USE OF THE LIFE CYCLE ASSESSMENT (LCA) FOR COMPARISON OF THE ENVIRONMENTAL PERFORMANCE OF FOUR ALTERNATIVES FOR THE TREATMENT AND DISPOSAL OF BIOETHANOL STILLAGE

By

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KEYWORDS: Vinasse, LCA, Fertigation, Biodigestion, Concentration, Combustion.

Abstract

New alternative routes for the treatment and disposal of stillage should be proposed, as fertigation could become unfeasible, due to the increasing transport costs and environmental concerns. The aim of this paper is to show the results of the application of the Life Cycle Assessment methodology for the analysis and comparison of four alternatives for stillage treatment and disposal: conventional ‘in natura’ fertigation, anaerobic digestion, concentration until 40% for fertigation and concentration until 65% for combustion in boilers using fuel oil as supplementary fuel. For the LCA study, a hypothetic Standard Sugar and Alcohol Mill was assumed with a milling capacity of 1.99 million tonnes of sugarcane per crop, producing 154 thousand tonnes of sugar and 81 thousand m³ of ethanol. The mill is located near the city of Sertãozinho and local soil characteristics were also considered. The environmental evaluation results comparing the 4 alternatives of disposal are shown. The Simapro® software and the CML 2 baseline 2000 are used as support tools.

Conventional and concentrated stillage fertigation alternatives have the best environmental performance. In the combustion of stillage, we considered the installation of pollution control devices for SO₂ and NOₓ with 95% efficiency. From the point of view of climate change, based on the life cycle greenhouse gases balance, the best alternative was biodigestion.

Introduction

Stillage, the most important by-product of sugarcane bioethanol production, is the aqueous by-product from the distillation of bioethanol. On an average, 8–15 litres of stillage is generated for every litre of alcohol produced.

The pollution load of the distillery effluent depends on different aspects related to the

Nomenclature

1,4-DB eq. 1,4 Dichlorobenzene equivalents
ACP Acidification Potential
ADP Abiotic Depletion Potential
CIP Clean In Place
ER Relationship between renewable energy output and fossil fuel energy input
ETP Eutrophication Potential
FEP Fresh Water Aquatic Ecotoxicity Potential
FU Functional Unit
GHG Greenhouse Gases
GWP Global Warming Potential
HTP Human Toxicity Potential
ISO International Standard Organisation
LCA Life Cycle Assessment
LCI Life Cycle Inventory
LCIA Life Cycle Impact Assessment
MEP Marine Aquatic Ecotoxicity Potential
ODP Ozone Layer Depletion Potential
POP Photochemical Oxidation Potential
SB System Boundaries
SSAM Standard Sugar and Alcohol Mill
TEP Terrestrial Ecotoxicity Potential
feedstock and process (Parnaudeau et al., 2008). Stillage might be handled several ways: discharge to an adjacent waterway or land area, return to agricultural fields (fertigation), anaerobic digestion and methane production, incineration, evaporation to an animal feed or use as an aquaculture feed (Willington and Marten, 1982; Wilkie et al., 2000; Pant and Adholeya, 2007; Mohana et al., 2009).

There has been a substantial development of life cycle methodologies to assess the energetic and environmental performance of product systems from cradle-to-grave, namely LCA (Malça and Freire, 2006).

The ISO, a worldwide federation of national standards bodies, has standardised this framework within the ISO 14040 series on LCA (ISO, 1997; 1998; 1999 and 2000).

Preliminary attempts of LCA application for the evaluation and comparison among alternatives of stillage treatment were accomplished by Rocha et al. (2007) and Rocha et al. (2008).

The objective of this work is to accomplish a comparative environmental analysis between the different scenarios corresponding to different stillage treatment and disposal alternatives.

