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Environmental Performance Assessment of Industrial Processes in Sugar Power Plants: A Proposed Methodological Framework

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Abstract: The implementation of an Environmental Management System (EMS) has a wide range of requirements, among which, an environmental performance measurement based on appropriate indicators to a company reality. The definition of these indicators should take into account specificities of the produced goods and adopted processes, once industrial wastes are the main causes of environmental damages. Sugar power industry has always been concerned with production performance and environmental issues. This trade generates, especially in its industrial stages, many wastes and potentially polluting byproducts. Based on the allocation given to wastes and byproducts generated in industrial steps of sugarcane processing, the purpose of this paper is to develop a specific methodological framework to assess the environmental performance of manufacturing stages in sugar power plants. The developed structure took into account 27 wastes and byproducts generated in sugar power production, which can be used both for individual environmental performance and for a group of companies of the sector.

Key words: environmental performance evaluation; sugar and ethanol plants evaluation; environmental management

1. Introduction

In recent decades, environmental accidents and international conferences on the subject "environment" have contributed significantly to the improvement of environmental regulations and society pressure for products and processes that do not spoil the environment [1]. In this context, companies started to direct more attention towards cleaner production processes, minimizing the demand on scarce natural resources and developing Environmental Management Systems (EMS) to monitor and control pollution levels also reducing environmental contamination risks [2].

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EMS implementation has some requirements, such as environmental performance measurement based on indicators that are adequate to the company reality. Even if these indicators do not fully express the reality, they make it easy and simple communication of a subject often complex [3].

Environmental performance indicators should take into account the specificities of produced goods and the adopted processes, since industrial wastes constitute the main causes of environmental damages. Therefore, each production process has naturally specific aspects to be considered to select the most appropriate environmental indicators [4-5]. Considering the previously mentioned, it is suggested that those factors are carefully surveyed as a prerequisite for construction of indicators that, in fact, can measure the environmental performance of a company [6].

Among the productive sectors that have always been worried about production and environmental performance, it can be highlighted the sugar power industry, which produces sugar, alcohol and more recently, electricity. Such enterprises have always faced environmental problems resulting from production process, since it generates potentially polluting wastes and byproducts, especially during industrial stages. As examples, vinasse and press mud can result in significant impacts to the environment if they are released directly in the wild [7].

According to allocations of waste and byproduct generated in industrial steps of sugarcane processing, this paper aimed to develop a specific methodological framework to assess the environmental performance of manufacturing stages in sugar power plants.

It is noteworthy to mention that the paper does not encompass agricultural stage wastes and byproducts, i.e., during sugarcane planting, cultivation, cutting, loading and transportation. This research is relevant insofar as it contributes to discussion on sustainability of the sugar power industry, developing most effective indicators to assess environmental impacts of such activity and as a tool to mitigate environmental liabilities.

2. Method

Method development was composed of three stages, namely:

(1) Identification and mapping of the stages within sugar power production and checklist of generated wastes and byproducts. By means of this step, it was built up an inventory of operations that generate wastes and byproducts in sugar and ethanol manufacture, identifying their characteristics, composition and possible destinations. For this, it was performed a field research in five Brazilian sugar power plants as well as a literature review. Plants were chosen by convenience and the employees responsible for production and environmental management were interviewed at each of them;

(2) Relative environmental impact quantification of each stage identified in step 1. For this, it was used the Analytic Hierarchy Process (AHP), a tool to support decisions on complex problems [8];

(3) Development of the methodological framework to assess environmental performance of the sugar power plants based on suitability of waste and byproduct disposal.

3. Environmental Performance Assessment

Companies have been adapting themselves to meet new market demands and economic goals. Thus, they have been following a new production paradigm, in which the adoption of cleaner technologies and study of environmental impacts of products throughout their life cycles are necessary [9-10].

Production goals aligned with environmental issues highlight the need for environmental performance indicators that can, in fact, not only measure current environmental impacts of production operations, but also indicate the environmental performance progress of interventions and improve it [11]. Thus, studies involving environmental practices adopted by companies, most of the time, bring certain taxonomies to facilitate understanding and development of environmental issues within organizations.

In this context, many authors present models and tools to identify and evaluate environmental management practices. Among the proposals presented in the literature, there are models such as the one proposed by Delmas and Toffel [12], which focus on the reasons for a company to adopt actions beyond those normally demanded by regulatory bodies.

