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THERMO-ECONOMIC ANALYSIS AND ENERGY POLICY OF A HYBRID ENERGY FROM WASTE PLANT

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Abstract. *This paper focuses on the energy analysis and plant design of a hybrid system based on EfW (Energy from Waste Plant) for improving its energy efficiency and the reduction of LCOE supported by waste management system. Based on the energy analysis of the plant, the incorporation of biogas, assuming annual RDF (refuse derived fuel) availability, and maximizing annual energy production, the best configuration of the cycle was determined according optima design. The efficiency was quantified and the LCOE (Levelized Cost of Electricity) was selected as economic index.*

Keywords: EfW, RDF, biogas, Hybrid System, Waste management System.

1. INTRODUCTION

Hybridization provides a more flexible energy dispatch, guarantees continuity and operational safety, and also allows the repowering, increase of the capacity factor, improving energy efficiency, minimizing fuel costs and reducing pollutant emissions (Arvizo et al., 2011).

The strategy of operation of hybrid plants has an important contribution to the economic feasibility and influences the design and dimensioning of the components. Technical and economic criteria should be analyzed to define the requirements to achieve the objectives of the hybrid plant. Thus, optimum dispatch is usually defined for: greater overall efficiency, higher annual electricity production, or even more economical / profitable operation of the plant.

In the context of waste energy recovery plants, several works were developed, also with the hybridization of the Energy from Waste (EfW) technologies with supplementary burning of natural gas in external superheater and with the use of gas turbines.

Korobitsyn et al. 1999, proposed the energy and exergetic analysis of three different concepts of gas turbine integration, municipal solid waste incineration, from the use of exhaust gases with preheated combustion primary air, steam overheating with exhaust gases from the gas turbine , superheat configuration and use as primary and secondary combustion air and a fourth configuration with exhaust gas by-pass. The results obtained showed that the efficiency increase was from 12 to 15%, in addition, proportions were established between the fraction of natural gas consumed in the gas turbine and the fraction of waste. The authors also called attention to the limitation of the amount of natural gas consumed within the scenario of increasing prices of this fuel.

Udomsri et. al., 2010 which presented economic feasibility results for the city of Bangkok, 5-year payback in a hybrid system with gas turbine, this type of configuration and source may correspond from 2.5 to 8% of the electric matrix.

Østergaard et al., 2010, evaluated other energy sources and integration with waste energy recovery systems for the city of Aalborg in Denmark. Zappini et al., 2010 evaluated the economic feasibility of using landfill biogas to generate electricity for an Italian city using fuel cells.

Tabasová et al., 2012, evaluated technically and environmentally the different processes of thermo-chemical conversion of urban solid waste, bringing promising technological trends, such as gasification. Di Gregorio and Zaccariello 2012, economically and environmentally evaluate a pilot gasification plant also indicating promising results.

Balcazar et al., 2013, evaluated the technical feasibility of a hybrid system applied to the city of São José dos Campos (São Paulo - Brazil), in which the increase of energy efficiency was verified through the adoption of the hybrid solution of energy recovery of turbine-associated waste as well as feasibility of the project, for the commercialization of electricity between 60 and 90 US $ / MWh, internal rates of return of 8 to 14%, and payback between 2.4 to 4 (considering carbon credit and gate fee) and from 3 to 16 years (scenario with no carbon credits and gate fee).

Considering that the energy hybridization of EfW with biogas, supported by a waste management system provide an opportunity to insert EfW in the scenario of the Brazilian Electrical Matrix, this work proposes the technical and economic analysis of this concept, defining design parameters based on optimization technics.

2. METHODOLOGY

The procedure proposed in this paper is based on the hybrid plant modeling and simulation for the annual energy balance, analyzing the municipal solid waste availability for base load power production and biogas production from landfill anaerobic digestion. The following parameters were analysed separately: (i) biogas production, (ii) waste contribution as RDF, (iii) annual energy production and (iv) fuel storage size.

The energy balance for annual performance and LCOE is calculated as technical and economical parameters.

