EXERGETIC ANALYSIS BASED ON THE ENVIRONMENTAL INDICATORS IN THE OPERATION OF A GENERATING GROUP WORKING WITH BIOGAS

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Abstract. *In this work, it was developed a prototype of energy generation system that uses biogas. It consists of a internal combustion engine coupled to a asynchronous motor capable to generate up to 5 kW in three phases of 220 volts. It was ended that the system is operational and it can in short period to be used for the maintainable handling of a sanitary landfill. In the aspect environmental impact, starting from an exergetic analysis done based on the environmental indicators: exergetic environmental efficiency ($\eta_{ex.env}$) and reason of total pollution (R_{pol}), the system represent an advantageous alternative to simple biogas burns, having an exergetic environmental efficiency ($\eta_{ex.env}$), in the order of 8 times larger and a reason of total pollution (R_{pol}), 10 times minor.*

Key words: biogas, residues, asynchronous generation, exergy.

1. INTRODUCTION

The biogas, that until there is little time it was simply faced as a unwanted by-product obtained starting from the anaerobic decomposition of the organic matter contained in the urban solid residues, animal residues and of domestic and industrial liquid effluents treatment stations, according to Pecora (2006), has in your use the possibility of reduction costs or even been a instrument of economical viability for depollution projects. This moment became attraction for the use of the biogas that is a fuel that can be applied directly to the existent machines, in a transition period for new technologies. Like example, fuel cells as mentioned in Van Herle et al. (2004). The viability and the successful use of biogas from numerous types of residues for electric power generation are a reality or has being discussed in several points of the planet as told in Goldstein (2004), Costello (2005), Azevedo (2000), Brookshire (1999), Sampat (1995) and Nogueira (1992). Or as part of a strategy of developing an energy matrix based on maintainable energies as having told in Rynk and Goldstein (2002), Goldstein (2003). A city like Porto Alegre produces, daily, more than a million kilograms of waste that is largely disposed in sanitary landfills. These landfills accomplish international control norms, anyway they represent a problem to the place where they are installed, in the environmental and social aspects. The liberated gas represents an environmental problem, because it contributes significantly to the Greenhouse Effect. Even the simple burning represents a gain for that purpose. This study was conducted in the Extrema landfill on the south side of Porto Alegre, which has ended more than four years ago, where a team of employees still monitoring, making repairs and managed liquid and gaseous residues that emanate from there.

The gaseous emanations are rich in methane, and they were used as fuel of a prototype of electric power system generation. The principal differentiate of this work: the use of a low cost engine associated to an asynchronous motor, robust and cheap, without biogas compression; the idea that the intern combustion engine is a disposable piece of the system and periodically it should be substituted; and the analysis environmental exergetic done in the landfill and in the generating system. In the social aspect the energy generated by the system can be applied in the proximities of the landfill, improving the life quality of the bordering populations, representing a compensation of the administrating landfill company in relation to the created upset (bad smell, circulation of garbage trucks and attraction of animals that represent zoonosis vectors). In the cases that the biogas production is an inevitable consequence, as in the sanitary landfills and several systems of effluents treatment, is possible to negotiate the called credits of carbon.

2. METHODOLOGY

The exergy can be used as ecological indicator, once the high exergetic efficiency means less exergetic losses to the atmosphere or smaller environmental damage. Thus, the term "exergetic efficiency", η_B, is proposed as an index of environmental performance that it includes the aspects of energy efficiency and environmental impact, and can be described by Eq. (2.1).

$$\eta_B = \frac{Effectiveness\ of\ Exergy}{Exergy\ Input} \tag{2.1}$$

In this work two indexes of exergetic analysis will be used, the exergetic environmental efficiency, $\eta_{ex,env.}$, and the reason of total pollution, R_{pol}, proposed by Makarytchev (1997) and it Mora and Oliveira Jr. (2004), adapted for analysis of the specific landfill. As larger the exergetic environmental efficiency and smaller the reason of pollution total, more sustainable will be the enterprise. The exergetic environmental efficiency, presented in Eq. (2.2), is the reason between the exit exergy, useful exergy produced in the process, B_{prod}, and the entrance exergy, that corresponds to the sum of the exergy of the natural and human resources used, $B_{res.nat}$, with the exergy of the natural resources preparation, B_{prep}, with the exergy of the residues deactivation, B_{dea}, and with exergy of the residues handling and disposition, B_{disp}.

$$\eta_{ex.env} = \frac{B_{prod}}{B_{res.nat} + B_{prep} + B_{dea} + B_{disp}} \tag{2.2}$$

These exergetics flows are presented schematically in the Figure 2.1, where they are indicated the exergys involved in the process and entrance or exit points.

