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OPTIMIZATION OF ENERGY SUPPLY AND CONVERSION IN A NORTHEAST BRAZIL HOSPITAL: USE OF PHOTOVOLTAIC PANELS

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Abstract. *The introduction of new energy sources in an energy supply and conversion system can be analyzed through optimization projects and from information on energy demands and equipments utilized in a specific consumer center. In the energy system presented herein, the following energy demands were considered: electricity, heat, steam and coolth. The consumer was a hospital, located in the city of Northeast Brazil. Commercially available equipment was considered as well as the possible utilization of two renewable energy resources: solar energy and biomass. Considering the installation of 200 photovoltaic solar panels, an optimal system was characterized as a result of the solution of a mixed integer linear program, which considered the annual total cost as the objective function to be minimized. For this scenario, the optimal solution included the utilization of biomass as an energy source to hot water and steam, with an annual cost 11% lower than the conventional solution.*

Keywords: *polygeneration, photovoltaic solar energy, biomass, optimization, linear programming.*

1. INTRODUCTION

Among the several existing possibilities to configure an energy system, the most known and utilized are the traditional system (with conventional equipments that realize single energy conversions to satisfy the energy demands of a specific consumer center), and the system based on energy integration (more elaborated, and makes the best use of energy flows). Polygeneration is defined as the combined production and utilization of two or more energy services, reaching the maximum use of the different energy sources available. Its main advantage is the efficient use of energy, since in polygeneration systems a more detailed study of the relationship generation-consumption is required. Other advantages include reliability and continuity in energy supply, besides a better use, when compared to autonomous systems. Both polygeneration and energy integration are promising tools to reach higher efficiency levels in the use of natural resources, and in the majority of cases, also a reduction in the environmental loads generated (Serra, Lozano, Ramos, Ensinas & Nebra, 2009).

In this context, some consumer centers stand out due to their high energy consumption, and others, such as hospitals, due to the continuous and simultaneous requirements for electricity and heat. Hospitals are, therefore, excellent centers for the potential implementation of polygeneration systems, since comfort conditions as well as electricity, hot water, heating and cooling must be continuously maintained. Recent studies have focused on the optimization of energy supply systems in hospitals (Ziher & Poredos, 2006; Arcuri, Florio & Fragiacomo, 2007; Lozano, Ramos, Carvalho & Serra, 2009; Romero, Carvalho & Millar, 2014a), but the optimal configuration of these systems is still a complex problem, due to the great variety of technological options for the supply and conversion of energy, daily and annual variations in energy demands, and yet variations in the prices and tariffs of energy. According to Shang and Kokossis (2005), the variability present in energy demands requires a project methodology that results in systems that produce efficiently (thermodynamic objective), that are capable of adapting to different demand and market conditions (operational flexibility), and that also operate with minimum cost.

This study adapts and extends the methodologies established in Romero, Carvalho e Millar (2014a; 2014b), which were based on Mixed Integer Linear Programming (MILP), a tool that has been widely applied to the optimization of energy supply systems (Yokoyama, Hasegama & Ito, 2002; Ren &Gao, 2012). The objective of the study presented herein goes a step further by considering photovoltaic solar energy as an available energy resource in the polygeneration superstructure. The superstructure of an energy system must contain, even if in a redundant manner, all energy resources that are available at the consumer center location. Also are included equipments that realize energy conversions, to guarantee that the energy demands are satisfied, either by a single equipment or by a combination of several (carrying out multiple stages of energy conversion, for example). Local energy resources must be part of the superstructure: in the case of Güssing (Austria), the utilization of local biomass eliminated the dependency on imported electricity (Hofbauer, Reinhard, Klaus, Reinhard & Christian, 2002). For Northeast Brazil, and more specifically the city of João Pessoa, solar energy is an important option. Obviously, an energy resource (local or not) can be part of the superstructure but not of the optimal solution. Due to its importance, factors such as the configuration of the system (type of technology employed and number of installed equipment) and operational strategy (operation mode of equipments throughout the year, including purchase flows of energy resources). Biomass can also be an attractive option, in the form of sugarcane bagasse, coconut straw, coconut shell, among others. Initiatives for the use of civil construction wood residues can also be important origins of biomass.

The energy of the sun can be used for heating as well as for the production of electricity. In Brazil, although still in a very shy manner, the utilization of this type of energy has been increasing each year. Besides economic and environmental advantages, there is a necessity to "ripen" the use of this resource given its high availability in the country, and also to accompany the global trends and favor its utilization in public and economic development politics.

