Evaluation of the environmental, technical and economic performance of anaerobic co-digestion processes in Colombian scenarios

A. Espejo1, P. Torres1, J. Mosquera1, C. Rangel2, I. Cabeza1,3, N. Ortiz1, P. Becerra1, P. Acevedo1,4

1 Department of Environmental Engineering, Universidad Santo Tomás, Bogotá, Carrera 9 No. 51 - 11, Colombia
2 Departament of Engineering Process, Universidad EAN, Bogotá, Carrera 11 No. 78 – 47, Colombia
3 Engineering Department, Politécnico Grancolombiano, Bogotá, Calle 57 No. 3 – 00 Este, Colombia
4 Department of Industrial Engineering, Universidad Cooperativa de Colombia, Bogotá, Avenida Caracas 37 - 63, Colombia
Introduction

Residual biomass from agro-industrial activities in Colombia

Implementation of biological processes for energy generation

Researches over the technical, environmental and economical approach
Several varieties of residues derivate from agro-industrial activities in Colombia are susceptible to be valorized, some of them are pig manure (PM), sewage sludge (SS), organic fraction of municipal solid waste (OFMSW), residues from the bottled fruit drinks industry (RBFDI) and cocoa industry residue (CIR).
Materials and Methods

The treatment capacity was defined by using the available information. After this, all the mass and energy balances were constructed for each substrate mixture.

The environmental performance was evaluated through the quantification of the potential environmental impacts employing the Life Cycle Assessment (LCA) technique using the SimaPro software, where the behaviour of the different mixtures was evidenced.

An economic evaluation was carried out, taking into account the operating and administrative costs, incomes, profits and depreciation of the equipment.

The best mixture was chosen by the methodology of the analytic hierarchy process.
Technical framework

Mosquera et al. [4] evaluated the anaerobic co-digestion of PM, SS, OFMSW, RBFDI and CIR, for the maximization of the biogas production of different mixtures.

Table 1. Maximized mixtures.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>PM (%)</th>
<th>CIR (%)</th>
<th>SS (%)</th>
<th>RBFDI (%)</th>
<th>OFMSW (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture 1</td>
<td></td>
<td></td>
<td>8.321</td>
<td>68.452</td>
<td>23.227</td>
</tr>
<tr>
<td>Mixture 2</td>
<td>28.297</td>
<td>35.336</td>
<td></td>
<td>36.367</td>
<td></td>
</tr>
<tr>
<td>Mixture 3</td>
<td>14.550</td>
<td>29.612</td>
<td></td>
<td></td>
<td>55.838</td>
</tr>
</tbody>
</table>

The residue availability reported by Piñeros et al [2], show that the residues are highly accessible in different municipalities of Cundinamarca, the cocoa industry is placed in Yacopí, piggery farms in San Antonio de Tequendama, sewage sludge from Madrid wastewater treatment plant, fruit juice industries are in Bogotá as well as the OFMSW recovery.
Life cycle assessment

Mass and energy balances

<table>
<thead>
<tr>
<th>Potential impact categories</th>
<th>Equivalent units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial acidification</td>
<td>Kg SO₂ eq</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>Kg PO₄ eq</td>
</tr>
<tr>
<td>Climate change</td>
<td>Kg CO₂ eq</td>
</tr>
<tr>
<td>Photochemical oxidation</td>
<td>Kg C₂H₄ eq</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>Kg CFC-11 eq</td>
</tr>
<tr>
<td>Abiotic depletion</td>
<td>Kg Sb eq</td>
</tr>
</tbody>
</table>

Table 2. Potential environmental impacts categories according to the EPD methodology
**Economic assessment**

**Step 1**
- Evaluation and quotation of basic equipment, auxiliary equipment, and services necessary for each plant.

**Step 2**
- Definition of direct and indirect labour required, and calculation of payroll including the benefits of the Colombian law.

**Step 3**
- Calculation of initial investment, working capital, production and administration costs.
- The net profits comprised a depreciation of 10%, taxes on profits and equity, and inflation as relevant variables for the calculation.

**Step 4**
- Calculation of financial indicators: Net Present Value (NPV), through the sum of the year-to-year profits carried at present value with an attractive minimum rate of 10%, minus the total investment; and the Internal Rate of Return (IRR), verifying the annual projection when the NPV begins to give a positive result to the investment.
The Analytic Hierarchy Process (AHP) has been widely used to evaluate alternatives based on different analysis criteria, where a hierarchical model is constructed to organize information and make decisions regarding an analysis of complementary criteria [15].

In this case, it permits the selection of the best scenario within the three different mixtures evaluated in previous stages.
Results and discussion

Technical framework

Table 3. Productive aspects evaluated for each mixture.

<table>
<thead>
<tr>
<th></th>
<th>Mixture 1</th>
<th>Mixture 2</th>
<th>Mixture 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capacity (Ton)</td>
<td>32.840</td>
<td>61.807</td>
<td>71.752</td>
</tr>
<tr>
<td>Reactor volume (m3)</td>
<td>6.148</td>
<td>9.225</td>
<td>9.846</td>
</tr>
<tr>
<td>Biogas production (m3)</td>
<td>1231.656</td>
<td>2943.175</td>
<td>3525.078</td>
</tr>
<tr>
<td>Potential (KWh)</td>
<td>1961.412</td>
<td>4687.006</td>
<td>5613.687</td>
</tr>
</tbody>
</table>
Fig. 1 Process flow diagram for Mixture 3.
Fig. 2 Comparative environmental profile of the three mixtures.
## Economic assessment and AHP results

Table 5. Results for the economic evaluation and analytic hierarchy process.

<table>
<thead>
<tr>
<th></th>
<th>Mixture 1</th>
<th>Mixture 2</th>
<th>Mixture 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total initial investment</strong></td>
<td>$2,580,118,254</td>
<td>$2,605,082,104</td>
<td>$2,607,350,904</td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td>$134,720,193</td>
<td>$4,184,207,848</td>
<td>$5,498,301,525</td>
</tr>
<tr>
<td><strong>IRR</strong></td>
<td>0.11</td>
<td>0.32</td>
<td>0.39</td>
</tr>
<tr>
<td><strong>Analytic hierarchy result</strong></td>
<td>0.476</td>
<td>7.989</td>
<td>9.683</td>
</tr>
</tbody>
</table>
Conclusions

- The best mixture to generate electric energy is mixture three since it generates the most significant amount of biogas at 56401,248 m3 per year.

- Mixture 3 obtained the best results in the economic study with an NPV for the last year of COP 5,507,646,009 and an IRR of 38.99%.

- Regarding the environmental analysis, it was also found that the mixture that generates less potential environmental impacts is mixture 3, closely followed by mixture 2.

- After conducting the LCA using the EPD methodology and the SimaPro databases, it was observed that the environmental impact is also associated with the size of the plant. These results are mainly because many operations generate the same impact with low production as with high production, when increasing capacity, there was a greater volume of a product without incurring in a significant increase in the environmental impact generated.
References


Thank you