2.1. HYBRID PLANT DESCRIPTION OPERATIONAL PARAMETERS AND ASSUMPTIONS

The hybrid system consists of a Waste Management System for specified RDF and Biogas for a integrated EfW Gasification Plant. The main purpose of the process is electricity production, but the conceptual design can be changed for industrial heat applications, or either combined heat and power.

The main challenge for EfW technology is managing the input fuel as it varies the composition and calorific heating value. RDF (refused derived fuel) is a way to control the fuel specification at minimum technical requirement for gasification plant to ensure the necessary thermal energy to the power block. This concept makes the generation of electricity more flexible from the mix of resources, more efficient and less polluting compared with standard EfW plants.

Another principle that is explored is the possibility of specifying fuels from the municipal solid waste and increasing the degree of recycling from the implementation of eco points. The implementation of waste management systems is not yet fully established in Brazil and this option may be an alternative, since it may incorporate greater technical feasibility.

In this study, two energy products from a waste management facility are produced: RDF, that has quality for thermochemical conversion processes, such as gasification, and biogas, obtained from the anaerobic biodigestion of the organic fraction of municipal solid waste will be used. The organic fraction of waste is segregated at 90% of raw gravimetry, selective collection is used to minimize the glass fraction and metals is recovery at waste management facility, that provides the RDF with less water and best calorific value.

Biogas production is a biological process that occur as from organic matter degradation at specific anaerobic conditions. The landfill reactor and biogas production is modeled as a function of input of organic material, methane potential and process conditions [14].

The waste RDF is storage (V-001) for gasification process (R-001) and the biogas is storage (V-002) for the gas turbine (GT-001). The gasification process occurs at atmospheric pressure and at 850oC. The chemical composition of the synthesis gas is estimated using equilibrium equations and minimization of Gibbs free energy. The waste heat from exhaust gases from gas turbines are recovery by HRSG (E-001), where the produced synthesis gas are using as fuel for duct burner, auxiliary biogas is available for start-up and power boosting at duct burn. The superheated steam is used by steam turbine at power block (ST-001), a re-heat is used to increase the efficiency of power block and reduce risk of condensation at last stage of steam turbine. At the E-001 air pre-heater is used to recovery part of waste heat for combustion efficiency improvement. The steam are condensing with air cooler condenser (E-006) and a feed water pre-heater battery (E-007 to E-012) is used so increase the water temperature, condensate pump (P-001 and P-002) increase the pressure of condensate to send back to HRSG (Fig. 1.). The corresponding operational parameters and assumptions are presented for every scenario in Table 1., it is based on best practice and supplier technical information.
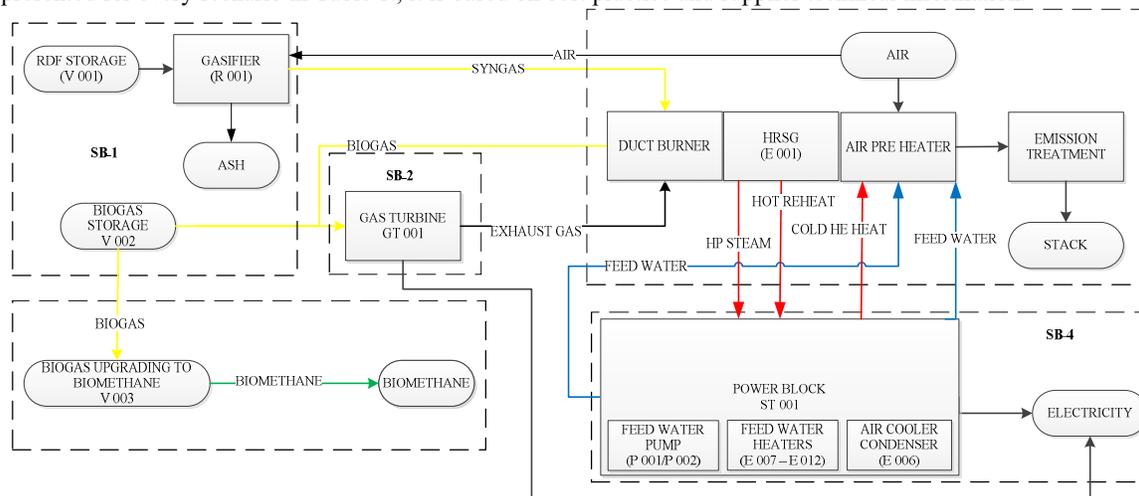

Fig. 1. Scheme of operation of the plant.