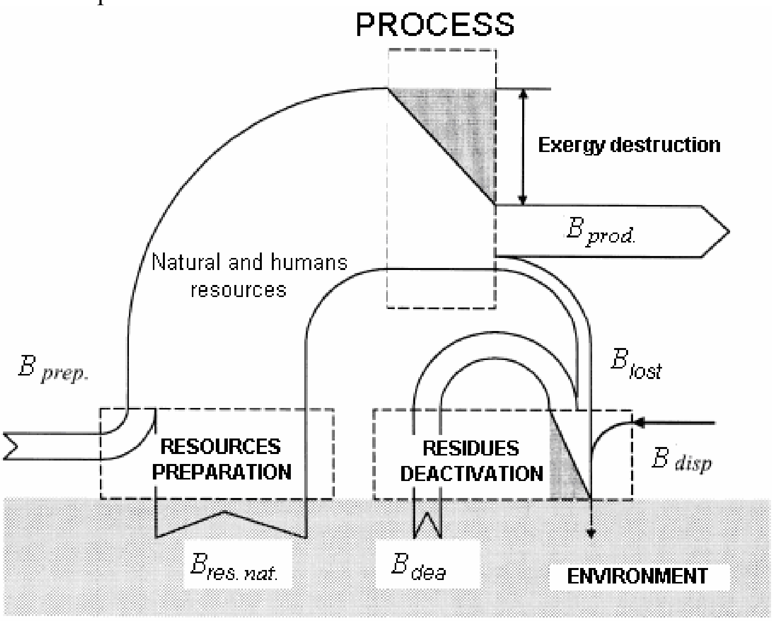

Figure 2.1–The exergy flows in a generic process. Source: Makarytchev(1997).

The reason of total pollution, in Eq. (2.3), is definite as being the reason between the entrance exergy, that corresponds to the sum of the lost exergy in the process, B_{lost}, with the residues deactivation exergy and the exit exergy represented by the useful exergy produced in the process.

$$R_{pol} = \frac{B_{lost} + B_{dea}}{B_{prod}} \tag{2.3}$$

The analysis exergetic in a sewage treatment station, for instance, there is a continuous flow of exergy in entrance and exit. In a sanitary embankment some flows happen in a discreet way in intervals of time different from the total duration of the enterprise. Any analysis, therefore, should take a useful landfill lifetime into account, considering the medium exergetic flows, being made a static analysis, even if some flows concentrate on the beginning of the activities and other in the end.

3. RESULTS

To principal exergetic entrance corresponds to the total exergy of the deposited solid residues, whose origin and year o deposition is presented in the table 3.1, and the electric power consumed in the handling processes and conservation of the landfill.

Table 3.1–Residues destined to the Extrema sanitary landfill, by year and by origin. (Values in t). Source DMLU 2004.

YEAR	TYPES OF RESIDUES					TOTAL / YEAR
	Domestic	Industrial C.II	Commercial	Public	Recycling Waste	
1997	15.647,456	-	-	-	-	15.647,456
1998	258.317,136	4.429,254	16.021,404	23.553,217	-	302.321,011
1999	168.774,375	2.380,560	10.259,996	16.107,947	-	197.522,878
2000	144.561,659	1.999,598	8.814,903	10.103,421	-	165.479,580
2001	84.101,696	967,042	258,503	1.550,919	728,310	87.606,469
2002	50.780,546	830,023	146,108	3.013,09	777,258	55.547,042
TOTAL	722.182,868	10.606,477	35.500,913	54.328,594	1.505,568	824.124,419

The most important exergetic exit corresponds to the biogas exit from the landfill, which now is just burned and almost converted that totally in carbon dioxide and water vapor. The other exits correspond to the liquid effluents with pre-treatment in stabilization lake, the treatment is done outside, in a sewage treatment station, what implicates in exergy consumed in effluents transport, will be ignored the exergy consumed in the solid residues transport from origin points to the landfill, since it would be consumed anyway. These exergy flows are represented in the Figure 3.1, second proposal of Makarytchev 1997.