Hunt and Auster [13], focused on business concern about environmental issues, proposed a five-stage model to classify studied companies. Rohrich and Cunha [11] proposed a taxonomy for environmental management systems of industrial organizations and analyzed its relationship with technological innovation adoption. While Jabbour and Santos [14] sought to integrate existing theoretical models, systematizing the concepts of "ambient intelligence" (AmI), climate change strategies and the role played by the production so that such strategies have the desired effect.

On the other hand, based on quantitative valuation, it is known the so called emergy method proposed by Odum [15] to evaluate environmental impacts caused by production system that analyzes rates related to the use of renewable and nonrenewable resources, local environmental and economic services and economic profitability of the productive system.

Tahir and Darton [4], in turn, suggested a broader method for measuring the environmental performance of a business from five steps. Over the past decade in particular, several studies have been published on indicators' definition, such as Campos and Melo [1], Thoresen [18], Jasch [19] and Sellito et al. [3].

It is important to highlight that environmental performance indicators should also take into account the specificities of produced products and adopted processes, once industrial waste is the main cause of environmental damages. Therefore, each production process has specific aspects to be considered for the selection of most appropriate environmental indicators.

4. Presentation of the Proposed Methodological Structure

It is considered as waste all that is produced and cannot be economically used. Otherwise, it will be considered as a byproduct, the substance or the material that meets the following requirements: (1) having future use; (2) being used directly without modification; (3) integrating a continuous production process [20].

However, both waste and byproducts may or may not be pollutants. This depends on the ability of the natural system to support the amounts of these materials introduced in the environment.

4.1 Sugar Power Production and Its Wastes and Byproducts

Wastes and byproducts generated by sugar power production stages were identified through survey and study. It was found 27 wastes and byproducts within the process. All of them were considered in the proposed model building process. Table 1 illustrates these wastes and byproducts, summarizing their potential impacts whether released in the wild without proper treatments.

Table 1 Wastes and Byproducts Generated by Sugar Power Production and Their Potential Impacts

Waste and Byproduct	Potential impact
Vinasse	Potentially polluting effluent to soil, surface and underground watercourses, since it is rich in organic matter (from 20,000 to 35,000 mg/l) and it has an acidic pH ranging from 5 to 5.5
Batteries	Waste containing heavy metals such as lead, mercury, nickel and cadmium, with high potential to contaminate soil and water
Crude ethanol	Byproduct highly contaminant of soil and water by containing acids, aldehydes, furfural, esters, higher alcohols and substances consisting of ammonia and amines
Lubricating oils	They have hydrocarbons and metals such as iron, lead, zinc, copper, chromium, nickel and cadmium. Once released into the soil, it runs off carried by rainwater, polluting soil and contaminating groundwater table. Whether released into surface waters, it forms a layer that prevents water oxygenation and photosynthesis in aquatic plants, which in turn, feed the fish
Burned lamps	It is a waste rich in mercury (heavy metal) with high potential for contamination of soil, water, plants and animals
Molasses	It consists mainly of sugars such as fructose, glucose and sucrose that have not crystallized in final produced sugar. Although it can be used as a fertilizer (composed by nitrogen, phosphates, calcium and magnesium as well as zinc, manganese, copper, iron and micronutrients), it can also be used as animal feeding. It is highly pollutant due to its high concentration, up to 85º Brix; therefore, having high biochemical oxygen demand (BOD)
Fusel oil	Potentially polluting effluent to watercourses and soil, which is basically composed of isoamyl alcohol, isobutyl alcohol, n-amyl alcohol, n-butyl alcohol, isopropanol, furfural, aldehydes and fatty acids

(Table 1 to be continued)

(Table 1 continued)