**LCA methodology for this study**

**Definition of the goal and scope**

The function of the systems of products analysed in this work relative to different alternatives for stillage treatment:

- **FCDCC**: conventional fertigation with *in natura* stillage distribution through concrete channels and dispersal on farms through diesel-fuelled motor-pumps.
- **ABDCC**: stillage anaerobic biodigestion, with the biogas used for electric power generation and the subsequent disposition of the resulting effluent on farms.
- **SCDTT**: stillage concentration by evaporation up to 40% of solids, distribution on farms through trucks.
- **SCCBA**: stillage concentration by evaporation up to 65% of solids, to allow incineration in a boiler, together with an auxiliary fuel for steam and electric power generation. The ashes can be used for supplementary fertilisation.

**Definition of the FU and SB**

The FU is 1 m³ of stillage treated/disposal. In the agricultural system, the sum of the fertigated area with application of ashes and/or the area fertilised with mineral fertilisers will be the same for the four scenarios, but the magnitude changes (Table 1).

The operations of soil preparation, herbicide application, pesticide and limestone, harvest and transport won't be considered because they are the same for all scenarios.

The capital infrastructure contributes on average less than 5% of the global impact in all the impact categories (Rocha, 2009). So the build-up stage of the systems of stillage will not be considered in this study.

**Table 1—Necessary information for inventory accomplishment.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Considered items</th>
</tr>
</thead>
<tbody>
<tr>
<td>FU</td>
<td>1 m³ of treated stillage</td>
</tr>
<tr>
<td>Reference flow</td>
<td>83.3 litres of ethanol</td>
</tr>
<tr>
<td>Sugarcane corresponding to the FU</td>
<td>1.67 tonnes of sugarcane</td>
</tr>
<tr>
<td>Fertigated and non-fertigated areas total</td>
<td>0.0192 ha</td>
</tr>
<tr>
<td>Allocation method</td>
<td>Mass or energy</td>
</tr>
<tr>
<td>Impacts evaluation methodology</td>
<td>CML 2 baseline version 2.03</td>
</tr>
<tr>
<td>Data requirements</td>
<td>Data obtained from literature</td>
</tr>
</tbody>
</table>

2
A SSAM in the municipal district of Sertãozinho, State of São Paulo, Brazil, was established, hypothetically (Figure 1). The total period of operation will be 20 years, with 210 days of crop a year (4440 useful hours of operation). The milling capacity is of 1.99 Mt of sugarcane per crop, producing 0.154 Mt of sugar and 81 000 m³ of ethanol.

The predominant soil in the region is of the type Rhodic Hapludox and Typic Hapludox, with an average composition of 33.8% silt and 52.9% of clay (Alves, 2002).

Table 2 shows the main parameters adopted in process simulation. It is considered that 12.0 litres of stillage per litre of ethanol will be produced with the composition shown in Table 3 (Elia Neto and Nakahodo, 1995).

The main agricultural parameters considered for energy and emission analyses are presented in Table 4. The diesel consumption in the equipment used during conventional fertilisation, fertigation with ‘in natura’ and concentrated stillage and fertilisation with ashes was calculated starting from indicators presented by Macedo et al., 2004. It is considered that the cycle of the sugarcane consists of the plant cane and four ratoon crops with an average productivity of 87 tc/ha.

![Fig. 1—Localisation of the SSAM in Sao Paulo State, Brazil.](image)

**Table 2—Parameters adopted for the process simulation.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific sugar production</td>
<td>80.0</td>
<td>kg_sugar/tc</td>
<td>UNICA (2008)</td>
</tr>
<tr>
<td>Specific ethanol production</td>
<td>50.0</td>
<td>l_ethanol/tc</td>
<td>UNICA (2008)</td>
</tr>
<tr>
<td>Bagasse production</td>
<td>260.0</td>
<td>kg_bagasse/tc</td>
<td>Ometto (2005)</td>
</tr>
<tr>
<td>Mechanical power demand of cane preparation and juice extraction</td>
<td>16.0</td>
<td>kWh/tc</td>
<td>BNDES and CGEE (2008)</td>
</tr>
<tr>
<td>Electric power demand of sugar and ethanol process</td>
<td>12.0</td>
<td>kWh/tc</td>
<td>BNDES and CGEE (2008)</td>
</tr>
<tr>
<td>Specific steam consumption</td>
<td>540.0</td>
<td>kg_steam/tc</td>
<td>BNDES and CGEE (2008)</td>
</tr>
</tbody>
</table>
In this work, it is assumed that the stillage is applied in the plant and ratoon cane with nitrogen (48 kg/ha) and phosphorus (125 kg/ha) complementation in the plant cane (Penatti, 2008, Pers. Comm.). The emissions originating from the mineral fertilisation were calculated by the indicators shown in Table 5.

