRes_k$ can be calculated as:

$$AnValEnvRes_k = \underbrace{REC_k}_{\mathit{carbon\ credits}} + \underbrace{BF_k}_{\mathit{bio\ fertilizers}} + \underbrace{EC_k}_{\mathit{evited\ costs}} \quad (14)$$

Eq. (15), presents the total value for each income calculated as:

$$\begin{aligned} AnValTot_k &= \varphi \cdot AnValEnvRes_k \\ &- AnTecCosts_k \end{aligned} \quad (15)$$

where: $AnValTot_k$ = Sum of total valuation;

$AnValEnvRes_k$ = Sum of total economic, environmental valuation and evited cost;

$AnTecCosts_k$ = Sum of total technical costs valuation. The economic analysis of this work considers the value of one dollar to four real (Brazilian money) according to the Brazilian exchange rate.

Then, this works presents Table 5 that shows the standard scenarios for economic valuation of environmental aspects [59].

Table 5 Scenarios analysis.

Feasibility indicators	Concentration scenario 1	Concentration scenario 2	Concentration scenario 3
Environmental fines	*	*	yes
Environmental licensing	*	*	yes
Fertilizers economy	yes	yes	yes
MARR	15%	10%	10%
Feasibility indicators	Electricity or RGN scenario 1	Electricity or RGN scenario 2	Electricity or RGN scenario 3
Environmental fines	*	*	yes
Environmental licensing	*	*	yes
Carbon credit	*	*	yes
MARR	15%	10%	10%

Table 6 Sensitivity analysis.

Feasibility indicators	Concentration conservative	Concentration optimistic	Concentration super optimistic
Fertilizers economy	10%	50%	90%
Feasibility indicators	Electricity conservative	Electricity optimistic	Electricity super optimistic
Energy value ($/MWh)	10%	50%	90%
Carbon credit	10%	50%	90%
Feasibility indicators	RNG conservative	RNG optimistic	RNG super optimistic
RGN value ($/m^3)	10%	50%	90%

where:

Environmental Fines: cost avoided with environmental fines that can be applied to sugarcane that violate environmental laws. This item was considering the cost of avoided standard fines of the sector that is in the level of $25,000. This amount was obtained after consulting the state and federal control and inspection bodies in Brazil.

Environmental licensing: economy with the exemption of environmental licensing fee due to the environmental policy proposed by the author to increase the best use of vinasse. That is, this item was completely withdrawn from the cost of the project the collection of 0.5% of the total value of the investment.

Fertilizers economy: mineral fertilizer economy due to the reduction of fertigation due to the concentration of the vinasse through evaporators. The value considered for this paper was $350 a ton of mineral fertilizer, that is, market value.

Carbon credit: the reduction of GHG is the main objective of the carbon credit market. The value used for carbon credit was the market value for November 2018, $20.74.

Taxes exemption: exemption from the property tax of automotive vehicles, being a government policy proposed by the author in search of the best use of vinasse.

This paper presents sensitivity analysis with the conservative scenario that shows a revenue increase of 10% in relation to the standard scenario (Table 5). The optimistic scenario presents an increase of 50% and the optimist scenario of 90%.

Table 6 presents in summary form the proposals' sensitivity analysis of the environmental aspects proposing conservative, optimistic and super optimistic scenarios.

where:

Fertilizers economy: if the price of mineral fertilizers increases, which can occur by determining the market forces of supply and demand of the sector, this item can increase and generate greater economic valuation of environmental resources.

Carbon credit: the market for valuation of carbon credit has its price and price changes and over time it is natural to raise this price and we can use the conservative, optimistic and super optimistic scenarios to carry out this sensitivity analysis.

In all sensitivity analyzed, the inflation rate of 3% (according to economical moment of Brazil) by year was used for the adjustment of energy input revenues.

3. Procedure for Selecting the Best Model

This questionnaire to mapping market desires in search of new technologies. It is important to define what are the economic indicators, technical or environmental aspects that would motivate investors to realize business and investments in new technologies with sustainability.

Fig. 2 presents and shows the percentages for each professional category that participated in this questionnaire.