Waste from the Laboratory of Sucrose Content Analysis (LSCA)	These are aluminum-based clarifying solutions; filter paper waste; wet cake (fiber analysis); impurity analysis ashes and reducing sugar analysis reagents performed in sugarcane evaluations. They are potentially polluting to water and soil
Bagasse	It is a byproduct composed primarily of fiber (cellulose) and water, also containing certain amount of sugar (2-3% of the bagasse wet-weight) and low pH (around 5.6). Bagasse cellulose, hemicellulose and lignin degradation may have great polluting effect on water if it is discarded into waterbodies with significantly increasing in BOD levels
Ferrous and non-ferrous scraps	Ferrous and non-ferrous metals such as aluminum, copper, brass, nickel, zinc are potentially contaminant to water and soil, both by plant, clay and organic matter absorption and water leaching
Effluent from vat washings	It is considered that the water from washing vats has about 20% of vinasse polluting effect
Effluent from floors and equipment washings	Effluent with non-uniform characteristics, BOD varying from hundred to thousand milligrams per liter and pH from very acidic to very alkaline. It may also have grease and oils. This is an effluent with high potential of water and soil contamination
Effluent from sugarcane washing	Effluent characterized by high rates of BOD, lots of organic matter, high content of solids and low pH
Press mud	The byproduct characteristics are affected in sugar maturation stage and by sugarcane variety, soil type, variations in broth clarification process etc. Organic nitrogen, calcium and phosphorus are among its main elements. It is composed by bagasse (11% lignin, 34% hemicellulose and 38% cellulose) and a small mineral fraction (mainly silicon). It has high polluting potential especially to water, what may cause significant damages to surface or groundwater whether improperly discarded
Yeast	It is a byproduct rich in protein and with a high concentration of B complex vitamin, being widely used in animal food composition and food industry. Since more than 87% dry matter weight is composed of organic matter; it becomes a high polluting material mainly to surface waters and groundwater
Bagasse burning ashes	Although chemically stable, non-toxic and without dissolved organic material, it is potentially polluting to surface waters. Silicon dioxide (SiO_2) predominates (60% of the mass), while potassium oxide (K_2O), magnesium oxide (MgO), phosphorous oxide (P_2O_5) and calcium oxide (CaO) together represent around 32% of the total ash mass
Ethanol dehydration waste	The zeolite resin is inert after finishing the adsorption power and becomes a rock of aluminum and silica. It has no polluting effect to the atmosphere, and low to the water and the soil, moreover it can cause silting in the water
Bagasse burning gas	It is flue gas composed by methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), nitrogen oxides (NO_x) and carbon dioxide (CO_2). There is no conclusive definition among scientists. Although it is found in the literature that CO_2 emissions from burning are not shown under renewable cycle of biomass, some authors have been challenging this hypothesis and claim that this sum is not zero; i.e., there is greater volume of CO_2 produced than captured by sugarcane. Moreover, some experts believe that CO_2 fixation in sugarcane fields occurs in greater volume than bagasse combustion CO_2 emission, once part of the CO_2 (captured by plants) will be converted into sugar, not ethanol; thereby not all CO_2 returns to the environment. In any event, it is unquestionable that methane and nitrous oxide have strong impact on the greenhouse effect, in which methane is twenty times more polluting than carbon dioxide
Bagasse burning particulates	It consists of soot particles, non-completely burned small bagasse fragments and silica. These have relative pollutant power to the atmosphere. While heavier and coarser materials are settled near plantations, the smaller and lighter particulates are spread remotely
Settled solids	Sugar power wastewater is deposited in settling tanks, so that high-density suspended solids are gradually decanted. Lower specific-mass materials, such as greases and oils, float up to the treatment liquid surface; and thus being separated and driven towards specific storage. The main contamination risk lies on surface waters, since it is a mixed slurry solids with very varied BOD rate
Gaseous emission effluent from vats	It is composed by CO_2 gas from must fermentation. Significant amount of CO_2 is released to the environment by fermenting million liters of must. Each 92g ethanol releases 88g carbon dioxide in the atmosphere. Despite there being current technologies for this CO_2 capture and storage, few industries use them
Effluent from treatment of combustion gases	Despite containing some organic matter, it has a low BOD rate (100 to 300 mg/l). It is a very hot effluent (temperature up to 80°C) and with a high soot load, which make impossible to be poured directly into water bodies or soil

(Table 1 to be continued)

(Table 1 to continued)

Flegmass	Flegmass is a liquid with fusel oil traits and low polluting potential. By each ethanol liter produced, it is estimated an average of 2.8 liter flegmass
Boiler discharge sludge	It is a sludge-form solid waste primarily composed of silica, calcium and magnesium. It is considered with low polluting potential to the soil or water sources. Some plants do not produce such waste given the boiler technology in use, once there are high levels of treatment and water quality control within used boilers
Effluent from barometric condensers and multi-jets	This is a low polluting potential effluent due to its low organic load, BOD (up to 40mg/l), and moderate temperatures (around 45ºC)
Effluent from evaporators	Effluents with low BOD and contamination risk to the soil or water
Boiler discharge effluent	Effluent with very low BOD, however with high concentrations of sludge and soluble solids and it should not be poured into water sources

