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Sustainability Evaluation of Sugarcane Bagasse Valorization Alternatives in Valle del Cauca - Colombia

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In the present paper, an evaluation methodology of the sustainability was proposed in order to select the best way to value the sugarcane bagasse, taking into account the environmental management of the process, economic indexes, and social relevant aspects. To evaluate the environmental dimension, the Life Cycle Assessment (LCA) methodology and the LCA specialized software SIMAPRO was used. Six Impact categories were evaluated: acidification (Kg eq SO_2), eutrophication (Kg eq PO_4), climatic change (Kg eq CO_2), photochemical oxidation (Kg eq C_2H_4), ozone layer depletion (Kg eq CFC-11) and abiotic damage (Kg eq Sb). It was found that in the case of co-generation use of sugarcane bagasse, the unitary process that generates greater environmental impact is the boiler and in the case of paper production, it's the pulp bleaching. The economic dimension was evaluated using the Life Cycle Cost (LCC) methodology. This methodology analyzes the economic aspects through the life cycle of the sugar cane bagasse. The Internal Rate of Return (IRR) was selected as the economic indicator, the value obtained for this indicator for the co-generation process was 0,355 and for the paper production process 1,816. Both results show economic cost-effectiveness. A stakeholder analysis was made in order to evaluate the social dimension. For each process, the power and interest criteria were evaluated. It was found that in the process of cogeneration, power and interest levels are 4 and 5,4 out of 10 respectively, and in the process of paper, power level was 3,1 and interest 5,2 out of 10. Finally, the results of the three dimensions were integrated using the Analytical Hierarchy Process methodology (AHP): Environmental dimension obtained with LCA, Economic dimension evaluated with LCC and social dimension calculated with stakeholder analysis. The main conclusion is that the most sustainable use of sugarcane bagasse is the raw material in the paper industry. Some sustainability recommendations were given for both processes evaluated.

1. Introduction

Sugarcane bagasse provides a high potential to Colombia's agro-industry because it's being used in energy cogeneration processes with excellent economic results, such as in paper and bioethanol production. Colombia's industry, until a few years ago began electricity production from cogeneration processes with sugar cane bagasse; its advances in the matter of energetic efficiency improvement has contributed to the point that energy production is now enough to run sugar mills, refineries and the surplus sold and transferred into the national electric network. Energetic cogeneration from sugarcane bagasse began its expansion in Colombia in the 90s and it's considered to be one of the best ways to use such residue. It is estimated that for the year 2017 cogeneration capacity will be 360 MW, and approximately 160MW of it could be sold to the local network (ASOCAÑA, 2012). When it is compared energy cogeneration using sugarcane bagasse with bioethanol production, cogeneration has more economic benefits for sugar processing plants than bioethanol production from bagasse. However, there haven't been any comparison studies in which the environmental and social aspects that intervene in both processes are evaluated (Mortari et al., 2014).
The concept of involving economic growth, environmental and social dimensions arose three decades ago in 'Our Common Future' from the World Commission on Environment and Development (WCED, 1987). It marked the beginning of a new era in development that seeks the balance between the three dimensions

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without compromising the capability of newer generations to satisfy their own needs (Sepiacci & Manca, 2015). Under this model, it's unknown if energy cogeneration is more sustainable in comparison with other uses. Considering that the development tendency of sugar plants is inclined towards refineries, analyzing the various uses that could bring newer and better benefits from a sustainability perspective is necessary (Dias et al., 2014). For the analysis of the environmental dimension in an industrial process, one of the more complete and precise tools is the methodology called Life Cycle Analysis (LCA). Previous works have been reported mentioning the sugarcane bagasse, focused on LCA to processes like ethanol production, new products, cogeneration and comparison with different industrial residues (Luz et al., 2010; Mashoko et al., 2013; Ojeda et al., 2011; Petersen et al., 2015). With respect to the economic dimension, the Life Cycle Analysis is complemented by the Life Cycle Costing LCC. In which the cost of an asset is evaluated throughout its lifespan. Here, four categories are evaluated: Inversion, operation, maintenance and costs of elimination at the end of product lifecycle (Luo et al., 2009). With respect to the social dimension, stakeholders' theory proposed by Freeman (2010), has become a staple for strategic business management. The theory visualizes the business from the different factors that affect it and are being affected by the decisions taken. It's built to understand the links that are created between these and therefore visualizes the corporative social responsibility of organizations. In order to integrate the three dimensions of sustainability, the Analytical Hierarchic Process Methodology AHP is proposed. The AHP formulates the decision problem with its relevant components, general objective, criteria and alternatives (Acevedo, 2012). This article presents a sustainability evaluation of different valorization alternatives for sugarcane bagasse using the methodologies mentioned above.