It is worth noting the great participation of engineers in this research, which is in line with the reality of the researched topic, which involves engineering in its production process, as well as technicians for performing operations and maintenance. The low percentage of respondents, operation, maintenance, researcher area is justified by the difficulty of accessing these professionals or audience of time before their troubled agendas to answer the questionnaire.

Fig. 3 presents which are the main technologies currently used by sugarcane plant for final destination of vinasse in Brazil.

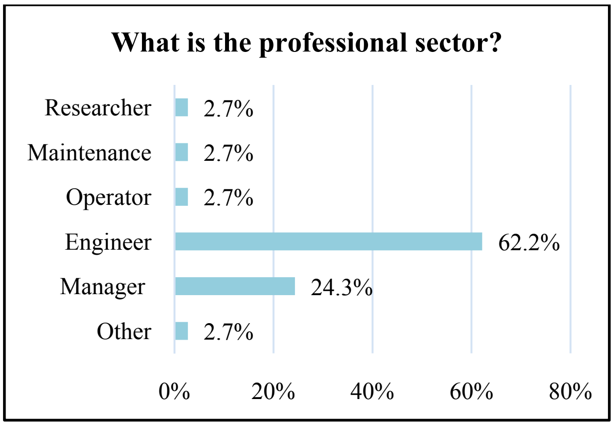

Fig. 2 Professional sector of answers.

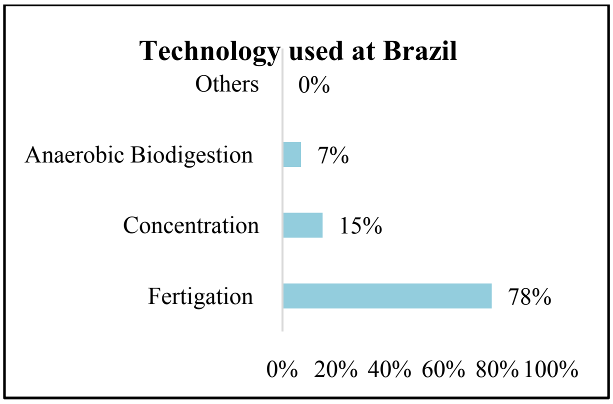

Fig. 3 Technology used at Brazil.

It is possible to view a great importance and predominance that the fertigation still has in Brazil little growth of the vinasse concentration and few biodigestion plants. This is the country's technological picture in this area.

The explanation for having more concentration plants than biodigestion is its lower initial investment value in relation to anaerobic biodigestion in the thermophilic phase, in particular [30].

Fig. 4 presents the minimal internal rate to motivate the implantation of new technologies of use of vinasse in your company.

Results of the questionnaires show clearly and unequivocally that most people will only change the technology to make better use of the vinasse if the NPV is positive and the internal rate of return of the project exceeds twenty five percent.

Fig. 5 presents this question about if the biodigestion technology is more economical process than fertigation.

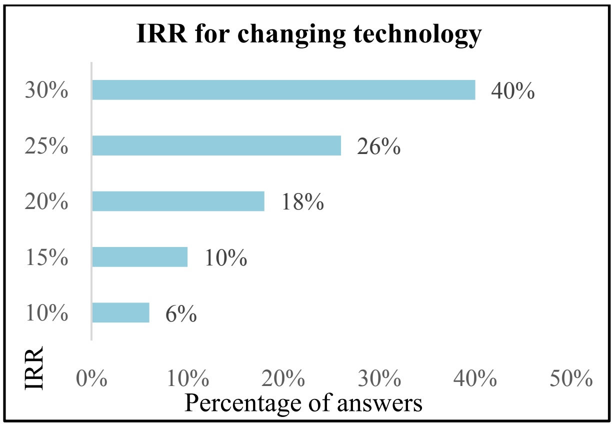

Fig. 4 IRR for changing technology.

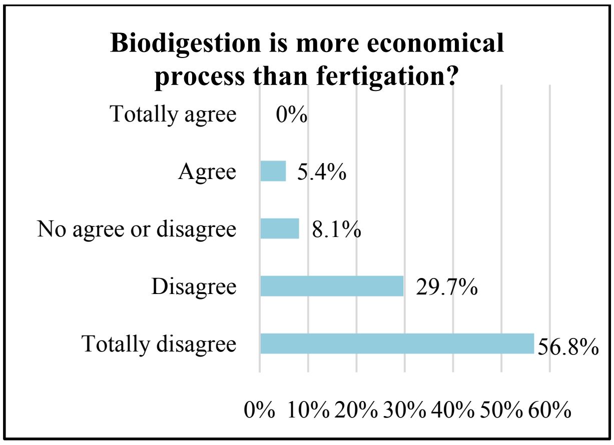

Fig. 5 Biodigestion versus fertigation.