Table 1. Operational parameters and assumptions of modeling of the hybrid plant.

Parameter	Units	Scenario Standart EfW	Scenario Hybrid EfW
Waste			
Annual availability	*t/year*	168,000	168,000
RDF	*t/year*	-	102,000
Biogas	*t/day*	-	50
EfW boiler efficiency	*%*	75	89.8
Gasifier cold efficiency	*%*	-	75
Gasifier load	*%*	-	75 - 100
Air/Air stoichiometric	*-*	1.2	0.37
Gas turbine efficiency	*%*	-	26.5
Gas turbine load	*%*	-	50 - 100
HRSG			
HRSG load	*%*	75 -100	35 - 110
Steam hign temperature	*°C*	420	540
Steam high pressure	*bar*	100	128
Steam production	*t/h*	65	85
Steam intermediate temperature	*°C*	420	540
Steam intermediate pressure	*bar*	30	30
Steam production	*t/h*	55,6	73,8
Power Block			
Gross power capacity	MW	17	28
Feed water heater	unit	5	5
Assumptions			
Pumps adiab. efficiency	*%*	80	80
Fan/Compressor efficiency	*%*	85	85
Pinch evaporator	*°C*	3	3
Exchangers ΔP	*mbar*	50	50

The output of gas turbine is 1.8 MW, and the steam turbine is 28MW, the total energy production at reference conditions are 29,8MW for the hybrid system. The comparison with standard EfW Plant is based on a mass burning technology operating a steam turbine with 17MW of nominal capacity.

2.2 FUEL PROPERTIES

Pure substances and the corresponding mixtures were modeled using the Peng- Robinson equation of state (real gas correction). The lower heating value was modeled using ISO 6976 and Dulong method.

Table 2 presents the composition (dry basis) used for MSW and RDF at hybrid plant inlet conditions. The elementary composition was calculated from waste gravimetric (Plano Municipal, 2016) and the RDF composition was estimated assuming the sorting of raw waste and segregation of organic matter and inert materials as glass and metal.

Table 2. MSW and RDF properties.

Parameter	Unit	Value	
Elementary composition		*MSW*	*RDF 90% segregation*
C	%$_W$	46.8	50.5
H	%$_W$	6.1	6.5
O	%$_W$	34.4	35.8
N	%$_W$	1.5	1.1
S	%$_W$	0.2	0.2
H_2O	%$_W$	31.6	13,5
Ash	%$_W$	10.8	6.0
Phisical and chemical properties			
Temperature	°C	25	25
Pressure	bar	1.05	1.05
Density	kg/m³	250	95
LHV	MJ/kg	11.8	16,8

Table 3 presents the composition (dry basis) used for biogas at hybrid plant inlet conditions. The raw biogas is captured from the landfill reactor, a pretreatment is used to remove water and contaminants, the biogas is then stored for the use into the hybrid plant.

Table 3. Biogas properties.

Parameter	Unit	Value
Composition		
CO_2	%$_v$	40
Methane	%$_v$	60
Phisical and chemical Properties		
Temperature	°C	25
Pressure	bar	1.05
Density	kg/m³	1.28
LHV	MJ/kg	17.68