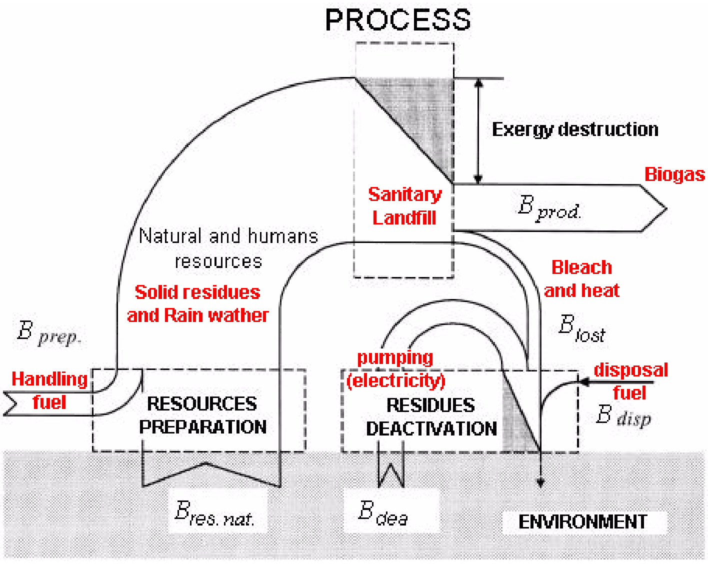

Figure 3.1 – Exergy flows in a sanitary landfill.

Considering the table 3.1, table 3.2 and table 3.3, starting from the exergy values cataloged in Szargut (1988), been suitable to admit that the exergy of the urban solid residues is approximately equal to the calorific power of these residues, whose value is about 5430 kJ/kg, as presented in Camilo et al. (2003) and CENBIO/INFOENER (2007). With the mass deposited in the landfill the exergy entrance of urban solid residues can be evaluated (the medium value considered constant along 20 years). Starting from the data supplied by DMLU can be determined the electric power entrance. The entrance of water of the rain can be determinate starting from the retired fluids that percolating the landfill and are removed daily. The consumption in the transport of this bleach corresponds to the medium consumption of fuels for transport. The preparation exergy was esteemed starting from the number of hours and of the machine type used in the handling of the residues in the landfill. These estimates are presented in the table 3.4.

For the exit exergy four situations were admitted: ideal situation, where the generated methane given as commodity and all your exergy is used in successive co-generation processes; generation + 20%, with a system low cost generation similar to the used, but with the best possible thermal efficiency associated to the use of at least 20% of the rejected heat, for example, heating of water, heating of greenhouses for production of vegetables or mushrooms, or still for the heating of close buildings; generator of low cost, with a generation system similar to the studied, but with better possible thermal efficiency, without other uses of the rejected heat; simple burns, with the current burns system of the methane in flares.

Table 3.2–Composition of the domestic solid residues of Porto Alegre in 2002. Source: Reis et al. (2002)

COMPONENTS	Humid weigh percentage
Organic matter easily biodegradable	43,83%
Rejects	20,29%
Plastic films	5,35%
Newspapers and magazines	4,57%
Rigid plastic	4,24%
Rags	3,53%
Glass	3,44%
Ferrous metal	3,18%
Paper	2,75%
Plastic PET	2,11%
Cardboard	1,94%
Packing long life	1,60%
Wood	0,73%
Aluminum	0,59%
Leathers	0,55%
Expanded polystyrene	0,48%
Rubber	0,29%
Other metals	0,22%
Ceramic	0,18%
Plastic PVC	0,13%
TOTAL	100,00%

Table 3.3 – Characterization of the domestic residues of Porto Alegre in 1997. Source: (DMLU).

COMPONENTS	Humid weigh percentage
Organic matter easily biodegradable	52,10%
Paper	11,26%
Reject	11,00%
Plastic films	7,57%
Rigid plastic	4,84%
Cardboard	3,75%
Rag / Leather	2,78%
Ferrous metal	2,00%
Glass	1,91%
Packings type “long life”	1,27%
Wood	0,87%
Aluminum	0,46%
Other metals	0,07%
Dish	0,07%
Rubber	0,05%
TOTAL	100,00%

Table 3.4 – The medium flow of the several variables for exergetic evaluation.