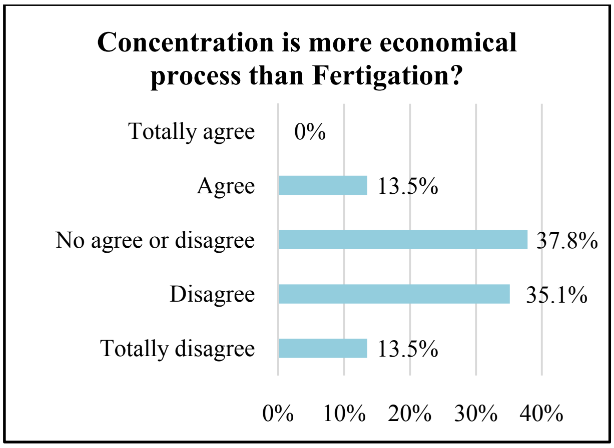

Fig. 6 Concentration versus fertigation.

However, this paper presents the more questions to study vinasse.

Fig. 6 realizes a question if the concentration of vinasse is a process of lower environmental impact than fertigation.

Fig. 7 presents the question if the companies only must shift current technology to others with lower environmental impact only if there are financial advantages.

It is possible to visualize that most of the respondents understand that fertigation is more economical than concentration of vinasse, which confirms the information obtained in this academy and industrial sector.

The answers show that most of the respondents understand that fertigation is more economical than biodigestion, which confirms the information obtained

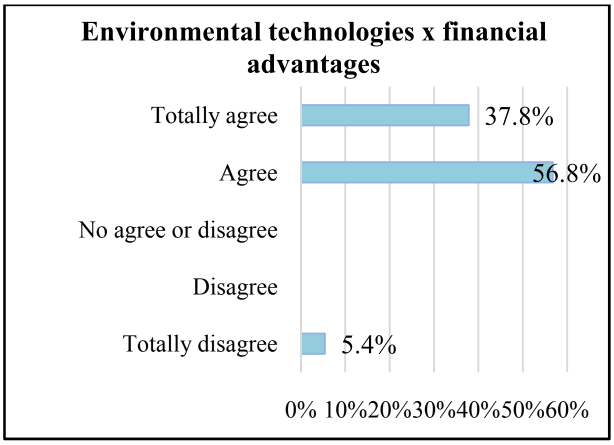

Fig. 7 Environmental technologies.

in the literature, companies in the sector besides class associations.

Any people that answer this questionnaire said that the best technological option will depend on the region or even the Brazilian state to implement the project since each state has its specific energy and biofertilizers offerings and demands.

Fig. 8 shows that the vast majority of companies agree that they should only change the technology option to one with better environmental performance if there are financial benefits or advantages to the company. That is, the environmental factor alone does not decide to change the most sustainable option.

All respondents agree that it is necessary to create greater incentives for the best use of vinasse so that we can disseminate technologies that are currently more environmentally viable, but still do not scale to be economically competitive.

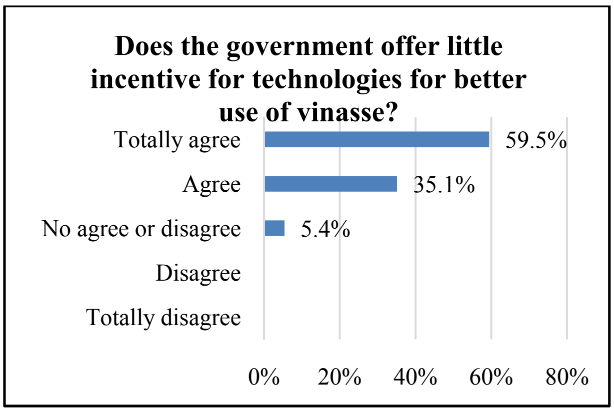

Fig. 8 Government incentive to vinasse.