The utilization of photovoltaic solar energy in Brazil nowadays is basically in autonomous systems (islanded), where the installation of distribution lines for electricity is not economically viable (Villalva & Gazoli, 2013). This is also the scenario of utilization in Northeast Brazil, where many locations still do not present connection to the electric grid. However, after resolution nº482/2012 from the National Electric Energy Agency (In Portuguese: ANEEL), the utilization of photovoltaic solar energy in distributed systems, i.e., connected to the electric grid, tends to grow. Currently there are 150 microgeneration enterprises installed in Brazil, of which 32 are located in Northeast Brazil (ANEEL, 2014).

According to Lozano et al. (2009), the most influential factors at the time of installing an energy supply system are the availability of fuels, price of electricity, prices of other fuels and their relationships with the price of electricity, as well as the legal conditions to sell self-generated electricity to the grid. The optimization model proposed herein compares the economic balances for all viable configurations contained in the superstructure of the energy system, and provides both the optimal configuration and optimal operation mode.

2. MATERIALS AND METHODS

2.1 Energy Supply and Conversion System

Polygeneration has the main objective of diversifying energy sources, characterized by the combined production of electric and thermal energies, and can include water desalinization (Rubio-Maya, Uche & Martinez, 2011), and production of syngas and syndiesel (Yang, 2013; Romero, Carvalho & Millar, 2014a). The idea is to always optimize the use of the available resources and satisfy the energy demands of a specific consumer center. For the polygeneration system herein presented, only the economic analysis motivates the decision for its installation. Legal and environmental aspects are not considered at this moment, once traditionally, investments in polygeneration always compete with other projects that can prove to be more economic.

Traditionally, thermodynamic and optimization approaches are the two main techniques utilized to synthesize an energy supply system (not considering heuristic models) (Serra et al., 2009). The thermodynamic approach applies thermodynamic analysis to reduce energy losses while providing information on the characteristics of the system. This approach presents the advantage of requiring simpler calculations. Linhoff and Flower (1978) used the thermodynamic approach for the synthesis of heat exchanger networks, maximizing heat recovery, Bejan and Mamut (1999) compiled a comprehensive assessment of the methodologies of thermodynamic optimization, and Favrat (2013) discussed the strengths and limits of this approach. For the analysis of thermal systems, the most used thermodynamic methodologies are thermoeconomic and pinch analysis.

However, thermodynamic approaches on their own cannot tackle the more holistic considerations needed for modern energy systems (Favrat, 2013) or provide the solution of different classes of problems in a systematic manner (Kim & Han, 2001). Also, thermodynamic methods are not adequate for the optimization of several different structures simultaneously (Tveit, Aaltola, Laukkanen, Laihanen & Fogelholm, 2006). An example of the optimization approach is mathematical programming, which combines binary, integer and continuous variables. Minoux (1986) presents the theory and algorithms for mathematical programming, Biegler and Grossman (2004) also present an overview of the technique along with applications to design and system engineering, and Grossman (2012) presents the advances in mathematical programming models. Mixed Integer Programming (MIP) restricts variables to binary and/or integer values (e.g., for decisions -yes/no-, counting -number of equipment-, and logical relationships). MIP is especially useful for the synthesis of energy supply systems and comprehends three important steps (Grossmann, Caballero & Yeomans, 2000): i) definition of a superstructure (representing all options of equipment and energy resources); ii) elaboration of a mathematical model that includes all operation options in the form of discrete variables, with continuous variables representing flows; and iii) solution of the model, which provides the optimal solution.

2.2 Consumer Center and Considerations on the Study Case

The consumer center studied is a university hospital, with a total area of 49.000 m², and 420 beds, located in the city of João Pessoa, state of Paraíba, Brazil. The following energy demands were considered; electricity, hot water, steam and coolth. The study extends itself throughout a period of one year, distributed in two representative days (week days and weekend/holidays) per month. Each day is divided into 24 hourly periods, yielding 576 different operation periods throughout the year.

Real electricity data was available, and the calculation of representative energy demands for hot water, heating, and cooth utilized the sequential application of the degree-days method (Erbs, Klein & Beckman, 1983), climate data (CLIMATICUS 4.2, 2005), occupation data (Nepote, Monteiro & Hardy, 2009) and data from energy audits (Araújo, 2004). Figures 1a to 1h show the energy demands for weekdays and weekends/holidays, for a summer month (January), a fall month (April), a winter month (July), and a spring month (October).