4.2 Quantitative Estimation of Relative Environmental Impact of Each Waste and Byproduct

At this part, it was used the Analytic Hierarchy Process (AHP) analysis method, which organizes data in a hierarchical structure to show the relationships of the goals, objectives, criteria and alternatives including uncertainties and other influences of the problem in question [16]. AHP problem structuring starts by defining the desired global objective. Then, criteria are defined and compose a tree structure, in which main objective stands for the tree root. As it moves away from the root, more specific factors are reached and the edges ("the leaves") represent the evaluation criteria. As we move away from root, most specific factors are found and the edges (leaves) represent evaluation factors and criteria. Within similar criteria group with same "father", it should be completed a pairwise comparison matrix (PCM), which has the preference levels obtained by factors' comparison. The AHP principle is to generate a priority vector by the largest eigenvector calculation for each PCM of the entire problem [17]. The pairwise comparison answers are obtained from interviews with experts or not on the subject; however, who are aware of the problem [8].

They are not made in absolute scale due to the nature of the components in multi-criteria decision. Since the problem is often abstract, it makes difficult to measure singly components, especially in same the scale. When comparing each two, the decision-maker preference for an "X" attribute to the detriment of a "Y" one, for example, "X" attribute gets weight "5". If both conditions have the same importance, it will be assigned weight "1". Table 2 defines and explains the concept of weights used in the AHP.

Pairwise judgment practical implementation by the AHP method was made using the *Make It Rational* software (http://makeitrational.com/features). For pairwise comparisons, a four-expert team was pulled together, all of them skilled in environmental management and sugar power production, who have been working in the industry for a period of at least four years (Table 3). The experts performed data input into the software, one by one; therefore, coincidences on pairwise comparison opinions were avoided. This was made both for the decision criteria as to the decision alternatives.

Table 2 Factors to Pairwise Comparisons

Importance grade	Definition	Explanation
1	Equally importance	Two factors contribute equally to the objective
3	Moderate importance of one factor over the other	Experience and judgment slightly favor one over the other
5	Strong or essential importance	Experience and judgment strongly favor one over the other.
7	Very strong importance	Experience and judgment very strongly favor one over the other. It is demonstrated in practice
9	Extreme importance	The evidence favoring one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is required

Table 3 Expert Team Skills

Expert	Experience in sugar power production	Experience in environmental management	Formation
A	5 years	7 years	Agronomist
B	6 years	10 years	Physicist
C	4 years	6 years	Environmental Engineer
D	4 years	4 years	Industrial Engineer

With a view to quantitative estimation of the relative environmental impact of each waste and byproduct, it was developed a hierarchical structure driven by three basic environmental components: soil, water and atmosphere. They were the evaluation criteria, being used as benchmarks in the peer evaluation of alternatives. These alternatives are the twenty-seven wastes and byproducts previously identified (Table 1).

The hierarchical structure can be seen below in Fig. 1. Relative environmental impact of each waste and byproduct was weighed through the AHP method, taking into account their possible impact whether released into the environment directly. For example, it was taken as a hypothesis both effluent being discharged directly into waterways for the pairwise comparison between vinasse and flegmass regarding to "water impact". In this case, appraisers weighed a 7:1 ratio, i.e., "vinasse" was considered highly dominant when compared to the "flegmass". This is due to the higher polluting effect of that waste, which presents very high BOD levels, while the later consists primarily of water with fusel oil traits and low BOD levels.