2. Material and methods

To develop this project 4 stages are considered: 1. Environmental dimension analysis (LCA). 2. Economic dimension analysis (LCC). 3. Social dimension analysis (Stakeholders analysis) and finally, 4. Integration of the last three dimensions in a sustainability index. This analysis was performed with the two most common types of sugarcane bagasse uses such as steam generation in a cogeneration system and paper production.

The LCA was based on the elaboration of mass and energy balance for the two types of bagasse usage. It was taken into account that out of the 21,000 KTon of sugarcane bagasse, 6,000 KTon are produced annually in the zone of study from which 5,100 KTon are used for cogeneration processes and 900 in paper production (ASOCAÑA, 2012). Mass and Energy Balance data were entered into SIMAPRO v. 8.0.5.13 software to perform an Inventory Analysis. Services and raw materials features were selected in the software according to its similarity to real entries. The following categories of impact were selected: Acidification, Eutrophication, Global Warming, Photochemical Oxidation, and Depletion of the Ozone Layer and Abiotic Depletion. These categories were analyzed through the Environmental Product Declaration EPD methodology (2013) contained in SIMAPRO software. The selection was based on environmental aspects involved in the cogeneration gas emissions (Petersen et al., 2015), landfills (Mu et al., 2010), water consumption (Buddadee et al., 2008) and chemical products (Luo et al., 2009). For the environmental assessment, environmental profiles were performed for the two processes selected. The profiles were built with the sum of total Kg eq of each of the 6 evaluated categories, and then the contribution percentages to each process stage were calculated. This was possible thanks to the fact that the sums made in the unit of each category.

The LCC methodology performed to this study was proposed by Durairaj et al. (2002). First, the operational profile was defined as continuous because both steam production and paper production work in a continuous way for 340 days and 25 days of the year were considered for maintenance and cleaning. The LCC was performed with a 10-year projection. The utilization factor was 1, bearing in mind that the equipment does not exceed its life cycle. Then, for each usage, the cost was described: initial acquisition, raw materials, services, carrying, labor, and maintenance. Finally, the Internal Return Rate (IRR) was calculated considering the following topics: in the first 5 years 10% depreciation on the initial investment, legal profits were calculated by subtracting pre-tax profits from accumulated depreciation, 30% of legal profits were taken as a tax on profits, the estate tax was calculated by subtracting from the total value of the investment the accumulated depreciation (was applied four per thousand tax) and after-tax profits were calculated by subtracting from profits before taxes, taxes on profits and wealth. Social dimension was analyzed through a 4 step methodology. First, the stakeholders were identified. Second, the power level for the stakeholder's was determined based on a preordered classification. Third, the interest level of the stakeholders was determined. Finally, the Power/Interest matrix and stakeholder mapping were constructed. The criterion to assess the Power and Interest of stakeholders was defined. For evaluation of sustainability, the Hierarchical Analytical Process (AHP) methodology was used to integrate the LCA results for the environmental dimension, the LCC for the economic dimension and the Stakeholder Analysis for the social dimension. Statistical weights were assigned to the results of the variables of each stage (LCC, LCA and Stakeholder analysis): environmental impact, IRR, power, and interest.

3. Results and Discussion

3.1 Environmental Dimension: LCA

In steam production, the environmental impacts are present in Figure 1. It shows the input percentages of each unitary process (Deaerator, tank, pump, boiler, and turbine), in each impact category. It's highlighted that the boiler has the highest environmental impact in the six categories. It's followed by the turbine's impact on the process, especially for the acidification category.