![Table 3](https://example.com/table3.png) —Physic-chemical parameters of stillage (Elia Neto and Nakahodo, 1995).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BOD</th>
<th>COD</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>CaO</th>
<th>MgO</th>
<th>MnO</th>
<th>Fe₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>mg/l</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>16 949</td>
<td>28 450</td>
<td>356</td>
<td>2034</td>
<td>515</td>
<td>225</td>
<td>5</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

![Table 4](https://example.com/table4.png) —Basic data for sugarcane production, harvesting and transportation (Macedo et al., 2008).

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>% cane stalks</td>
<td>14.22</td>
</tr>
<tr>
<td>Fiber</td>
<td>% cane stalks</td>
<td>12.73</td>
</tr>
<tr>
<td>Trash (dry basis)</td>
<td>% cane stalks</td>
<td>14.00</td>
</tr>
<tr>
<td>Cane productivity</td>
<td>t/ha</td>
<td>87.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fertiliser utilisation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P₂O₅ Plant cane</td>
<td>kg/ha</td>
</tr>
<tr>
<td>Plant cane without stillage</td>
<td>kg/ha</td>
</tr>
<tr>
<td>P₂O₅ Ratoon cane</td>
<td>kg/ha</td>
</tr>
<tr>
<td>Ratoon cane without stillage</td>
<td>kg/ha</td>
</tr>
<tr>
<td>K₂O Plant cane</td>
<td>kg/ha</td>
</tr>
<tr>
<td>Plant cane without stillage</td>
<td>kg/ha</td>
</tr>
<tr>
<td>Nitrogen Ratoon cane with stillage</td>
<td>kg/ha</td>
</tr>
</tbody>
</table>

| Nitrogen Ratoon cane without stillage | kg/ha |

![Table 5](https://example.com/table5.png) —Factors for emissions resulting from mineral fertilisation.

<table>
<thead>
<tr>
<th>Released substances</th>
<th>Quantity</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission to the air resulting from nitrogen fertilisation</td>
<td>CO₂</td>
<td>3.64 kg CO₂/kg N</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>0.05 kg N₂O/kg N</td>
</tr>
<tr>
<td></td>
<td>NOₓ</td>
<td>0.053 kg NOₓ/kg N</td>
</tr>
<tr>
<td></td>
<td>NH₃</td>
<td>0.026 kg NH₃/kg N</td>
</tr>
<tr>
<td>Emissions to underground water (lixiviation)</td>
<td>NO₃⁻</td>
<td>0.065 kg NO₃⁻/kg N</td>
</tr>
<tr>
<td></td>
<td>PO₄³⁻</td>
<td>0.128 kg P/kg P₂O₅</td>
</tr>
<tr>
<td></td>
<td>K⁺</td>
<td>0.01 kg K⁺/kg K₂O</td>
</tr>
</tbody>
</table>

**Description of evaluated scenarios**

**Scenario I: FCDCC – Conventional fertirrigation**

The stillage application rate during fertirrigation is 183 m³/ha, calculated according to CETESB (2005). The scenario I scheme is shown in Figure 2.

The mass and energy balances were calculated using the software GateCycle® (Figure 3). The steam parameters considered were 6.5 MPa and 480°C.
Fig. 2—Scheme of the FCDCC scenario.
Information about environmental impacts to atmosphere from stillage application to soil is practically nonexistent; only CO₂ emissions were considered according to Almeida (1983).