The hospital presents the following annual energy demands: 2791 MWh of electricity, 1947 MWh of hot water, 138 MWh of steam, and 2309 MWh of coolth. Electricity was charged with an hour-seasonal tariff, presenting differentiated tariffs for peak and off-peak periods: US$51.60/MWh for off-peak periods, and within the peak periods (between 18h and 21h) the value is US$79.60/MWh.

Steam demand was considered constant during the period in which the sterilization central is open, during 6h and 20h, in addition to the steam demand of a hot counter in the restaurant, during lunch and supper times. The hot water demand presents two contributions: laundry (operating between 8h and 18h), and the internal use of the hospital (no interruptions).

The tariff for natural gas (US$48/MWh – PBGAS, 2013) does not include hourly or seasonal differentiation, and if equipment that is driven by natural gas is installed, the costs already include connection to the distribution network (gaseoducts).

The tariff considered for diesel (US$59.60/MWh) also does not consider hourly or seasonal differentiation, and the costs of installation of equipment driven by diesel includes the costs associated with storage.

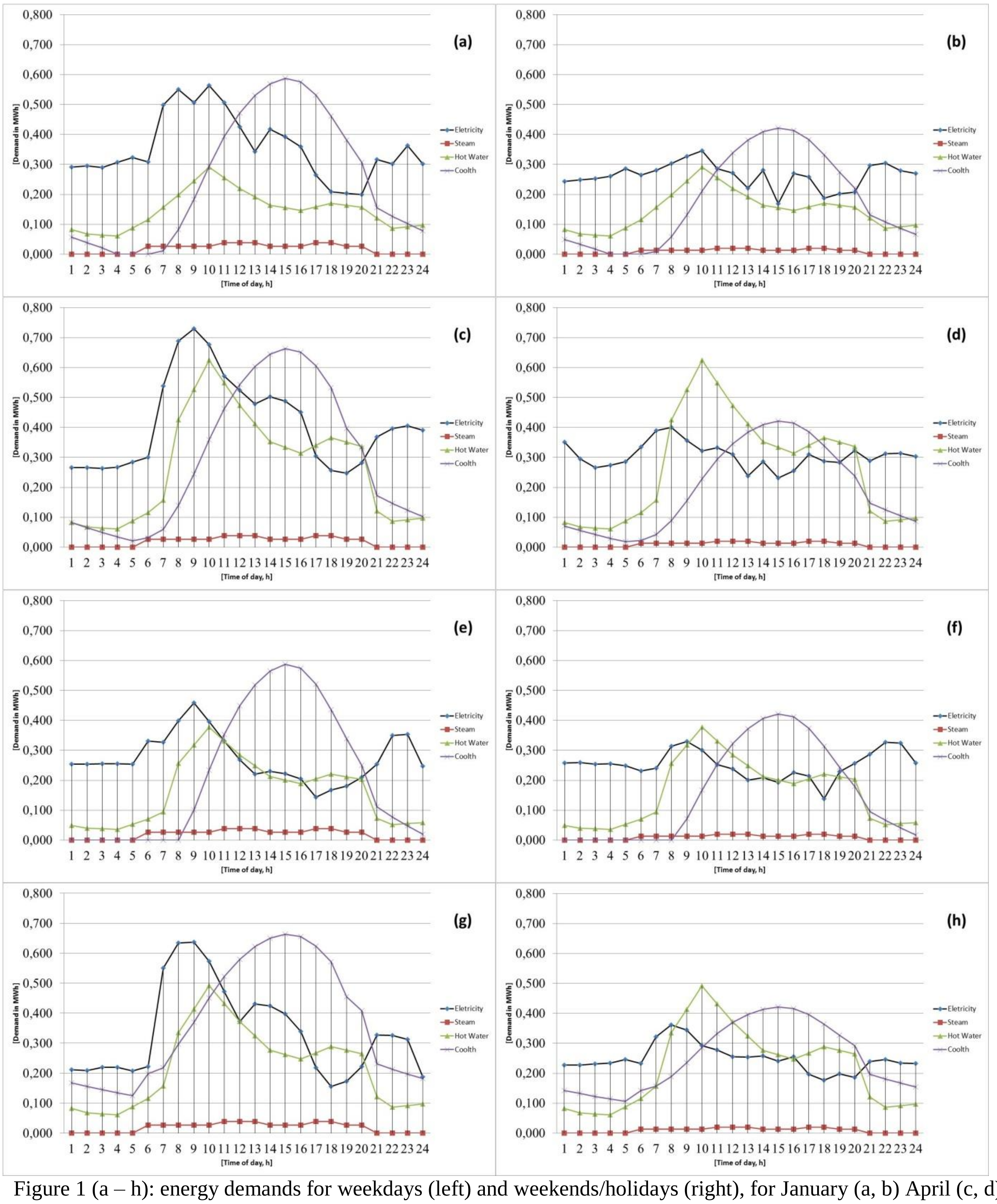

Figure 1 (a – h): energy demands for weekdays (left) and weekends/holidays (right), for January (a, b) April (c, d), July (e, f) and October (g, h).

The biomass considered herein originates from sugar cane bagasse. The state of Paraíba counts with nine sugar cane plantations that extend to 26 municipalities along the coast line, all located in the proximity of João Pessoa (Nova Cana, 2015). This energy resource was considered basically to meet the hot water and steam demands of the hospital (through boilers). Considering a Lower Heating Value of 3200 kcal/kg (Alfa Laval , 2015), 20 % humidity, and the price of US$ 48.00 per tonne of sugarcane bagasse (Cana Online, 2015), the final price utilized in the optimization model was U $ 13.20/MWh for biomass.

2.3 Photovoltaic Solar Energy

Photovoltaic (PV) solar energy is characterized by the production of electrical current through the direct catchment of solar light. This current is collected and processed by control and conversion devices, and can be stored in batteries or directly utilized in systems connected to the electric grid (Villalva & Gazoli, 2013).

Currently in wide expansion, the use of this type of energy is the fastest-growing around the world. In Brazil, with publication of regulation nº 482 by Brazilian Electricity Regulatory Agency (In Portuguese: ANEEL) (ANEEL, 2012), which establishes the general conditions for distributed microgeneration and minigeneration access to electricity distribution systems, the utilization of PV energy is also in the spotlight. The concepts of microgeneration and minigeneration are presented in regulation nº 482 (ANEEL, 2012): microgeneration