Variable	Nature	Exergy in kW	Medium flow of mass in kg/s
Natural human and resources $B_{res.nat.}$	Urban Solid residues	7113	1,31
	Rain Water	26,46	0,53
	Total	7139,46	1,84
Preparation B_{prep}	Fuel handling (diesel)	990	0,0221
Deactivation B_{dea}	Electric power pumping and other	2,1	-
Losses B_{lost}	Bleach	27	0,54
	Heat of the carbon dioxide	0,088	-
	Heat of the methane	0,187	-
	Heat of the bleach	2,08	-
	Carbon dioxide	51,07	0,113
	Total	80,425	0,741
Disposition B_{disp}	Fuel discards (diesel)	18,8	0,00042
Useful product B_{prod}	Methane	4777	0,0919

Being applied Eq. 2.2 and 2.3, is possible to determine the indicators exergetic environmental efficiency, $\eta_{ex,env}$., and the reason of total pollution, R_{pol}, for the proposed situations, what is presented in the Table 3.5.

Table 3.5 – Exergetics environmental indicators for the situations proposed for the sanitary embankment.

Indicator	Ideal situation	Generation + 20%	Generator of low cost	Simple burns
Efficiency environmental exergetic, $\eta_{ex,env}$.	0,59	0,22	0,12	0,015
Reason of total pollution, R_{pol}	0,017	1,8	3,8	39

Therefore, not existing use of the biogas, the exergetic environmental efficiency is practically zero, while the reason of total pollution is about ten times high than in the case of the use of the low cost generator.

An analysis in dynamic way of the environmental indicators is also possible, however, the results tend to be similar to the static analysis, after the landfill closing. For that are considered the flows of exergy of the natural and human resources, useful product and the exergy losses, except for the bleach (considered constant), variables as the variations of the biogas flow from the landfill were esteemed by the software LandGem, furthermore, is only considered the handling exergy only for the years in that the residues were deposited. With that is obtained curves of the indicators environmental exergetic environmental efficiency, $\eta_{ex,env}$., and the reason of total pollution, R_{pol}, for the twenty years of useful life of the Extrema sanitary landfill, presented in Figure 3.2 and 3.3.

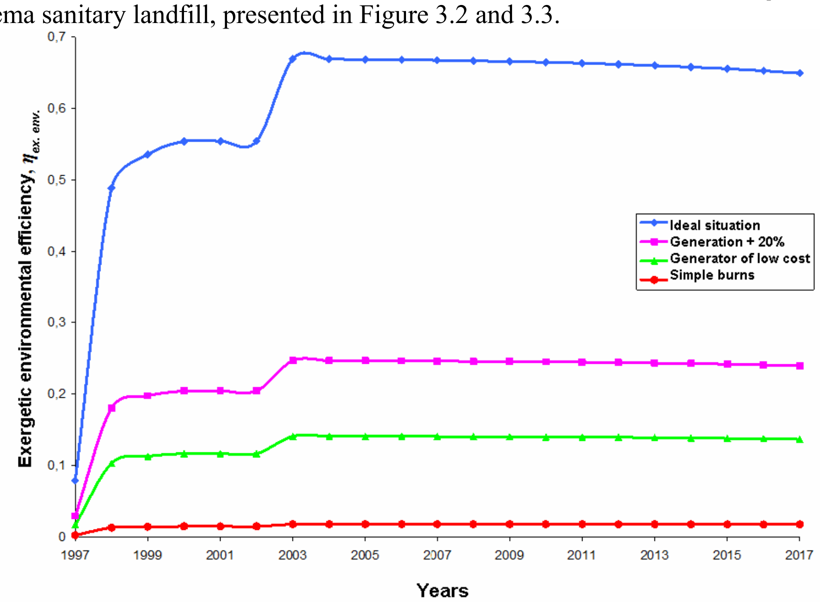

Figure 3.2 – Variation of the indicator exergetic environmental efficiency along the years.