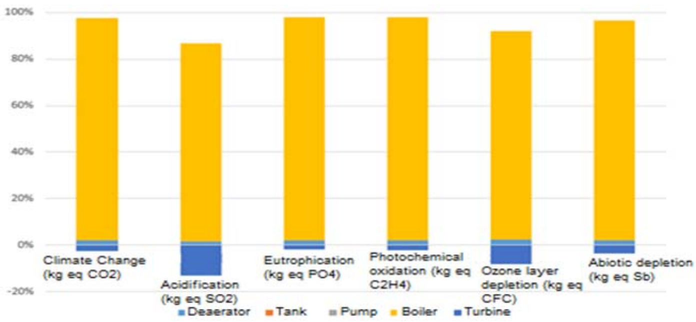

Figure 1. Environmental profile for the steam generation process.

Until a few years ago, coal was the fuel used in the boilers. A comparison of the results obtained in this LCA was of 1 kg of steam generated with coal fuel from the SIMAPRO database as it's shown in Table 1. It's seen that the contribution in the acidification category of bagasse is lower than that of coal because the emissions of sulfur oxides are lower. However, in the other categories bagasse fuel generates greater impact and it is due to the types of boilers used and the high degree of incomplete combustion that occurs with this fuel. In addition, the software takes into account the cumulative impacts related to the production, extraction, and transport of sugarcane. In the present study, the CO2 generated can be of biogenic or fossil origin, however, its environmental impact on the global warming category is not altered by this condition.

Table 1: Comparison of the impacts generated with bagasse and with the usage of coal in the production of 1 kg of steam

Impact Category	Units	Coal fuel SIMAPRO	Sugarcane Bagasse Fuel
Acidification	Kg eq SO_2	0.0021	0.00117
Eutrophication	Kg eq PO_4	8.9 e-5	2.32
Global warning	Kg eq CO_2	0.277	2
Photochemical Oxidation	Kg eq C_2H_4	8.64 e-5	0.0106
Depletion of Ozone Layer	Kg eq CFC	0	2.67e-10
Abiotic Depletion	Kg eq Sb	5.13e-10	2.04e-7

In the case of paper production, the effects present in an environmental profile are shown in figure 2. The percentage of contribution per process is shown for each of the impact categories. The unitary process that generates greater environmental impact is the pulp bleaching, followed by the pulp washing.

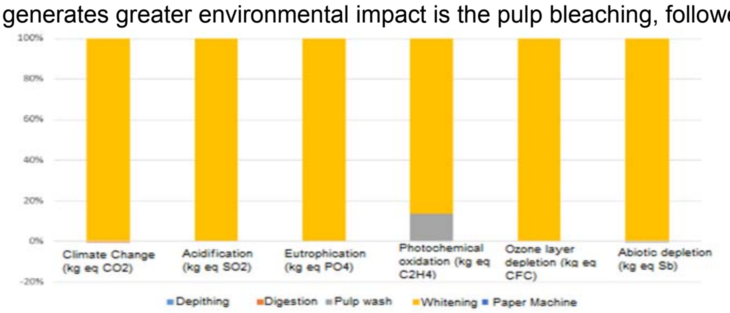

Figure 2. Environmental Profile in the paper production process from bagasse.

An analysis of the behavior of the impact categories in the production process of paper from bagasse was made. Two types of paper were taken from the SIMAPRO database for comparison. For all categories of impact, contrary to what is theoretically stated, the environmental impact of paper produced with sugar cane bagasse outweighs the other two types of paper (Table 2). In fact, less chlorine dioxide is used in the pulp whitening. Although, it’s considered that the pulping process with the lesser environmental impact is with the use of sodium hydroxide (as it is used in the Cauca Valley, Colombia), for these categories the lesser impact is with the used of sulfate (corresponding to the database).

Table 2: Comparison of the impact generated with bagasse and coal for the generation of 1 kg of Paper.