**Scenario II: ABDCC – Stillage biodigestion**

The bio-digestion plant is composed of four internal circulation anaerobic reactors.

The generated biogas will be used in internal combustion engines for electricity generation, the resulting effluent of the bio-digestion process will be applied on farms through waterproof concrete channels and the dispersal will be accomplished by diesel motor-pumps (Figure 4).

The rate of application of the bio-digested stillage in the agricultural soil is 266 m³/ha.

It is considered that the biogas has the following composition: 60% CH₄, 39% CO₂ and 1% H₂S. The PCI and PCS of the biogas are 18.20 MJ/kg and 20.19 MJ/kg respectively, the specific mass is 1.10 kg/m³ and the mass flow 0.593 kg/s.

The total electric power consumed by the bio-digestion system is 539.0 kW and, for FU, the consumption will be 2.46 kWh.

The sizing of the power generation system was accomplished using the software Thermoflex®, and consisted of 2 motor-generators Jenbacher®, each one with a nominal power of 2.56 MW and global efficiency of 40.0% and 1 group motor-generator Wartsila® with a nominal power of 1.35 MW and efficiency of 31.0%; in that way, the groups will generate 16.82 kWh/m³ of stillage.
Scenario III: SCDTT – Stillage concentration and fertirrigation

In this scenario, the stillage is concentrated by evaporation up to 40.0% solids. The design of the plant was accomplished using the software Aspen Plus® (Moura, 2008, Pers. Comm.).

In the scheme, 5 evaporation effects were considered also a condenser and a CIP system.

Figure 5 displays the outline of the cogeneration plant for this case. The efficiency of the cycle was 19.0%, therefore 173.29 kWh/m³ of stillage are generated. In the whole plant, 2430 kW are consumed; therefore, to the FU, it corresponds to 11.11 kWh.

Surplus electricity is 142.14 kWh. The allocation of the atmospheric emissions will be based on the share of generated/consumed electricity in the following way: 11.6% for the process, 6.4% for the stillage concentration plant and 82.0% for surplus electricity.

The rate of application of concentrated stillage will be 9.25 m³/ha. The fertirrigated and non-fertirrigated areas for the FU will be 0.0081 e and 0.0111 hectares, respectively (Figure 6).

Scenario IV: SCCBA – Stillage concentration and incineration

The stillage is concentrated up to 65% to enable the combustion of the stillage in boilers. The design of the plant was accomplished using the software Aspen Plus® (Moura, 2008, Pers. Commun.). The ashes that result from the combustion can be used in partial substitution of the mineral fertilisers. The concentration plant will have a scheme equivalent to the one in the previous scenario; however, it should have an additional evaporation effect, having in total 6 effects (Figure 7).
Fig. 5—Cogeneration plant modeling results for SCDTT scenario.

Fig. 6—Stillage concentration plant modeling results for SCDTT scenario.
Fig. 7—Scheme of the SCCBA scenario.
Results

Inventory of the consolidated life cycle

The methodology and indicators used in the LCI in this work are described in detail in Rocha (2009). Three evaluation categories were used for the evaluation of the environmental loads in LCI: energy evaluation (output/input energy relationship), GHG emissions balance in relation to the surplus electricity exported for the public grid, and characterisation/normalisation of the environmental impacts in agreement with a specific Eco-Indicator (CML 2 baseline 2000 version 2.03).

Electricity exported as a function of the emission of CO₂ equivalent

For the four appraised alternatives, the value of the electricity exported to the net was determined, and the emissions of GHG released during the system operation (emissions of the mineral fertiliser, cogeneration, use of diesel oil, decomposition of the stillage, etc.), based on the characterisation model developed by IPCC (2006).

The characterisation factors are expressed using the global warming for a horizon of 100 years (GWP100), in kg of CO₂ equivalent/kg of emitted substance.