2.3. VARIABLES PROFILES

With the aim of analyzing the conceptual design of a hybrid system, in comparison with the standard technical solution for EfW, a set of two scenarios were considered to achieve an annual energy profile and LCOE, that correspond to a power system configuration: Scenario 1: Standard EfW and Scenario 2: Hybrid (EfW + Biogas), were the amount of fuel consumption during the year (t/year) and fuel composition as LHV - low calorific value (MJ/kg) vary (Fig. 2.).
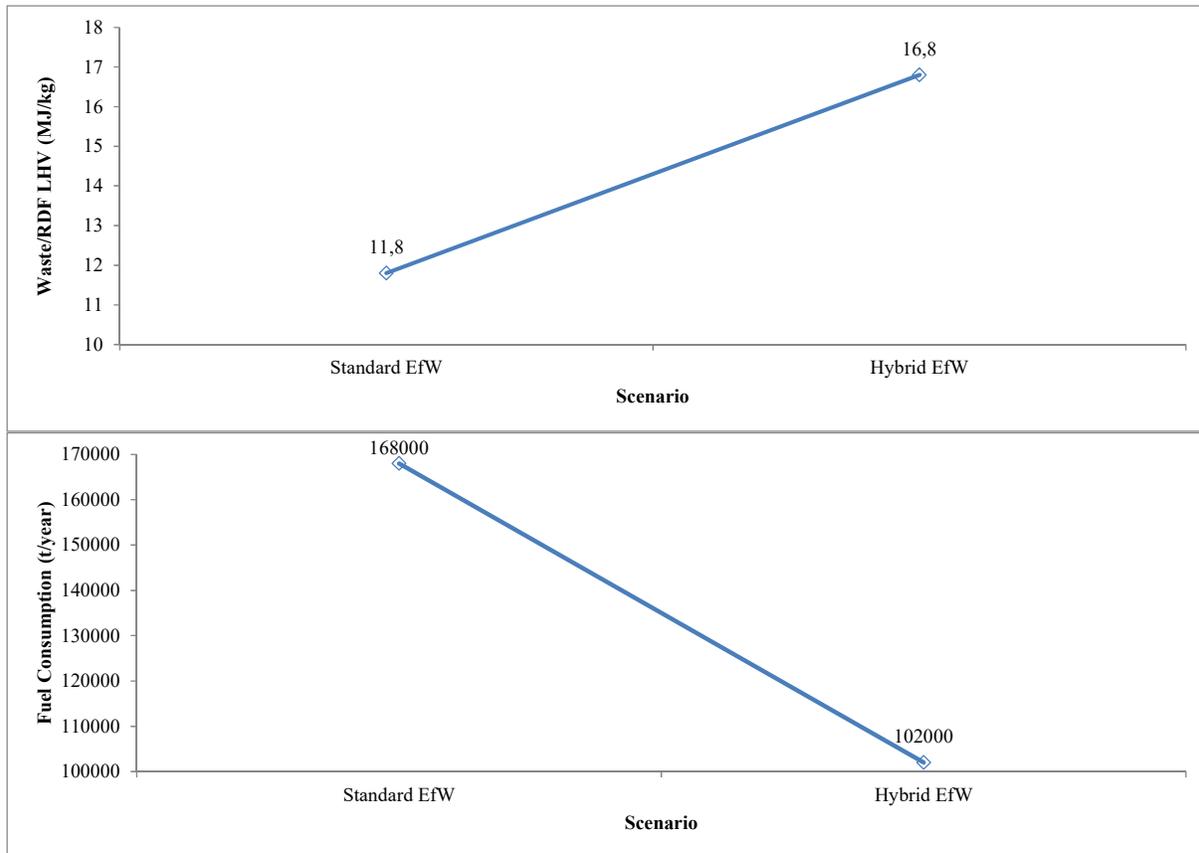
Fig. 2. Parameters profile.

As mentioned above, the chosen variables were: (i) biogas production, (ii) waste contribution as RDF and biogas (waste segregation in Fig. 2, varying from 0 up to 90% - the waste segregation contribute for high quality of RDF and biogas production from organic matter converted by anaerobic biodigestion, is limited at maximum 90% efficiency).

The hybrid system was modeled and the mass and energy balance was performed using the simulation tool Ebsilon® Professional 13.01 ("Energy balance and simulation of the load response of power generating or process controlling network structures").