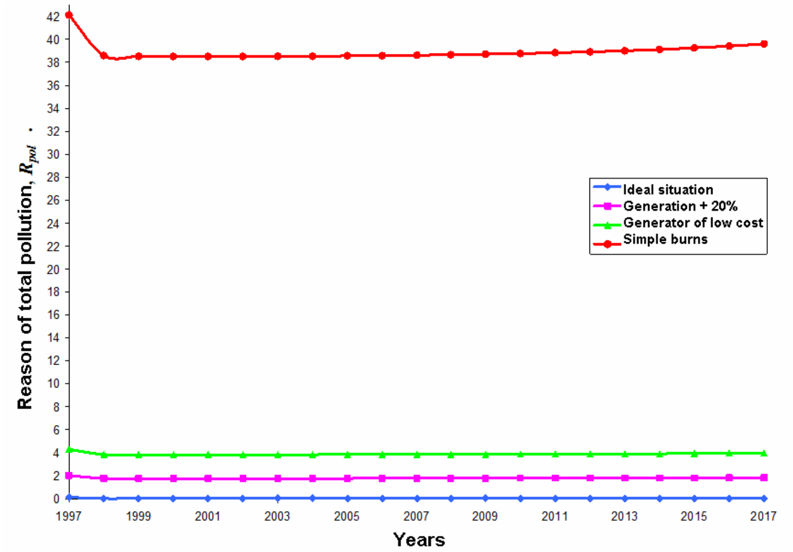

Figure 3.3 – Variation of the indicator reason of total pollution along the years.

Observing the curves of the Figure 3.2 and 3.3, can be observed that, in the case of the indicator exergetic environmental efficiency there were just significant variations until the following year to the closing of the embankment, being stabilized in the subsequent period in values a little above the medium ones presented in the table 3.5. This is becouse the handling exergy to have reduced to zero after the landfill closing. To the indicator reason of total pollution, the approach with the medium values was still more sensitive; practically there were only significant variations for simple biogas burns in the first year of operation. In the case of the Extrema landfill there was a topographical recovery, that in any way should be done. In a topographical recovery done with inert embankment, it just exists entrance exergy, not existing of exit exergy. Therefore, it is extremely unfavorable in exergetics terms. When the topographical recovery is made with the use of urban solid residues they can be obtained more interesting environmental results with regard to the sustainability of the processes - naturally that followed a series of premises of rational use of the energy resources of there coming.

For the generating system he entrance exergy corresponds to the atmospheric air added to the biogas and the exit corresponds the electric power generated as produced useful exergy, besides the exhaust gases, the degraded lubricating oil and the heat changed with the atmosphere, that represent exergetics losses. Although part of the escape gases represents an environmental improvement for providing the conversion of methane in to carbon dioxide. The exergy flow in the generation system is schematically represented in the Figure 3.4, according to the proposal of Makarytchev (1997).

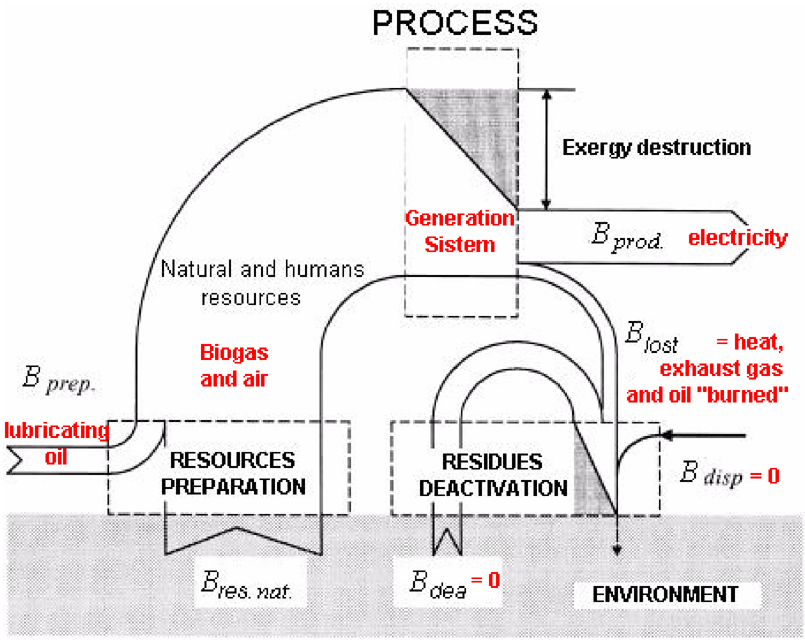

Figure 3.4 – Exergy flow in the generation system.

To facilitate the exergetic analysis it was taken as base the curve presented in the Figure 3. 5, that represents the specific consumption for potency generated kg/kWh, from where she can determine the matter flows involved in the transformation of thermal energy in the system and the value of the electric potency, respectively. The results were adopted for the smallest measured specific consumption. Starting from the exergy values cataloged in Szargut (1988) for the several substances, it is possible to determine the exergy of the atmospheric air and biogas. Being considered the stechiometric operation regime**,** that is the most favorable for engines with gaseous fuel, and the data on gaseous emission lifted, was estimated the volume, escape gases medium composition and the respective chemical exergy. The exergy of the lubricating oil was obtained starting from the calorific power of the used lubricating oil, of approximately 41800kJ/kg, presented in CEMPRE (2007).