Impact Category	Units	Whitened Kraft paper SIMAPRO	Un-Whitened Kraft Paper SIMAPRO	Sugarcane bagasse Paper
Acidification	Kg eq SO_2	0.0115	0.0094	0.747
Eutrophication	Kg eq PO_4	0.00504	0.0052	0.293
Global warning	Kg eq CO_2	1.69	1.25	101
Photochemical Oxidation	Kg eq C_2H_4	0.000504	0.000445	0.0324
Depletion of Ozone Layer	Kg eq CFC	1.8e-7	1.4e-7	9.1 e-6
Abiotic Depletion	Kg eq Sb	2.81 e-6	8.42e-6	0.000478

3.2 Economic Dimension: LCC

The elements used to calculate the LCC dimension to produce steam and paper are shown in Table 3 (Becerra, 2016). Transportation costs were calculated for the paper production process taking into account that vehicles to transport the bagasse have a capacity of 30 Ton with 3 trips per day, so each car can transport 90 Ton / day. The cost per day of this element has a value of 753,800 COP. Labour was calculated taking into account that the average salary for the two harvesting processes is 2.5 times the legal minimum monthly wage in Colombia. Maintenance costs were calculated taking 5% of the initial investment value of the plants (Becerra, 2016).

Table 3: Descripción de los elementos de costo

Element	Value (COP)	Element	Value (COP)
Initial Acquisition Costs:		Utilities costs:	
Steam production	1,152,000,000,000.00	Softened water (m^3)	130.00
Paper production	7,719,138,560.00	Treated water (m^3)	97.00
Raw Materials costs:		Electricity (KWh)	263.00
Bagasse (Ton)	30,000.00	Steam (Kg)	190.00
NaOH (Kg)	4,850.00	Waste water treatment (m^3)	70.00
Lime (Kg)	540.00		
Chlorine Dioxide (Kg)	9,600.00		

Having in mind the mentioned above, the IRR for steam production is 0,335 and that of paper production is 1,816. It was obtained bearing in mind the cost of acquisition of each plant, the raw materials, (bagasse, hydroxide, lime, and chlorine dioxide), industrial services (soft water, treated water, electricity, steam and wastewater treatment), transport, manpower, maintenance costs, income, and utilities. The Income considered for the steam generation was electricity and steam. As for the paper production, it’s electricity and paper.

3.3 Social Dimension: Stakeholder analysis

The Stakeholders identified for these two processes were the investors, the shareholders, workers, environmental authorities, entities from the sugar sector, towns, communities, clients, suppliers, the educational sector, and competence. From each group of interest, the interests and power variables are identified and qualified for the sugarcane bagasse processes. Figure 3 shows the distribution of each stakeholder and four quadrant analysis. It is highlighted that the environmental authorities play an important role in the two processes; therefore it’s positioned in quadrant A. For the paper production usage it’s found that the majority of groups are placed in the B quadrant therefore for this process it is deduced that there is interest but the actors have no economic or political power. On the mapping of the steam process, there is a good position for the clients and shareholders who are sugar processing plants with steam production.

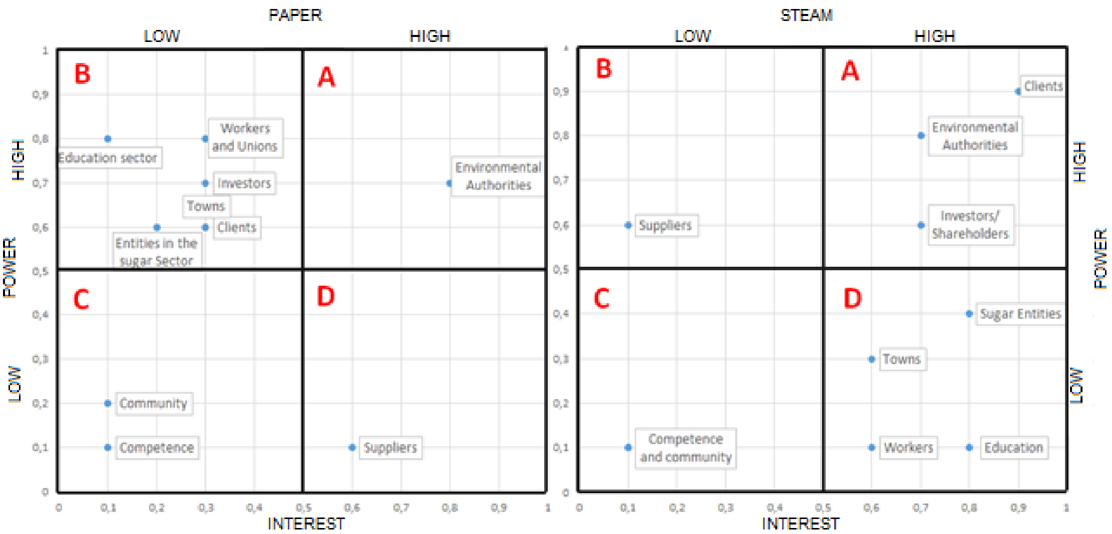

Figure 3. Mapping of the Stakeholders.