2.4. ENERGY EFFICIENCY

The energy efficiency is based on the mass and energy balance, considering the annual operation:

$$\overline{\eta_{elHybrid}} = \frac{\int_0^{8765}(P_{Tel}+ P_{Bel})}{\int_0^{8765}(Q_{fuel})} \qquad (1)$$

where $\eta_{elHybrid}$ average electrical efficiency of hybrid power plant, P_{Bel} the electrical energy produced by steam turbine (bottoming cycle), P_{Tel} the electrical energy produced by gas turbine (topping cycle), Q_{fuel} the chemical energy from fuel (biogas and RDF).

Another important parameter is the capacity factor, CF, concerning the annual generated energy and the installed capacity of power plant,

$$CF = \frac{\int_0^{8765}(P_{Tel}+ P_{Bel})}{8765*P_{nominal}} \qquad (2)$$

where $P_{nominal}$ is the installed capacity of power plant.

2.5. HYBRID SYSTEM CONFIGURATION

The main goal for the hybrid system is to produce as much electricity as it is possible, using the available municipal solid waste (Plano Municipal, 2016) and biogas resources. Different operation strategies for hybrid systems can be used for annual energy production, for this assessment was assumed constant electrical power output during the year. The system was design for high flexibility and the EfW gasifier and boiler waste heat recovery admit all combination of load to provide the maximum energy efficiency at power block.

For annual simulation was developing an algorithm for different conditions of energy resources availability, and for different operational strategies. It means mode for maxima annual energy production, or power reduction for EfW and waste storage level controlling (Fig. 3.).
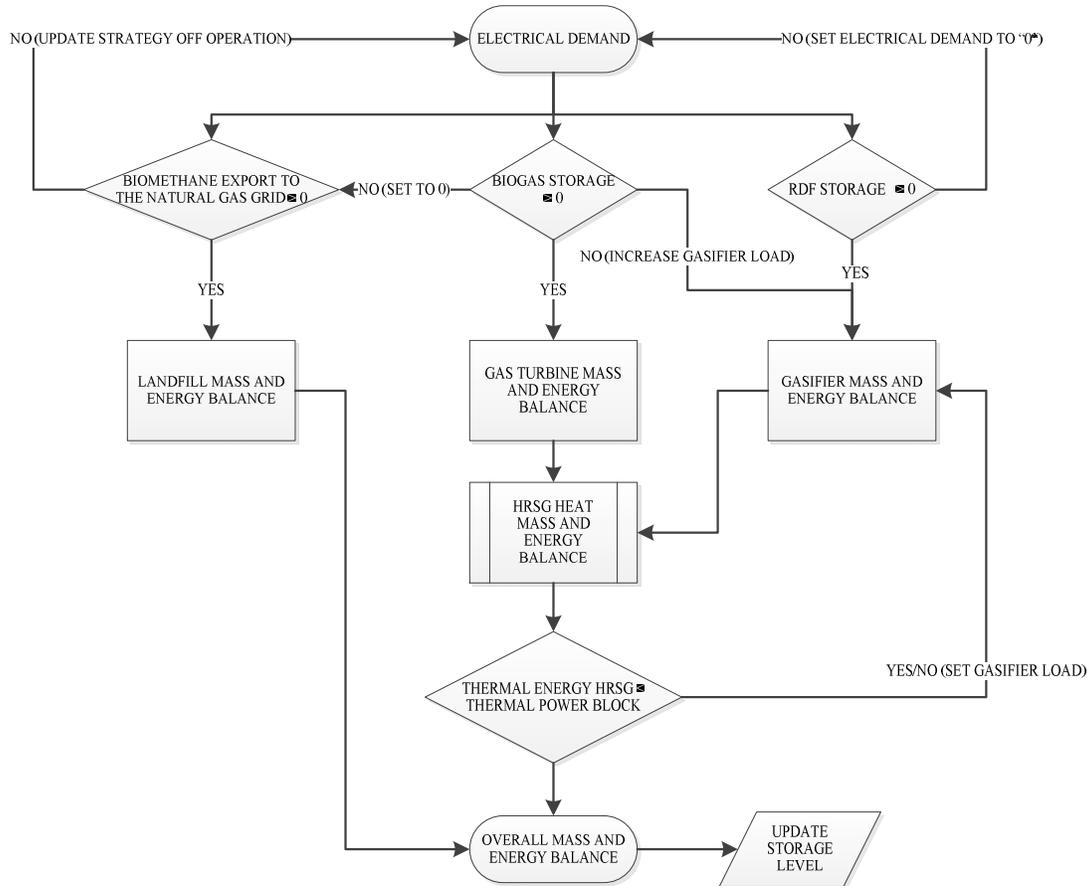
Fig. 3. Algorithm of integration of CSP in the plant model.