is the electricity generation system with installed power under 100 kW and that utilizes hydraulic, solar, wind, biomass, or qualified cogeneration energy, according to ANEEL regulations, and connected to the distribution grid through consumer unit installations. Minigeneration is defined as an electricity generation system with installed power between 100 kW and 1 MW, and that utilizes the same sources indicated in the definition of microgeneration.

The motivation for the use of PV energy arises due to the practicality of its implementation and simple maintenance. Additionally, regulation nº482 (ANEEL, 2012) indicates the possibility of an energy compensation system, where the surplus generated electricity is fed into the distribution grid and registered as energy credits, which can be consumed in up to 36 months.

The studies that propose the utilization of PV solar energy in hospitals are not recent. Between the years of 1987 and 1990, a project that utilized PV solar systems for emergency lighting was applied to the District Hospital of Bawku, in Ghana (Santos & Jabbour, 2013). In 2006, theoretical studies in an Italian hospital investigated the utilization of PV energy in hybrid systems, and an Iranian hospital study demonstrated that the amount of natural gas required to meet the hospital demands could be halved with the incorporation of PV solar energy in a hybrid system that included cogeneration (Santos & Jabbour, 2013).

The proposal of this study is to introduce, within the polygeneration superstructure, PV panels for electricity production, interconnected to the distributed grid. The PV generation system is basically constituted by PV panels and inverters only, as electricity storage will not be considered at this point. Information was obtained from consultation to PV panel (Kyocera, 2014) and inverter (Santerno, 2014) manufacturers. The cost of the system was US$ 880/panel, already including the cost for the panel, inverter, installation materials, transportation and assembly. The area of the panels is 1.64 m2. The costs considered for maintenance are low, and for large systems as in condominiums and hospitals, which require annual maintenance, US$ 10/m2 includes cleaning the panels, tightening of connections and oxidation elimination, etc. The energy performance of a PV solar system depends basically on the following factors: available irradiation. area, inclination, and panel efficiency. An incorrect selection of inclination reduces the catchment of solar rays and compromises the production of electricity by the PV module (Villalva & Gazoli, 2013). According to the basic rules presented by the manufacturers, and with the objective of optimizing the production of electricity, the inclination angle of the panels to be installed in the hospital must be 10º since the geographic latitude of the municipality of João Pessoa is 07° S.