The substances considered in this study were CO₂ (1.0 kg CO₂ eq./kg), CH₄ (23.0 kg CO₂ eq./kg), CO (1.53 kg CO₂ eq./kg) and N₂O (296 kg CO₂ eq./kg). The results are shown in Figure 8.

![Fig. 8](image)

The smallest emissions of GHG per kWh of generated electricity correspond to the scenario ABDCC (1.92 kg CO₂ eq./kWh), followed by FCDCC (2.13 kg CO₂ eq./kWh), SCCBA (2.16 kg CO₂ eq./kWh) and SCDTT (2.28 kg CO₂ eq./kWh).

Evaluation of the energy flows (Output/Input relationship) of the scenarios of disposition of the stillage

In the specific case of this study, the ER relation will indicate which scenario contributes to the largest global energy recovery from stillage before the final disposition in the soil.

The amount of necessary ethanol to assist the functional unit (83.3 litres) and the electricity exported to the net were considered as exits of the system.

The outlet will be formed by the sum of the input amounts multiplied by the respective energy coefficient (Figures 9–12 and Table 6).
Fig. 9—Energy inputs and outputs considered for the evaluated scenarios for FCDCC.

Fig. 10—Energy inputs and outputs considered for the evaluated scenarios for ABDCC.

Fig. 11—Energy inputs and outputs considered for the evaluated scenarios for SCDTT.

Fig. 12—Energy inputs and outputs considered for the evaluated scenarios for SCCBA.
Table 6—Energy balance for evaluated stillage disposal and treatment scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Renewable energy output (MJ/m³ stillage)</th>
<th>Fossil fuel energy input (MJ/m³ stillage)</th>
<th>ER</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCDCC</td>
<td>118.45</td>
<td>2477.36</td>
<td>20.9</td>
</tr>
<tr>
<td>ABDCC</td>
<td>133.17</td>
<td>2538.56</td>
<td>19.1</td>
</tr>
<tr>
<td>SCDTT</td>
<td>152.56</td>
<td>2372.96</td>
<td>15.6</td>
</tr>
<tr>
<td>SCCBA</td>
<td>544.16</td>
<td>2564.36</td>
<td>4.7</td>
</tr>
</tbody>
</table>

The alternative with the best energy performance was FCDCC (20.9), followed by ABDCC (19.1) and SCDTT (15.6). The SCCBA alternative presented an energy balance of 4.7 which is lower than that reported in the literature for the whole production cycle of ethanol (Macedo et al., 2004). That is due to the use of fuel oil (9.66 kg fuel oil/m³ stillage) as auxiliary fuel for stillage combustion.

Characterisation and normalisation of the environmental impacts

In this stage, the potential effects caused by the environmental loads emitted in the product system are described in terms of consumption of natural resources, or in impacts caused to the ecosystem and human health, depending on the type of model used (midpoint or endpoint indicator).

The LCIA of the four treatment alternatives and disposition of the analysed stillage were accomplished through the use of the method CML 2 baseline 2000, with the help of the computational tool Simapro 7.0®.

Figure 13 displays a summary of the values of these categories for the disposition alternatives and treatment of the analysed stillage in percentile. Figure 14 presents a percentile comparison of the contribution of each evaluated scenario in each impact category.

In relation to the characterisation of the impacts (Figure 13), the SCDTT scenario obtained the best environmental behaviour in 5 categories, FCDCC scenario was better in 2 categories, ABDCC scenario was better in 1 category and SCCBA was better in 1 category (Table 7).
In relation to the normalisation of the impacts (Figure 14), the CML 2 baseline 2000 considers the emissions of the equivalent substances for the year of 1990. The normalisation factors are: ADP (6.32×10⁻¹² kg Sb eq./year), GWP (2.27×10⁻¹⁴ kg CO₂ eq./year), HTP (1.67×10⁻¹⁴ kg 1,4-DB eq./year), FEP (4.83×10⁻¹⁵ 1,4-DB eq./year), MEP (1.32×10⁻¹⁵ kg 1,4-DB eq./year), TEP (3.79×10⁻¹² kg 1,4-DB eq./year), POP (9.59×10⁻¹² kg C₂H₄ eq./year), ACP (3.09×10⁻¹² kg SO₂ eq./year) and ETP (7.53×10⁻¹² kg eq./year). Therefore, in the global sum of all the categories, dimensionless the option of SCDTT obtained the best environmental performance (−1.14×10⁻¹¹), followed by FCDCC (−1.01×10⁻¹¹), ABDCC (−9.47×10⁻¹²) and SCCBA (−7.58×10⁻¹²).