3. RESULTS

3.1. CURRENT ENERGY BREAKDOWN

The energy analysis and energy breakdown is based in an annual operational profile. The main gain of the hybrid system is increase of capacity factor due to increasing the rate of utilization of power block from the RDF availability. The energy efficiency in different scenarios varies from the steam conditions (temperature and pressure) but also it is affect by the power block size, comparatively small scale for utility power production.

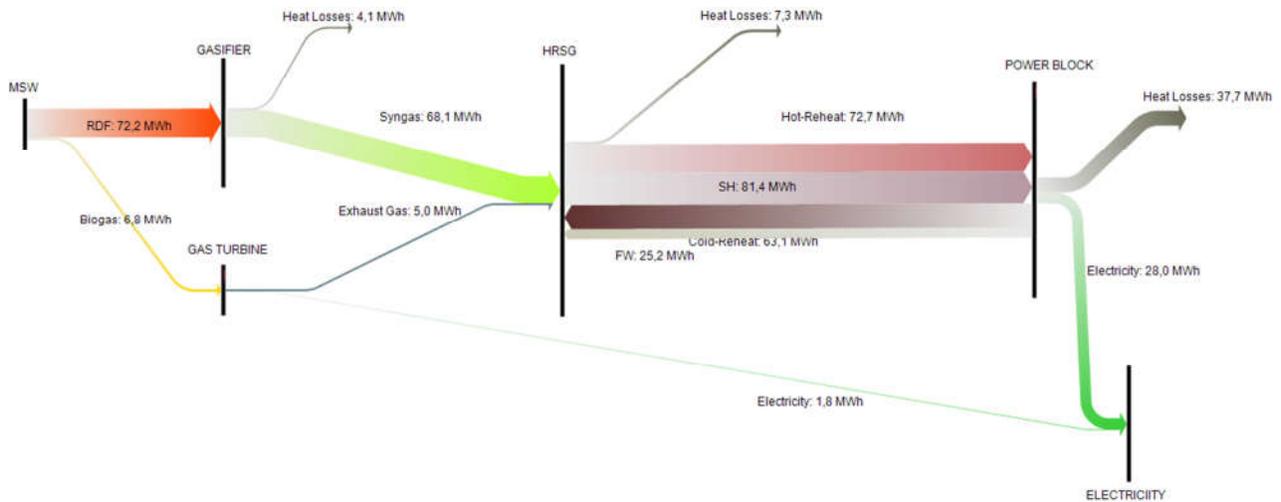At design conditions the energy breakdown is presented at Fig. 4.

Fig. 4. Sankey diagram of hybrid plant subsystems, at design conditions, energy flows in MWh.

Considering the energy and mass balance in the different scenarios, Fig. 5 presents the main results: (i) energy production (in Fig. 5., varying from 134,104 up to 232,710 MWh/year), and (ii) energy efficiency (varying from 37 to 40%).