2.4 Economic Considerations

Table 2 shows the technical and economic characteristics of the equipment that belongs to the superstructure (Figure 2). Technical information was obtained from manufacturer catalogs, and prices were obtained through direct consultation. On the left side of Table 1, the rows indicate the technologies that are potentially installable, and the columns indicate the energy resources available. The coefficient in bold indicates the flow that defines the productive capacity of the equipment, and positive and negative coefficients, indicate, respectively, that an energy flow is either produced or consumed.

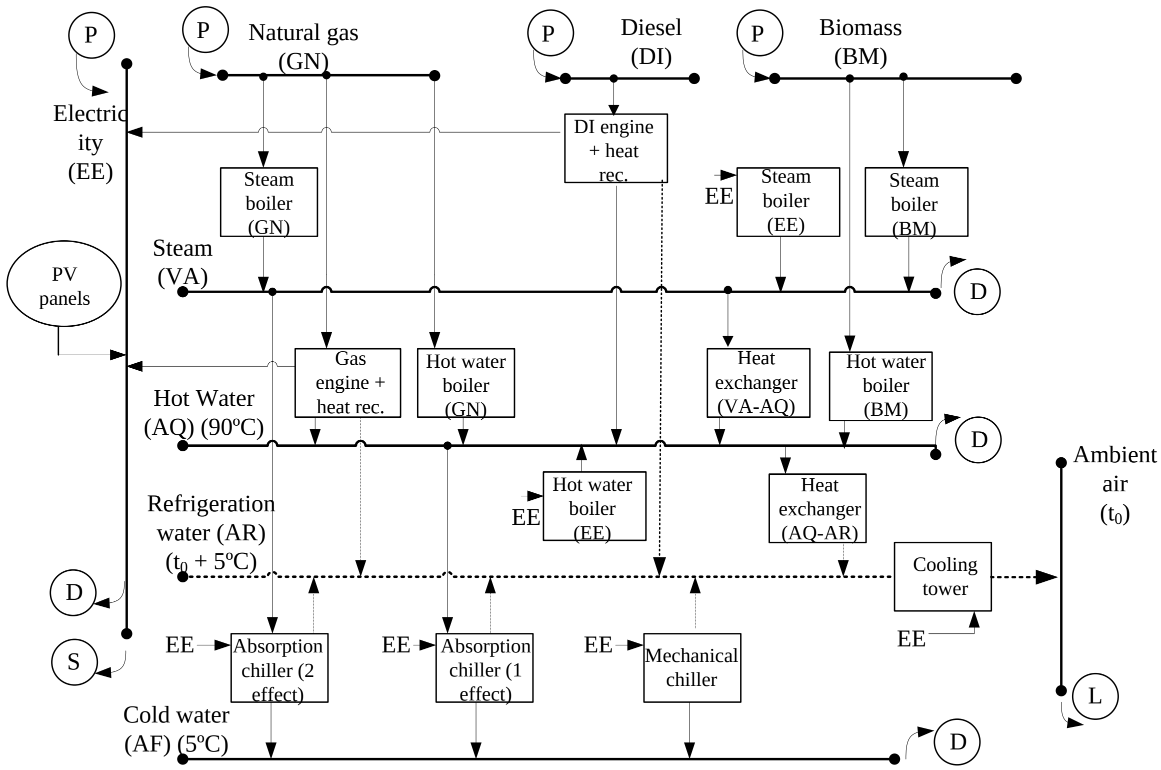

Figure 2 - Polygeneration superstructure for the hospital

Table 1 - Matrix of technical production coefficients and technology data (Romero, Carvalho & Millar, 2014b).