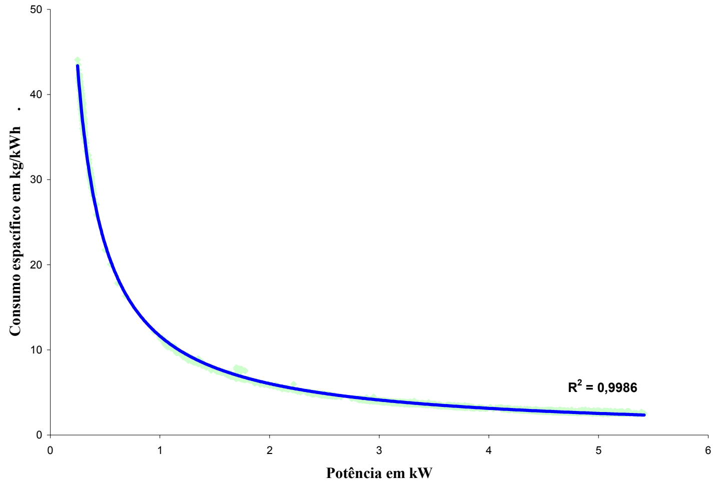

Figure 3.6 – Relationship between the specific consumption and the electric power.

Table 3.6 – The medium flow of the several variables for evaluation exergetic of the generation system.

Variable	Nature	Exergy in kW	Medium flow of mass in kg/s
Natural and human resources $B_{rec.env.}$	Biogas	16,6	0,000672
	Atmospheric air	0,257	0,00531
	Total	16,9	0,00598
Preparation B_{prep}	Lubricating oil	0,186	0,00000444
Losses B_{lost}	Heat	15,6	-
	Escape gases	1,45	0,00598
	Lubricating oil (burned)	0,186	0,00000444
	Total	17,2	0,00598
Useful product B_{prod}	Electric power	1	-

For the exit engine exergy three situations were admitted: prototype, where the environmental indicators are obtained starting from the constant data in the Table 3.6; generation + 20%, starting from an estimate with a system low cost generation similar to the used, but with the best possible thermal revenue associated to the use of at least 20% of the heat rejected for, for example, heating of water, heating of greenhouses for production of vegetables or mushrooms, or still for the heating of close buildings; estimated generator, an operation estimate with a generation system similar to the studied, but with better possible thermal revenue, without other uses of the rejected heat.

Being applied Eq. 2.2 and 2.3, is possible to determine the environmental indicators exergetic environmental efficiency, $\eta_{ex,env}$., and the reason of total pollution, R_{pol}, for the proposed situations, what is presented in the table 3.7.

Table 3.7– Exergetics environmental indicators to the proposed situations in the generating system.

Indicator	Prototype	Generation + 20%	Estimated generator
Exergetic environmental efficiency, $\eta_{ex,env}$	0,058	0,39	0,20
Reason of total pollution, R_{pol}	17	2,1	4,9

4. CONCLUSION

For this work was built a simple prototype to be executed. It is appropriate for electric power generation in small and average climbs, mainly for the handling of the landfill and environs. The generated energy has good quality and it can be used in the great majority of the uses. It is possible to implant it in generating industries of biogas. It can be applied in landfills with deposition starting from 16 tons a day, with operation the full in the second year of operation. With the sale of credits of carbon, it can turn a lucrative sanitary landfill. In environmental terms it is renewable and sustainable, and it rehabilitates an energy one that before was a problem. The gaseous emissions of the motor don't represent environmental damage, once they transform methane in carbon dioxide, what is better in terms of green house effect. The analysis environmental exergetic in terms of the indexes: exergetic environmental efficiency, $\eta_{ex,env}$, and reason of total pollution, R_{pol}, appeared for the great advantage of the use of this system in relation to simple biogas burns, in a minimum proportion of 8 and 10 times, respectively. Including, in relation to these indicators, with the rational use of energy produced, is environmentally more interesting achieve a topographic restoration whit urban solid waste than with inert material. The methodology developed for environmental analysis to be applied in this landfill can be used in any other similar venture. Socially it can be used to electrify small close places to the points of biogas generation, in compensation to the upset created starting from the installation of a landfill. It was ended that the system can be implemented quickly, and it has viability technical, economical, environmental and social.

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