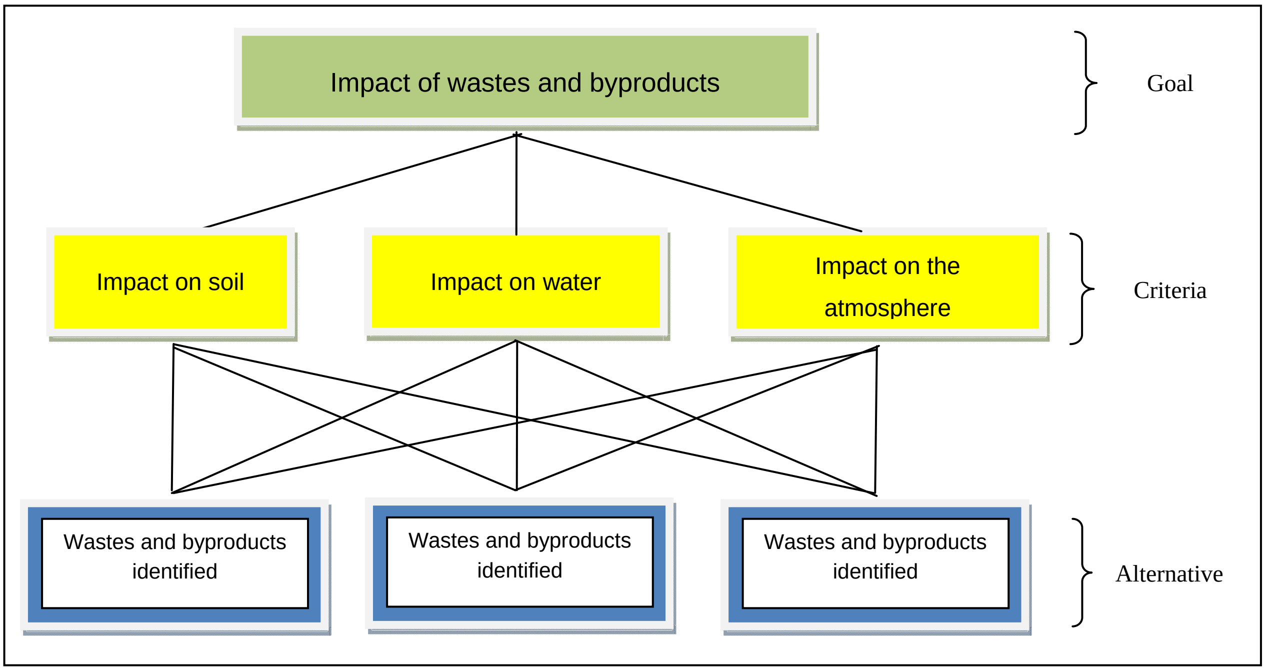

Fig. 1 Hierarchical Structure Adopted

Fig. 2 shows pairwise comparisons results considering the aforementioned criteria (atmosphere, water and soil impacts). By expert team considerations, sugar power industrial production showed great environmental impact on waters (67.4%), followed by soil (22.6%) and atmosphere (10.07%). Relative weighting for each waste and byproduct showed a consistency rate (CR) of 0.082. It is said that 0.10 or less is considered an acceptable rate [8].

Fig. 3 shows the results of the relative weighting of potential environmental impact of each waste and byproduct.

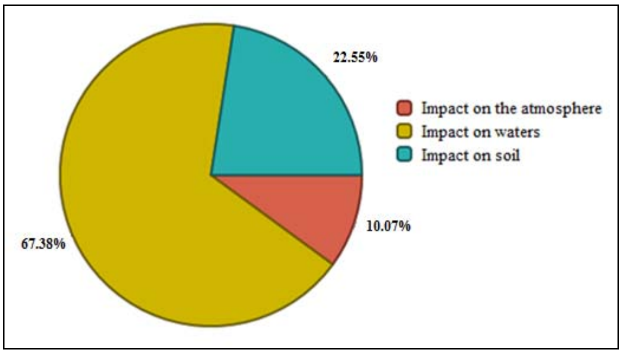

Fig. 2 Pairwise Comparison Results among Criteria of the Established Hierarchy

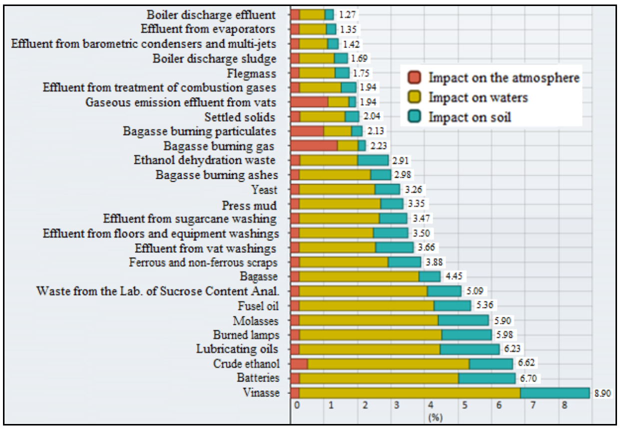

Fig. 3 Graphical Results of the Relative Weighting of Environmental Impact among the Twenty-Seven Wastes and Byproducts