Energy production and energy efficiency for the hybrid scenario present the best results for the different configurations analyzed. This option, coupled with the operating strategy, enables the best use of the plant and a high capacity factor. In relation to fuel storage, it is possible to optimize the capacity according to the operational strategies; however the seasonal nature of waste generation as well as the possibility of operational unavailability requires a minimum storage (Fig. 5.).
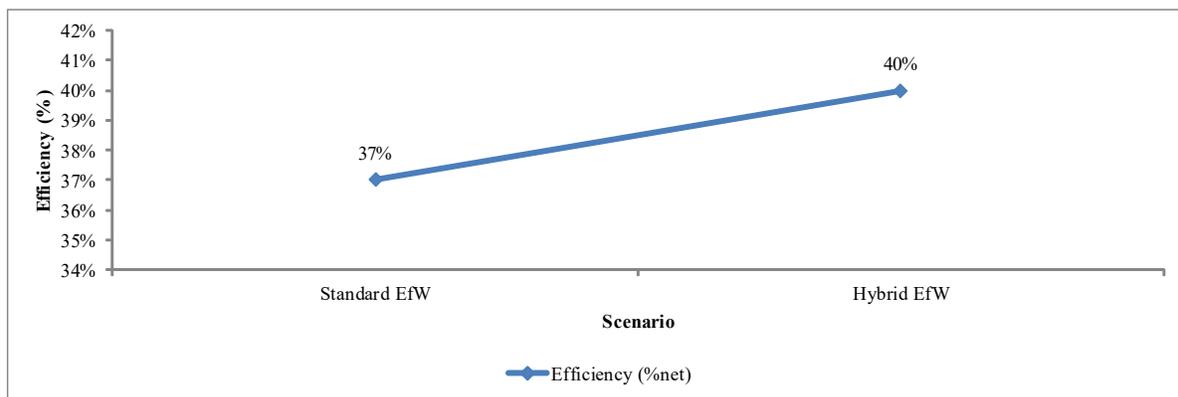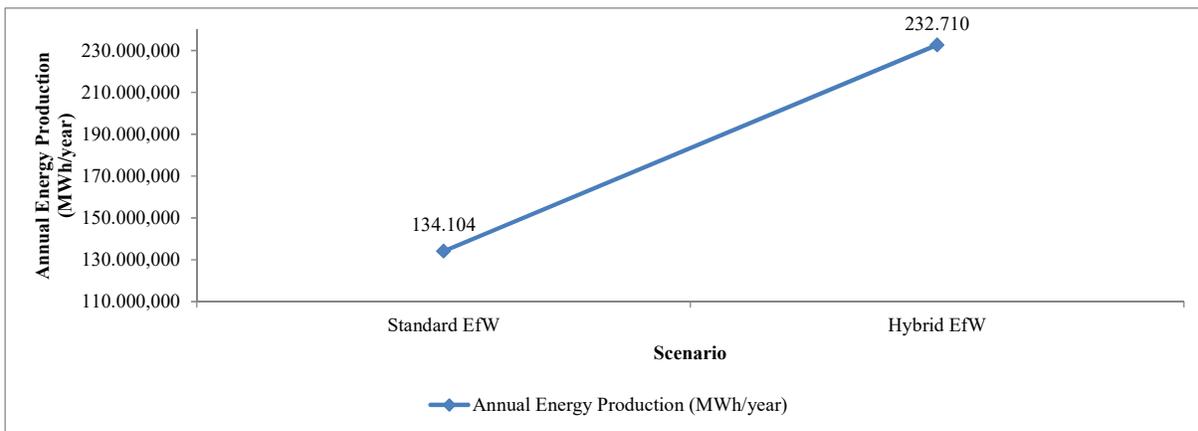

Fig. 5. Plant energy indicators through scenarios profile.

3.2. LCOE

The LCOE – Levelized Cost of Electricity are based on equity capital expenditures (CAPEX), divided into two first years (60%/40% - construction time), the annual energy production during the year (AEP) and the annual operational expenditures (OPEX). The plant lifetime and the internal rate of return (IRR) were assumed 25 years and 10%, respectively. Additionally for EfW and Hybrid scenario there is an additional revenue, that is the gate fee. In the proposed concept of the hybrid system third revenue is the sale of the biogas/biomethane surplus.