3.4 Sustainability Indicator

As it's observed in Table 3, the sugarcane bagasse usage doesn't have an adequate level of sustainability because steam generation obtained a result of 1.44 over 3 and the paper production has a result of 1.87 out of 3. The dimension that influences the results the most is the environmental because it receives the lowest qualifications from the comparison with products similar to the software SIMAPRO. For the case of the steam production, it was compared with steam production from coal and the only category that is favored is the acidification. It's possible that the combustion process isn't having results in an efficient way, therefore, the results in the Global warming category doesn't surpass the results for coal. For the case of paper production, it was compared to production of Kraft paper with and without whitening. None of the impact categories had better results than the compared processes.

Table 3: Sustainability analysis for the use of sugarcane bagasse with AHP method.

DIMENSION	Max Value	Steam Production Value	Qualification	Paper Production Value	Qualification
Environmental Dimension: LCA (1)					
Acidification (0,1)	0,1	0.00117 Kg eq SO_2	0,072	0.747 Kg eq SO_2	0,059
Eutrophication (0,2)	0,2	2.32 Kg eq PO_4	0,000	0.293 Kg eq PO_4	0,097
Global Warming (0,3)	0,3	2 Kg eq CO_2	0,000	101 Kg eq CO_2	0,189
Photochemical Oxidation (0,1)	0,1	0.0106 Kg eq C_2H_4	0,000	0.0324 Kg eq C_2H_4	0,056
Ozone layer decay (0,1)	0,1	2.67e-10 Kg eq CFC	0,100	9.1e-6Kg eq CFC	0,061
Abiotic Decay(0,2)	0,2	2.04e-7 Kg eq Sb	0,000	0.000498e-7 eq Sb	0
Environmental Dimension	1		0,172		0,462
Economic Dimension: LCC (1)					
Internal Rate of Return	1	0,335 dimensionless	0,800	1,816 dimensionless	1
Economic Dimension	1		0,800		1
Dimensión Social: Análisis de Stakeholders (1)					
Power	0,5	4	0,200	3,1	0,155
Interest	0,5	5,4	0,270	5,2	0,260
Social Dimension	1		0,470		0,415
Total Sustainability	3		1,442		1,877

The concentration of carbon dioxide applied has to be revised because the results from the environmental evaluation in the software show the impact of the whitening unitary process. On the economic dimension the after doing LCC the indicator of sustainability taken was the behavior of the Internal Rate of Return, which had the best results in the paper production process. The Internal Rate of Return lowers in the cogeneration processes for steam in the sugar process facilities because it requires a large initial inversion. The social dimension had results similar in both processes; however, the low level is compared with the economic dimension. This is due to the big quantity of groups involved which present low levels of power and interest for the use of sugarcane bagasse.

4. Conclusions

When incorporating the LCA (on the Environmental Dimension), the Analysis of Lifecycle Costs (Economic Dimension) and the Analysis of the Stakeholders (Social Dimension), the indicator of sustainability was built in order to obtain a pertinent vision of sustainability of the types of usage for sugarcane bagasse. It recognizes the flaws in the respective dimension, building an effective and efficient tool. In spite of what the authorities of the sector regarding the usage of sugarcane bagasse, with the results of this study it is evidenced the low sustainability that the use of this kind of agro-industrial waste with high energetic content. Improving the unitary processes environmentally critical becomes necessary as well as analyzing the possibility of new usages that show better levels of sustainability on a social and economic dimension. The proposed methodology in the present work was established to analyze the alternatives that exist today for the usage of sugarcane bagasse, however, due to its characteristics, it can be used to give viability to new alternatives for usage such as ethanol production from lignocellulose, production of biopolymers amongst others.

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