4.3 Evaluation Framework of the Disposal of Wastes and Byproducts

For the above considerations, it was possible to create a methodological framework for an environmental performance evaluation of one or more sugar power plants following a categorical evaluation of each waste and/or byproduct allocation. Table 5 shows this methodological framework. First line in the table lists all 27 wastes and byproducts assessed; then, the second line shows their respective weights, according to Table 4. Third line (blank) ought to be fulfilled by the environmental suitability evaluation carried for each waste and byproduct allocation and all surveyed plant. In this case, it was used a binomial scale, in which environmentally appropriate adjustment receives grade 1, if not, the grade is zero.

The fourth and last line of Table 5 (absolute assessment of wastes and byproducts) displays the weighted score for each waste and byproduct. It results from the multiplication of received points by relative weighting of each such item. Evaluation results must be shown within the last column (absolute evaluation of the plant). This result is expressed in percentage values and presents the company assessment regarding adequacy in waste and byproduct disposals.

4.4 Application Example

As an example of the methodology application, it is presented the evaluation of fourteen sugar power plants belonging to the Mogi Guaçu river basin (MGRB), Southeastern Brazil. Currently, environmental issues should be studied at basin level, since local environmental quality is inwardly associated with types of occupation and use of soil and natural resources, with emphasis on surface and groundwater [21].

The MGRB (Fig. 4) has a total area of 17,460 square kilometers and lies on one of the most industrialized regions of the country, encompassing 43 municipalities with 1.46 million inhabitants [22].

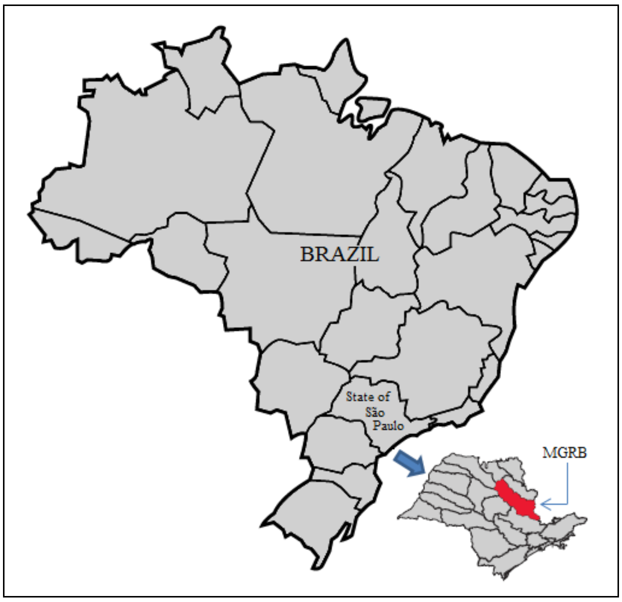

Fig. 4 Location of the Mogi Guaçu River Basin (MGRB), São Paulo State, Brazil - adapted from [23, 24]