Both the operating revenues (gate fee and sale of biogas/biomethane) are very positive for the LCOE reduction of these scenarios (Fig. 6.).
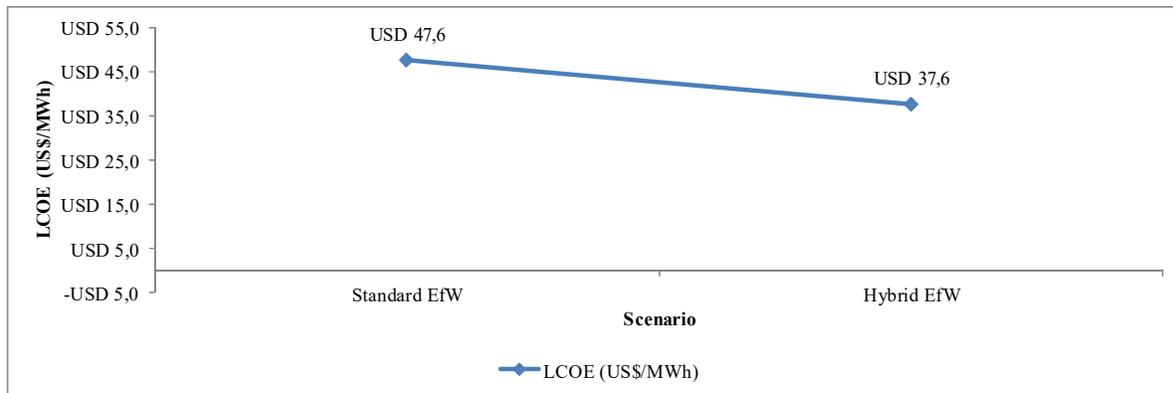

Fig. 6. LCOE through scenarios profile.

4. CONCLUSION

According to the obtained results, the energy efficiency and the capacity factor have greater influence over the hybridization scenarios. These parameters are directly associated with the waste availability and the arrangement of gasification technology that permit increase the steam process parameters, based on operational strategy for maximum power production.

The suggested arrangement of hybrid plant can be optimized for future energy projects with dispatchability requirements and to achieve best economics revenues, because it is very flexible and can operate with different operational strategies. Economic analysis show a strong LCOE reduction for a hybrid system compare with standart EfW. That could be a great opportunity for the hybrid EfW technology into the Brazilian energy matrix, with more competitiveness, including the possibility of areas where the municipal solid waste or other renewable source are available, as agriculture residues and wood.

5. ACKNOWLEDGMENTS

6. REFERENCES

Arvizu, D., Balaya, P., Cabeza, L. et al., 2011. Special Report on Renewable Energy Sources and Climate Change Mitigation SRREN, Chapter 3. Direct Solar Energy. Cambridge and New York: IPCC. Available at: 〈 http://srren.ipcc-wg3.de/〉 . Accessed on sep/2011.

Di Gregorio F, Zaccariello L. Fluidized bed gasification of a packaging derived fuel: energetic, environmental and economic performances comparison for waste-to-energy plants. Energy 2012; 42:331e41

Juan Galvarino Cerda Balcazar, Rubens Alves Dias, José Antonio Perrella Balestieri Analysis of hybrid waste-to-energy for medium-sized cities Energy 55 (2013) 728e741

Korobitsyn MA, Jellema P, Hirs GG. Possibilities for gas turbine and waste incinerator integration. Energy 1999; 24:783e93.

Østegaard PA, Mathiesen BV, Möller B, Lund H. A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass. Energy 2010; 35:4892e901.

Tabasová, A., Kropác J, Kermes V, Nemet A, Stehlík P. Waste-to-energy technologies: impact on environment. Energy 2012; 44:146e55.

Udomsri S, Martin AR, Fransson TH. Economic assessment and energy model scenarios of municipal solid waste incineration and gas turbine hybrid dual fueled cycles in Thailand. Waste Management 2010; 30:1414e22.

Zappini G, Cocca P, Rossi D. Performance analysis of energy recovery in an Italian municipal solid waste landfill. Energy 2010; 35:5063e9

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