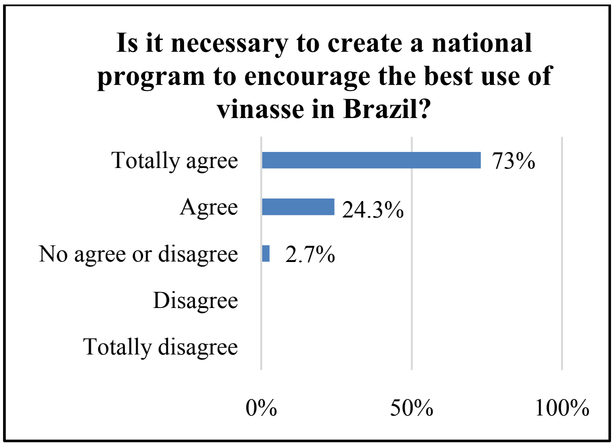

Fig. 9 Nacional program of vinasse.

Fig. 9 presents the question about if it is necessary to create a national program to encourage the best use of vinasse in Brazil.

Fig. 9 shows that majority of respondents agree that it is necessary to create a national program to encourage the best use of vinasse in Brazil, with lines of credits and auctions of specific energies for this type of energy input.

It is possible to view a great importance and predominance that the fertigation still has in Brazil little growth of the vinasse concentration and few biodigestion plants. This is the country's technological picture in this area.

Finally, the economic valuation of environmental aspects leads to a greater viability of the use of vinasse in the analyzed technologies and the importance of government policies to enhance the use of these technologies.

4. Applications

Results of the questionnaires show clearly and unequivocally that most people will only change the technology to make better use of the vinasse if the NPV is positive and the IRR of the project exceeds 25%.

Fig. 10 presents economy analysis of technological option for best use of vinasse, considering the economic valuation of environmental aspects: carbon credits, avoided costs of soil pollution through possible environmental fines and the economy with the purchase of mineral fertilizers.

It is visualized that the best option for better use of vinasse after technical, economic and environmental analysis is generation of energy through biodigestion in all of scenarios analyzed. Special attention is paid to scenario 3 for gas, where environmental options have better return because governmental incentive with the automotive vehicle tax exemption has an extremely positive impact on the project's viability with the significant increase of NPV of this scenario.

It should be visualized that the scenarios with reduction of the minimum attractiveness rate return

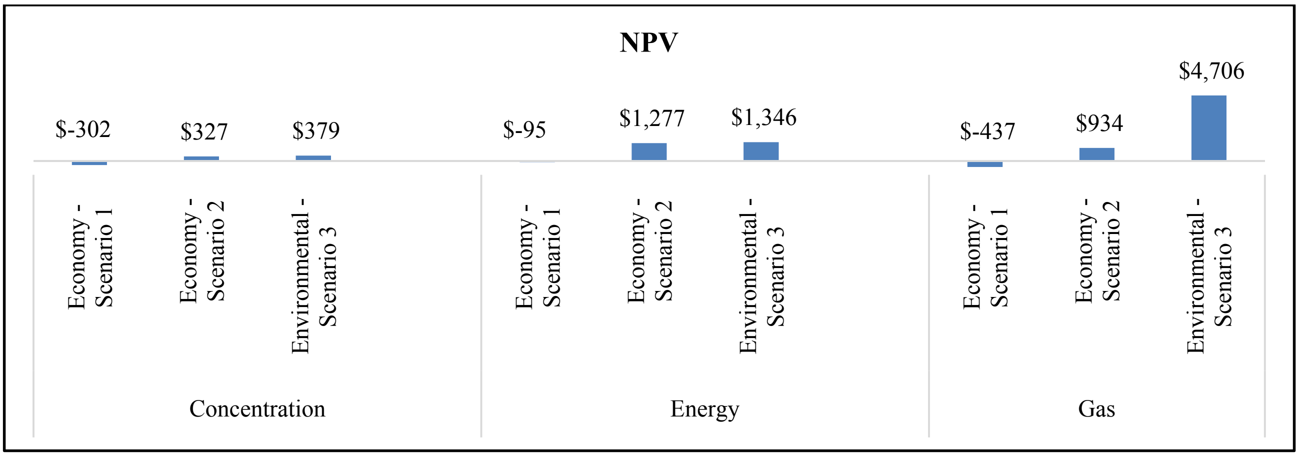

Fig. 10 NPV of technological option for best use of vinasse.