Table 7—Characterisation of the environmental impacts of the considered scenarios.

<table>
<thead>
<tr>
<th>Impacts categories</th>
<th>Unit</th>
<th>FCDCD</th>
<th>ABDCC</th>
<th>SCDTT</th>
<th>SCCBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADP</td>
<td>kg Sb eq.</td>
<td>−0.0455</td>
<td>−0.0551</td>
<td>−0.0171</td>
<td>0.1430</td>
</tr>
<tr>
<td>GWP</td>
<td>kg CO₂ eq.</td>
<td>−698.0</td>
<td>−703.0</td>
<td>−749.0</td>
<td>−648.0</td>
</tr>
<tr>
<td>ODP</td>
<td>kg CFC-11 eq.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HTP</td>
<td>kg 1,4-DB eq.</td>
<td>66.9</td>
<td>66.9</td>
<td>61.3</td>
<td>66.7</td>
</tr>
<tr>
<td>FEP</td>
<td>kg 1,4-DB eq.</td>
<td>0.0203</td>
<td>0.0204</td>
<td>0.0185</td>
<td>0.0234</td>
</tr>
<tr>
<td>MEP</td>
<td>kg 1,4-DB eq.</td>
<td>36.0</td>
<td>38.1</td>
<td>33.1</td>
<td>43.2</td>
</tr>
<tr>
<td>TEP</td>
<td>kg 1,4-DB eq.</td>
<td>0.00031</td>
<td>0.00523</td>
<td>0.00027</td>
<td>0.00373</td>
</tr>
<tr>
<td>POP</td>
<td>kg C₂H₂</td>
<td>−0.00419</td>
<td>0.00337</td>
<td>−0.00264</td>
<td>0.00283</td>
</tr>
<tr>
<td>ACP</td>
<td>kg SO₂ eq.</td>
<td>0.0103</td>
<td>0.1950</td>
<td>0.0556</td>
<td>0.1670</td>
</tr>
<tr>
<td>ETP</td>
<td>kg PO₄³⁻ eq.</td>
<td>0.6430</td>
<td>0.6700</td>
<td>0.5970</td>
<td>0.5940</td>
</tr>
</tbody>
</table>

Conclusions

The recovery of the energy value of the stillage could be accomplished before its final disposition. In this scenario, the anaerobic bio-digestion was shown to be quite favourable in three indicators: use of the soil, emission of GHG as a function of the generated kWh, and also in the use of abiotic resources. The energy recovery through combustion was shown to be environmentally...
unfavourable due to the intensive use of auxiliary fuel (fuel oil), which turned it into an unfavourable scenario from the energy point of view.

The application of LCA for evaluation of the environmental impacts caused by the stillage does not allow a complete analysis, because associated uncertainties exist about the lixiviation and volatilisation of the stillage applied to the soil. Besides, ions in the stillage, mainly potassium, phosphorus (phosphate) and the nitrogen compounds can be lixiviated for the water table. The great obstacle in relation to the quantification of these impacts is the nonexistence of reliable information on what really happens with the stillage when it is applied to the soil.

Acknowledgement

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LE RECOURS À L’ÉVALUATION DU CYCLE DE VIE (ECV) POUR LA COMPARAISON DE LA PERFORMANCE ENVIRONNEMENTALE DE QUATRE APPROCHES ALTERNATIVES POUR LE TRAITEMENT ET ELIMINATION DE LA VINASSE PROVENANT DE LA PRODUCTION D’ETHANOL

Par

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MOTS-CLÉS: Vinazas, Élimination Finale, Cycle de Vie Analyse.