Table 4 Evaluation of the Sugar Power Plants

Waste and byproduct	Evaluation
Vinasse	All plants claimed to meet São Paulo State standards for vinasse management, what means that the byproduct is applied in agriculture through irrigation according to established scientific parameters. Destination is considered environmentally friendly (grade 1)
Batteries	All plants argued to dispatch this waste to accredited companies. Destination is considered environmentally friendly (grade 1)
Crude ethanol	Companies asserted to reprocess raw ethanol or sell it. Destinations are considered environmentally friendly (grade 1)
Lubricating oils	All plants affirmed to send this waste to companies specialized in oil re-refining. Destination is considered environmentally friendly (grade 1)
Burned lamps	Companies stated to dispatch it to industrial landfill or specialized recycling companies. Destinations are considered environmentally friendly (grade 1)
Molasses	It was checked that this is sold or routed to ethanol production. Destinations are considered environmentally friendly (grade 1)
Fusel oil	Twelve plants declared to sell the oil, and therefore were graded 1. Two of them treat as wastewater and therefore received zero
Waste from the Laboratory of Sucrose Content Analysis (LSCA)	Seven plants argued to discard them into industrial landfill, and other seven told that they send to specialized companies. Destinations are considered environmentally friendly (grade 1)
Bagasse	All plants allocate the bagasse back to boilers for power production, and the surplus is sold. Destinations are considered environmentally friendly (grade 1)
Ferrous and non-ferrous scraps	All plants (except one) designed this type of material to recycling companies. One of them discard non-ferrous scrap into industrial landfill. Destinations are considered environmentally friendly (grade 1)
Effluent from vat washings	One of the plants returns it to the steering barrel. One of the plants does not produce this effluent. The twelve remaining plants use in crop growing. Destinations are considered environmentally friendly (grade 1)
Effluent from floors and equipment washings	One of the plants adds it into the sugarcane washing water. Two of them forward it to wastewater. All other designed the effluent to crops (grade 1)
Effluent from sugarcane washing	Four plants do not produce such effluent. The remaining ten manage it to the closed circuit and fertigation. All of them are considered environmentally friendly destinations (grade 1)
Press mud	All plants intended this byproduct to sugarcane fields. Destination is considered environmentally friendly (grade 1)
Yeast	Nine plants sell this byproduct. Four of them incorporate it into vinasse for fertigation. One of them sells it or incorporates to vinasse. Destinations are considered environmentally friendly (grade 1)
Bagasse burning ashes	All plants intended this waste to farming. Destination is considered environmentally friendly (grade 1)
Ethanol dehydration waste	Only two plants affirmed to produce this waste, which is sent to industrial landfill. Destination is considered environmentally friendly (grade 1)
Bagasse burning gas	All plants declared to expel this gas out by chimneys. This is even a practice deemed legal by environmental regulators. However, gases emitted by burning bagasse have great pollutant effect in the atmosphere. Destination is considered environmentally inadequate (grade 0)
Bagasse burning particulates	All plants declared to meet official state resolutions on washing of gases from bagasse combustion (grade 1)
Settled solids	All plants declared to take decanted solids from tanks to sugarcane fields. Destination is considered environmentally friendly (grade 1)
Gaseous emission effluent from tanks	All plants release this gas waste into the atmosphere. Destination is considered environmentally incorrect (grade 0)
Effluent from treatment of combustion gases	Ten plants declared to use this effluent within closed circuit and crop fertigation. Four of them apply it into crops with vinasse. Destinations are considered environmentally friendly (grade 1)
Flegmass	Six plants return this effluent to the head of column A (ethanol distillation process). Eight plants use it in crop growing. Destinations are considered environmentally friendly (grade 1)
Boiler discharge sludge	Three plants do not produce such waste. Eleven plants use it in crops. Destination is considered environmentally friendly (grade 1)
Effluent from barometric condensers and multi-jets	Ten plants declared to reuse these effluents in closed loop structure. Four plants reuse them in crops. Destinations are considered environmentally friendly (grade 1)
Effluent from evaporators	Four plants use this effluent in boilers. Two of them direct it to crops. Nine of them reused it as vegetal vapor. Destinations are considered environmentally friendly (grade 1)
Boiler discharge effluent	Four plants use this effluent in the closed circuit. Two plants reuse in other process steps. Eight of them send it to crop use. Destinations are considered environmentally friendly (grade 1)

Table 5 Methodological Framework for Assessing the Environmental Performance of Sugar-Power Plants

Waste/by-product	Relative weighting	Sugar-power plant	Absolute evaluation of waste/by-product
Boiler discharge effluent	1.27		
Effluent from evaporators	1.35		
Effluent from barometric condensers and multi-jets	1.42		
Boilers discharge sludge	1.69		
Flegmass	1.75		
Effluent from treatment of combustion gases	1.94		
Gaseous emission effluent from vats	1.94		
Settled solids	2.04		
Bagasse burning particulates	2.13		
Bagasse burning gas	2.23		
Ethanol dehydration waste	2.91		
Bagasse burning ashes	2.98		
Yeast	3.26		
Press mud	3.35		
Effluent from sugarcane washings	3.47		
Effluent from floors and equipment washing	3.50		
Effluent from vats washing	3.66		
Ferrous and non-ferrous scraps	3.88		
Bagasse	4.45		
Waste from the Laboratory of Sucrose Content Analysis	5.09		
Fusel oil	5.36		
Molasses	5.90		
Burned lamps	5.98		
Lubricating oils	6.23		
Crude ethanol	6.62		
Batteries	6.70		
Vinasse	8.90		
Absolute evaluation of the sugar-energy plant			