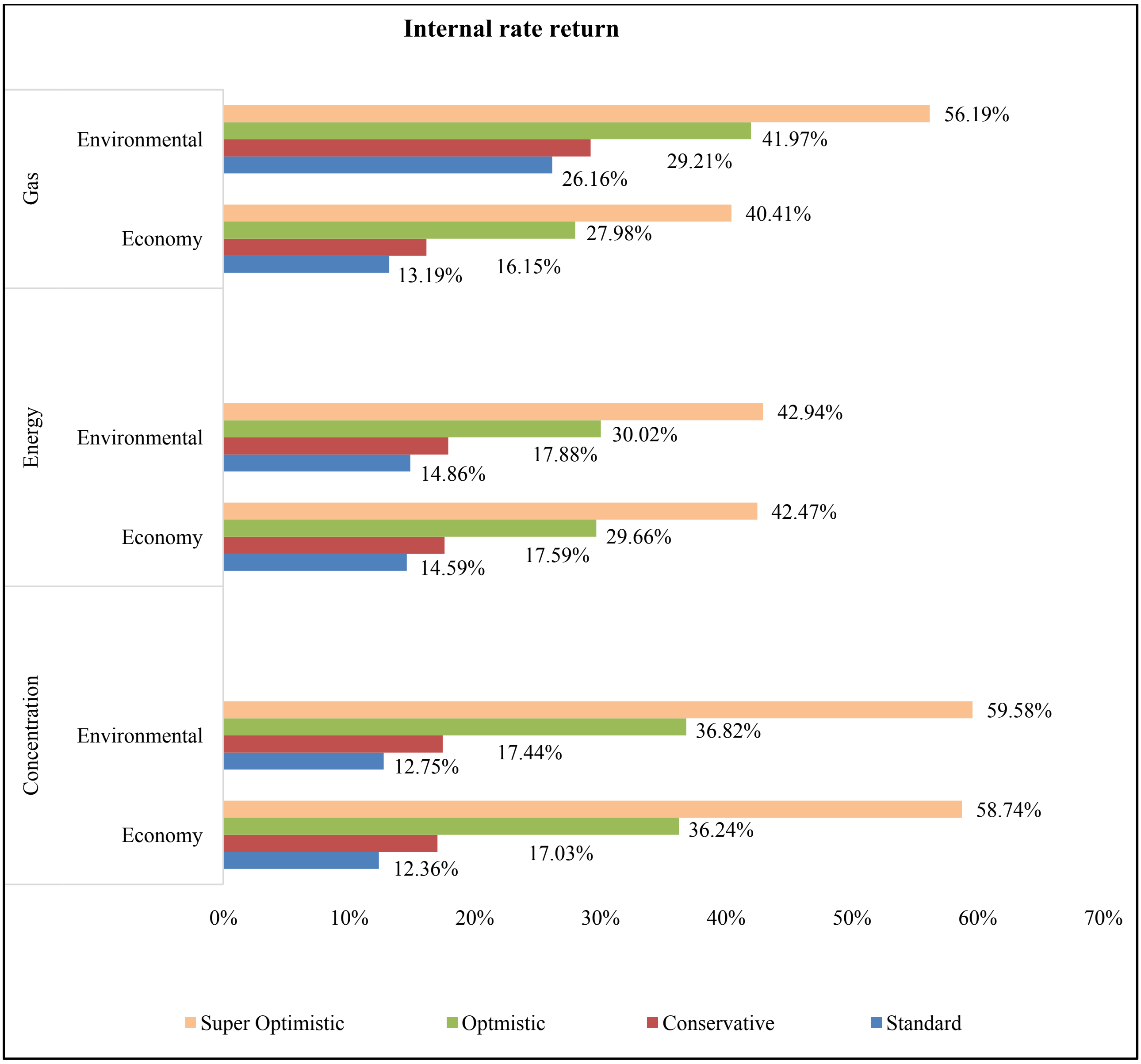

Fig. 11 Internal rate of return of technological option for best use of vinasse.