Résumé

Des nouveaux itinéraires alternatifs pour le traitement et l'élimination de la vinasse doivent être proposés, car la fertigation pourrait devenir non acceptable, en raison de l'augmentation des frais de transport et des préoccupations environnementales. Le but de cette communication est de démontrer les résultats de l'application de la méthodologie d'évaluation du cycle de vie (ECV) pour l'analyse et la comparaison de quatre approches de traitement et d'élimination de la vinasse: fertigation conventionnelle ‘in natura’, digestion anaérobie, concentration jusqu'à 40% pour la fertigation et concentration jusqu'à 65% pour la combustion dans les chaudières utilisant du fioul comme carburant. Pour l'étude ECV, un complexe industriel standard hypothétique de sucre et d'éthanol avec une capacité d'usinage de 1,99 millions de tonnes de canne à sucre par campagne, produisant 154 000 tonnes de sucre et de 81 000 m³ d'éthanol, a été considéré. Le complexe est situé à proximité de la ville de Sertãozinho et les caractéristiques du sol ont été prises en compte également. Les résultats de l'évaluation environnementale en comparant les quatre approches pour l'élimination de la vinasse sont détaillés. Le logiciel Simapro® et le CML2 baseline 2000 ont été utilisés comme outils de support. L'élimination de la vinasse par fertigation par mode conventionnelle et par concentration se sont avérées les meilleures approches sur le plan environnemental. Dans la combustion de la vinasse, nous avons pris en considération l'installation de dispositifs antipollution pour SOx et NOx à une efficacité de 95%. Du point de vue du changement climatique, basé sur l'équilibre du cycle de vie des gaz à effet de serre, la meilleure alternative était la biodigestion.
EMPLEO DE LA EVALUACIÓN DEL CICLO DE VIDA (LCA) PARA LA
COMPARACIÓN DEL COMPORTAMIENTO AMBIENTAL DE CUATRO
ALTERNATIVAS PARA EL TRATAMIENTO Y DISPOSICIÓN
DE LAS VINAZAS RESIDUALES DEL ETANOL

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PALABRAS CLAVES: Vinazas,
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Resumen

ES CONVENIENTE proponer nuevas rutas para el tratamiento y disposición de las vinazas residuales
de la producción de etanol en cuanto la fertirrigación puede resultar inviable debido a los
incrementos de los costos de transporte y preocupaciones ambientales. El objetivo de este trabajo es
mostrar los resultados de la aplicación de la metodología de Evaluación del Ciclo de Vida (LCA, en
inglés) para el análisis y la comparación de cuatro (4) alternativas para el tratamiento y la
disposición de las vinazas residuales: convencional con fertirrigación ‘al natural’, digestión
anaeróbica, concentración hasta el 40% (de sólidos) para fertirrigación y concentración a 60% para
combustión en calderas empleando fuel oil como combustible complementario. Para el estudio del
LCA, se asumió un hipotético Central Productor de Azúcar y Alcohol (SSAM), con una capacidad
de molida de 1.99 millones de toneladas de caña por zafra, produciendo 154 mil toneladas de azúcar
y 81 mil m³ de etanol. El central está localizado cerca de la ciudad de Sertaozinho y se consideraron
las condiciones de los suelos locales. Se presentan los resultados de la evaluación ambiental al
comparar las cuatro alternativas de disposición. Se emplearon como herramientas de soporte digital
el software SIMAPRO® y la baseline CML 2, 2000. Las alternativas de fertirrigación convencional
y la de concentración tuvieron en general el mejor desempeño ambiental. En la combustión de las
vinazas consideramos la instalación de componentes de control de la contaminación, con 95% de
eficiencia para SOx y NOx. Desde el punto de vista del Cambio Climático, basado en el balance del
Ciclo de Vida de Gases de Efecto Invernadero, la mejor alternativa resultó la biodigestión.