Table 6 shows the categorical evaluation of each plant for each waste and byproduct. The table also provides the relative weighting of each material and the absolute evaluation (last table line). At the rightmost column, it is possible to observe each plant absolute grade. At the bottom right, it can be found the final quantitative assessment averages for all plants, concerning discard allocation. It was concluded that the surveyed sugar power plants have correctly allocated around 95% of their wastes and byproducts.

5. Last Remarks

Sugarcane industries besides generating sugar, ethanol, power and other marketable byproducts, employs methods and processes of high potential impact on the environment. The sector has been

Table 6 Application Example of the Framework on MGRB Plants

Waste/by-product	Relative weighting →	Sugar-power plant ↓	A	B	C	D	E	F	G	H	I	J	K	L	M	N	**Absolute evaluation of waste/by-product →**
Boiler discharge effluent	1.27		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.27
Effluent from evaporators	1.35		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.35
Effluent from barometric condensers and multi-jets	1.42		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.42
Boilers discharge sludge	1.69		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.69
Flegmass	1.75		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.75
Effluent from treatment of combustion gases	1.94		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
Gaseous emission effluent from vats	1.94		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Settled solids	2.04		1	1	1	1	1	1	1	1	1	1	1	1	1	1	2.04
Bagasse burning particulates	2.13		1	1	1	1	1	1	1	1	1	1	1	1	1	1	2.13
Bagasse burning gas	2.23		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Ethanol dehydration waste	2.91		1	1	1	1	1	1	1	1	1	1	1	1	1	1	2.91
Bagasse burning ashes	2.98		1	1	1	1	1	1	1	1	1	1	1	1	1	1	2.98
Yeast	3.26		1	1	1	1	1	1	1	1	1	1	1	1	1	1	3.26
Press mud	3.35		1	1	1	1	1	1	1	1	1	1	1	1	1	1	3.35
Effluent from sugarcane washings	3.47		1	1	1	1	1	1	1	1	1	1	1	1	1	1	3.47
Effluent from floors and equipment washing	3.50		1	1	1	1	1	1	1	1	1	1	1	1	1	1	3.50
Effluent from vats washing	3.66		1	1	1	1	1	1	1	1	1	1	1	1	1	1	3.66
Ferrous and non-ferrous scraps	3.88		1	1	1	1	1	1	1	1	1	1	1	1	1	1	3.88
Bagasse	4.45		1	1	1	1	1	1	1	1	1	1	1	1	1	1	4.45
Waste from the Lab. of Sucrose Content Analysis	5.09		1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.09
Fusel oil	5.36		1	1	1	1	1	1	0	1	1	1	1	0	1	1	4.61
Molasses	5.90		1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.90
Burned lamps	5.98		1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.98
Lubricating oils	6.23		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.23
Crude ethanol	6.62		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.62
Batteries	6.70		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.70
Vinasse	8.90		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.90
Absolute evaluation of the sugar-power plant ↓			95.83	95.83	95.83	95.83	95.83	95.83	90.47	95.83	95.83	95.83	95.83	90.47	95.83	95.83	Plants average 95.06

adopting innovations on industrial waste management, both due to law enforcement and environmental awareness by the entrepreneurs.

Based on waste and byproduct allocations of each sugarcane industrial stages, this study aimed to develop a specific methodological framework to assess the environmental performance of sugar power plants.

To this end, the research identified twenty-seven generated wastes and byproducts. Both can be clean, depending on natural system ability to support discarded amounts. These materials were taken as alternatives to be confronted to criteria such as impact on water, soil and atmosphere. Their relative environmental impact weighting is a complex problem to be solved, since the appreciative classification of pollutants requires both knowledge of the consequences in terms of environmental impacts as well as a comparative reflection between these consequences. This problem involves products of large differences in chemical and physical nature; many harmful effects could be poorly designed at different natural environments; and changes on these effects may occur over time.

The developed framework can be used for individual or group assessment of sugar power plants.

In addition, it allows the assessment along time by measuring the result of actions taken to improve the environmental performance of certain plant or group of plants.

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