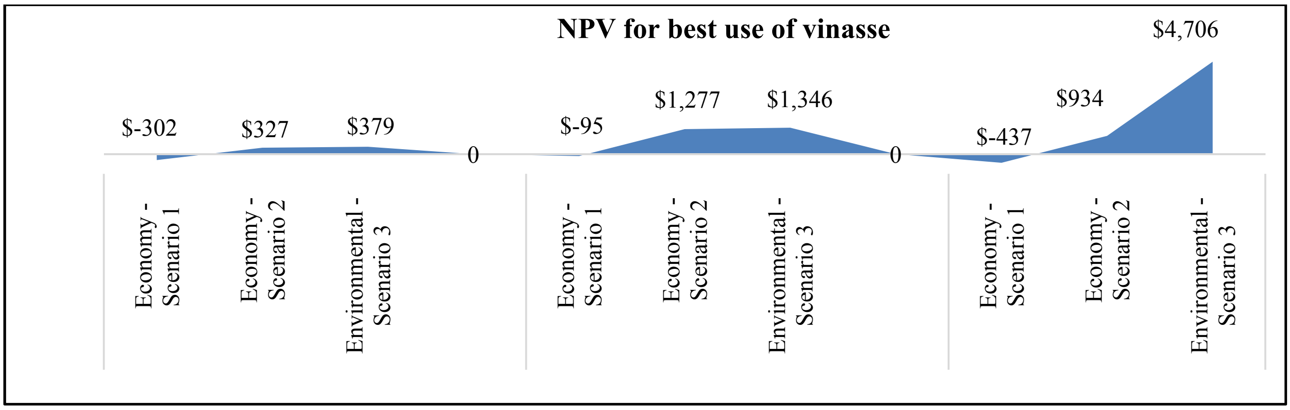

Fig. 12 NPV of technological option for best use of vinasse.

from fifteen to ten percent (scenarios 2 and 3) improve economic viability in all scenarios.

Fig. 11 presents the IRR of technological option for best use of vinasse, considering economic and environmental scenarios considering the sensibility analysis with IRR and your evolution with the percentage increase of revenues of 10% in the conservative profile, 50% in the optimistic and 90% in the super optimistic for technology of vinasse concentration. In Fig. 11, environment presents only significant importance for RNG generation from vinasse, while in energy and concentration the weight is almost insignificant. In energy, the environmental aspects considered were carbon credit, environmental fines and license, while for concentration, environmental aspects are environmental fines and license.

It is particularly interesting to observe that typical fines practically do not affect the decision of technology choice. Otherwise, RNG environmental aspects are of great importance for the decision of the technology. The governmental incentive considered dominated such aspect. It enforces the importance of government policies for the best use of vinasse. Fig. 12, presents NPV of technological option for best use of vinasse.

5. Conclusions

Fertigation technologies were evaluated as baseline scenario. Vinasse concentration and anaerobic digestion of vinasse in Brazilian sugarcane plants are studied in this paper.

The environmental analysis showed a decrease in GHG emissions, minimizing the possibility of contamination of groundwater in addition to the economy with mineral fertilizer, costs avoided with environmental fines and damage to the image of the sugarcane plant.

This work concludes that quantifying environmental impacts on cash flow is a way of increasing the economic viability of projects in this area. Therefore, what needs to do to implement such projects in the whole country is not a subsidy, but rather a quantification of environmental aspects.

Economically the option with better viability is the production of electric energy. The production of RGN had results close to electric energy. However, the concentration of vinasse is feasible, but it can be even better if it is possible to quantify other environmental aspects together with a sensitivity analysis considering a diesel oil price, increasing above the average of 5% per year that was seen the last decade.

It is necessary to point out that this study considered a sugarcane plant standard for the whole country. The best technological option will depend on the region or even the Brazilian state to implement the project since each state has its specific energy and biofertilizers offerings and demands.

It is possible to conclude that the internal rate of return considering the economic valuation of environmental aspects is in levels above 20% or 25%, that is, a percentage that is present in the answers of the questionnaires applied to specialists in the sector.

Typical fines and environmental license practically do not affect the decision of technology choice. The only significant weight of environmental aspect is the governmental police suggested for the use of RNG.

Finally, it is important to be able to value economically other impacts and environmental resources coming from technological options of better use of vinasse in the next studies of the sector.

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