	Technical production coefficients									Equipment		
	GN	BM	DI	VA	AQ	AR	AA	AF	EE	Cost CINV (10^3 US$)	Cost O&M (US$/ MWh)	Nom. Power PNOM (MW)
Gas engine	-2.63				1.10	0.45			**1**	185.00	6.00	0.41
Diesel engine			-2.66		0.80	0.50			**1**	90.80	6.00	0.36
Steam boil (GN)	-1.18			**1**						21.29	0.89	0.30
Steam boil (BM)		-1.40		**1**						20.40	3.20	0.25
Steam boil (EE)				**1**					-1.15	20.40	0.89	0.15
Heat exchang (VA-AQ)				-1.10	**1**					3.56	0.89	0.40
Hot water boil (GN)	-1.22				**1**					19.72	0.89	0.30
Hot water boil (BM)		-1.25			**1**					25.00	3.20	0.17
Hot water boil (EE)					**1**				-1.11	11.28	0.89	0.15
Heat exchang (AQ-AR)					-1.10	**1**				2.96	0.89	0.40
Absorption chil (2x)				-0.77		1.77		**1**	-0.01	186.08	4.00	0.46
Absorption chil (1x)					-1.32	2.32		**1**	-0.01	215.88	4.00	0.49
Mechanical chiller						1.21		**1**	-0.21	58.00	1.77	0.28
Cooling Tower						-1.00	**1**		-0.02	11.28	4.00	1.00

The complexity of the problem is perceptible, once all energy demands vary hourly, throughout the day, throughout the year.

For the current economic and financial Brazilian scenario, considering a lifetime of 15 years for the system and an interest rate of 10% per year, a capital recovery factor of 0.13/year was obtained.

A polygeneration system can be designed to operate autonomously, but the possibility of connection to the electric grid can be extremely advantageous for the sale of surplus cogenerated electricity, realizing economic benefits in this way.

The problem to be solved consists of two simultaneous tasks: selection of the combination of technologies (type and power installed) that are capable of meeting the energy demands of the hospital, and establishment of the operation mode for all equipment installed, for each time interval defined.

2.5 Optimization Model

Once the environment for the installation of the polygeneration system is defined, along with its energy demands, and with information on the technical, economic and legal parameters, the next step is the formulation of the mathematical model. An optimization model was elaborated, based on MILP, and its solution allows for all energy flows to be known. The solution also provides the result of an economic evaluation, selecting the best configuration of the system (type and number of equipment installed) and the operational strategy (how to operate each piece of equipment), obtaining minimum annual cost.

The objective function was selected from an economic perspective, which considers the annual costs: fixed costs (initial investment in equipment) and variable costs (purchase of energy resources to meet the demands, O&M costs). The objective function can be represented in simple algebraic language as:

MINIMIZE Annual Costs = (Fixed Costs) + (Variable Costs) (1)

$$\text{Fixed costs} = (FRC) \cdot (FCI) \cdot \left[\sum_i CINV_i \right] \quad (2)$$

$$\text{Variable costs} = (\text{Cost of natural gas}) + (\text{Cost of biomass}) + (\text{Cost of diesel}) + (\text{Cost of electricity}) - (\text{Electricity credits}) \quad (3)$$

The total investment cost (CINVi) is the number of equipment installed multiplied by the individual cost. FRC is the capital recovery factor, introduced previously, and FCI is an indirect cost factor that agglutinates engineering, transportation, installation, supervision, service, and contingency costs, resulting in 15% of the investment cost in equipment.

The possibilities of interaction of the polygeneration system with the economic environment can be represented by a binary matrix (0 = no, 1 = yes) with indicators for the possibilities of purchase (INDCOM), demand (INDDEM), sale (INDVEN) and waste (INDDES, e.g., in the case excess heat is evacuated) for each of the energy resources available j:

INDCOM	INDDEM	INDVEN	INDDES	
1	0	0	0	(natural gas, j=1)
0	1	0	0	(steam, j=2)
0	1	0	0	(hot water, j=3)
0	0	0	0	(refrigeration water, j=4)
0	0	0	1	(ambient air, j=5)
0	1	0	0	(cold water, j=6)
1	1	1	0	(electricity, j=7)
1	1	0	0	(diesel, j=8)
1	1	0	0	(biomass, j=9)

(4)

For each time interval, the production of energy is restricted to the installed capacity of equipments and an energy balance must be fulfilled for each utility j (energy resource):

$$Production_j - Consumption_j + Purchase_j - Sale_j - Demand_j = 0 \quad (5)$$

More details on the basic model (objective function, capacity limits, production restrictions and balance equations for equipment and overall system) can be found in Romero, Carvalho e Millar (2014a). The novelty introduced herein is the introduction of PV panels in the superstructure, for the production of electricity. Equation (5) is modified only for electricity, including a term that represents the Net Absorbed Radiation (NAR) by the PV panels. Equation (6) contemplated the possibility that the electricity from the PV panels (EEPV) can be utilized in the polygeneration system:

For j=7, and for each hour, and each day:

$$Production_j - Consumption_j + Purchase_j - Sale_j - Demand_j + EEPV = 0 \quad (6)$$

$$EEPV = NPS \cdot A \cdot (Rad / 1000) \cdot eff \quad (7)$$

$$NPS <= NPV \quad (8)$$

Equation (7) defines the electricity produced by PV panels, originated from the radiation absorbed during each hour, for each day, by the panels, where A [m2] represents the surface of each panel/ eff is the efficiency of each panel (manufacturer data)/ Rad [Wh/m2, J/m2] is the global radiation per surface unit in horizontal plane, due to the geographic location; NPV is the number of PV panels installed, and NPS is the number of active PV panels for each time interval considered in the balance equations. NPS is used as a restriction in Equation (8) to represent the degree of utilization of the panels.

Utilizing all energy forms available in the superstructure, as well as individual or multiple energy conversions, the optimization model compares all the possible ways to meet the energy demands of the hospital. This is carried out hour-by-hour, for each day of the year, obtaining a total annual cost (configuration and operational mode). Therefore, all economic balances for all viable configurations contained in the polygeneration superstructure are compared, yielding the minimum annual cost.

3. RESULTS

The optimization model contains 124.842 variables, of which 1756 are integers. The model presents 81.051 restrictions, and was solved after 19.926 iterations. The solution of the optimization model, including the mandatory installation of 200 PV panels, provides the data shown in Table 2. Table 2 also shows the result of another optimization, referred to as reference system, where only conventional equipment is utilized to meet the energy demands of the hospital. The possibilities of cogeneration and utilization of biomass are not included in the conventional system.

Table 2 – Minimum annual cost for the polygeneration system with 200 PV panels installed.

	Economic Optimal		Reference system*	
Composition of system	Número (Installed power)		Number (Installed Power)	
Gas engine	0 (0 MW)		- (0 MW)	
Diesel engine	0 (0 MW)		- (0 MW)	
Steam boiler (GN)	0 (0 MW)		1 (0.300 MW)	
Steam boiler (BM)	1 (0.250 MW)		0 (0 MW)	
Steam boiler (EE)	0 (0 MW)		0 (0 MW)	
Heat exchaner (VA-AQ)	1 (0.400 MW)		1 (0.400 MW)	
Hot water boiler (GN)	0 (0 MW)		1 (0.300 MW)	
Hot water boiler (BM)	2 (0.340 MW)		0 (0 MW)	
Hot water boiler (EE)	1 (0.150 MW)		1 (0.150 MW)	
Heat exchanger (AQ-AR)	0 (0 MW)		0 (0 MW)	
Double-effect absorption chiller	0 (0 MW)		0 (0 MW)	
Single-effect absorption chiller	0 (0 MW)		0 (0 MW)	
Mechanical chiller	3 (0.810 MW)		3 (0.810 MW)	
Cooling tower	1 (1.000 MW)		1 (1.000 MW)	
Photovoltaic panels	200 units		--	
Electricity imports	3244 MWh/year		4281 MWh/year	
Electricity produced by PV panels	129 MWh/year		--	
Electricity credits	--		--	
Natural gas imports	--		1528 MWh/year	
Diesel imports	--		--	
Biomass imports	2663 MWh/year		--	
Initial investment in equipment	US$	587.089	US$	374.670
Annual cost of electricity imports	US$/year	180.489	USS$/year	233.979
Annual credit with electricity exports	US$/year	--	US$/year	--
Annual cost of natural gas imports	US$/year	--	US$/year	73.335
Annual cost of diesel imports	US$/year	--	US$/year	--
Annual cost of biomass imports	US$/year	35.150	US$/year	--
Operation and Maintenance costs	US$/year	21.813	US$/year	16.716
Annual cost of equipment**	US$/year	76.322	US$/year	48.707
TOTAL annual cost	US$/year	331.774	US$/year	372.758

The economic optimal presents a lower annual total cost, when compared to the reference system (10.99% lower). When analyzing the initial investment in equipment, a higher value is verified due to the installation of PV panels and biomass boilers (more expensive than traditional boilers). However, this value is compensate by 22.86% less electricity being imported from the grid.

The production of only 129 MWh/year of electricity through PV panels does not allow for the credit compensation due to minigeneration, as foreseen by legal constraints (regulation nº482 - ANEEL, 2012). For the amount of panels installed, no surplus electricity is fed into the grid. This production can be considered inexpressive if the high investment costs are considered for the implementation of this type of technology.

In the optimal system, the steam demand is satisfied by a biomass steam boiler, and excess heat goes into a heat exchanger, to meet the demands of hot water. The remaining hot water demand is met by two biomass hot water boilers plus an electricity boiler. All coolth originates from mechanical chillers. Diesel and natural gas were not utilized in the reference system neither in the optimal system. No absorption chillers were installed. The amount of heat originated from these mechanical chillers is entirely evacuated through the cooling towers.

Among the results presented for the optimal configuration, the purchase of biomass (2663 MWh/year) for utilization in boilers must be highlighted, as the low purchase price makes the use of biomass technologies more attractive from an economic point of view.

3.1 Others Results

3.1.1 Variation of interest rates and mandatory installation of 200 panels

A sensitivity analysis was carried out to verify the influence of the interest rates on the configurations obtained by the optimization model. The base interest rate was 10%, which was used to build Table 3. When the interest rates were decreased to 8% and 6%, there was no difference in the solution provided by the optimization model (same results as Table 3). When the interest rate dropped to 4%, the electric boiler was not installed and in its place, an additional biomass boiler was installed for the production of hot water. However, considering the reality of the Brazilian market in 2014, with inflation rates of 6.75% and interest rates between 10-11%, using a 4% interest rate does not reflect at all the reality of the market.

3.1.2 Free optimization with different investment costs

This sensitivity analysis removed the mandatory installation of 200 PV panels, and varied the capital cost for the PV system. The results obtained from solving the optimization model are shown in Table 3.

Table 3 – Cost for the panels and economic minimum.

Investment costs for PV panels	Configuration of the system: installation of PV panels
Base case: US$ 880/unit	no installation of PV panels
US$ 440/unit	no installation of PV panels
US$ 256/unit*	830 panels installed, but no electricity exports
US$ 220/unit	1000 panels installed**, but no electricity exports

* Starting point for installation of PV panels
** A maximum amount of 1000 PV panels was considered as a restriction.

It is observed that the cost of photovoltaic system deployment is high, preventing the compensation of the generated energy, along the lines of resolution n° 482 da ANEEL. However, even with the reduction of 75% of the initial investment cost for installation of photovoltaic solar panels, the optimal solution did not export electricity to the electric grid because the cost is still higher than the credits offered by the current legislation.

The legislation in force is comprehensive regarding the implementation of renewable sources for distributed generation. However, given the results obtained herein for the free optimization of the system, the use of other resources should be considered (e.g., biomass).

4. CONCLUSIONS

The installation of new energy systems and the optimization of these projects requires a real and comprehensive analysis from different viewpoints: technical, economic, environmental, etc., and should also reflect, as closely as possible, the actual conditions of use. The energy system that allows the hospital to meet the energy demands prioritized only the economic aspect, seeking the minimum total annual cost.

This work presents the optimal configuration for a polygeneration system, using renewable sources (solar photovoltaic and biomass). An analysis of the economic impact caused by the incorporation of these sources was also presented. It was observed that for current conditions (available number of photovoltaic panels: 200), the installation is not attractive from an economic perspective. The high cost of implementation, in addition to low production of electricity, do not enable the hospital to take advantage of this resource to realize economic benefits. The optimal solution, however, suggested the installation of biomass boilers for better utilization of this energy resource, given its low cost.

In general, low variability was observed in the configurations obtained, in which the cooling demand was always met by mechanical chillers.

As a suggestion for extending this work, the introduction of more equipment in the superstructure can be considered, such as biomass turbines, which can take advantage of the low price of the resource for electricity or steam generation .

Sensitivity analyses can be carried out by varying economic conditions (factor amortization), price of biomass (including introducing a constraint on consumption, simulating a finite daily or monthly stock), and initial investment in solar panels (simulating a government grant for example). It is also interesting to perform the optimization of the system from an environmental point of view, using the technique of Life Cycle Analysis (LCA), and verify what setup and operation is obtained when the objective function considers the minimization of environmental impacts.

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6. RESPONSIBILITY NOTICE

The authors Danielle Delgado, Ricardo Chacartegui, Luiz Morera Junior and Monica Carvalho are the only responsible for the printed material included in this paper.