Study on the Technical and Economic Viability of a Polygeneration Energy System Applied to a Hospital Unit in Bahia's Countryside, Brazil

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The present study aims to propose a polygeneration system model, integrating multiple forms of energy generation, such as photovoltaic systems, heat pumps, and other existing storage models to be used in a small-sized hospital unit in Bahia's countryside. A polygeneration system was developed through a basic Project of the individual components and their integration as a unified system. The COP value, energy saving, and macro investment predictions were calculated, and financial indicators such as payback time, VPL, and TIR were determined. The results showed that the proposed system can supply the hospital's energy demands and be considered a stimulating investment.
Keywords: Polygeneration. Heat Pump. Photovoltaic System. Hospital.

Introduction

The world has been going through a renewal in how energy is generated and managed, all the way to its utilization. The concept of sustainability goes through the primary idea of green consumption, also paying attention to generating energy and energetic efficiency, configuration, and transformation of the existing systems. According to the data from ANEEL [1], approximately 14.8% of national energy production is compromised from generation to consumption availability.

Espírito Santo and colleagues [2] state that the efficient use of natural resources and energy generation decentralization through polygeneration can contribute to primary energy saving and the planet's health.

Many studies on polygeneration have been developed around the world. For instance, Pina and colleagues [3] developed a polygeneration analysis destined for a hospital unit located in Campinas (Brazil), composed of a photovoltaic system, photothermic system, biomass generator, and natural gas associated with thermal storage units and net connection. Calise and colleagues [4] approach a polygeneration system analysis, also destined for a hospital, using a natural gas-powered engine, heat exchangers, an absorption chiller, a cooling tower, and other components. Other polygeneration systems were developed and studied in the literature [5, 6].

Photovoltaic systems are a more promising electric energy generation alternative because they provide sustainable energy at an attractive energy-saving cost. According to data from ABSOLAR [7], in the last 12 years, the capacity of installed photovoltaic generators in Brazil has increased from approximately 8 MW to over 32 MW till June 2023.

Heat pumps are another application for a generator system that has increased in the number of researches for using and commercializing. According to Fischer and colleagues [8], heat pumps are already a well-known technology. They play a more and more critical role in Europe for cooling and heating buildings due to their capacity to increase energetic flexibility, integrate other systems, reduce CO_2 emissions, and improve efficiency.

A polygeneration system was proposed and studied in Chiang Mai, Thailand, by Kong and colleagues [9]. The model proved that combining systems enables a more significant individual performance generation for the thermic and photovoltaic systems and the heat pump.

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The present study introduces as its primary focus the proposition for a polygeneration energy system for hospital units, including photovoltaic systems and heat pumps, among other generation and storage systems already known. It intends to prove its technical and economic viability for a small-sized hospital unit in Bahia's countryside.

Materials and Methods

The polygeneration system analysis began with the consumption unit selection and knowing its energy demands. In the work of Melo and colleagues [10], a polygeneration system study, data from a hospital in Buritirama, Bahia (-10,72N, -43,65L) were available. The hospital is considered small-sized, with an approximate area of 783 m², with 15 bed rests and one birth room, operating 24 hours a day, with 17 collaborators and an average of 15 patients daily.

The hospital's energy load comes from electric and thermal hot water and air conditioning. Regarding the electric energy consumption for the hospital, there is an average of 6,857.83kWh/month, with approximately 10.62% for electric showers, 45.45% for air-conditioning, and 43.92% for other equipment and lighting.

Thermal loads have peak power calculated for February of 31.66 kW and a maximum monthly load of 11,102.85 kWh/month for air-conditioning units and 713.00 kWh/month for electric showers. Electric showers drive the hospital's hot water demand, considering COP equals 1. Cooling demand comes from air-conditioning units, with a COP value of 3. The electric energy is provided by the concessionary electric net [10].

After the energetic demand determination, the macrostructure for the polygeneration system was defined for analysis. The proposed system presents a photovoltaic system and uses the concessionary electrical network for feeding the electric energy, an air-water heat pump for generating hot water, an absorption chiller for cold water, and accumulation tanks for cold and hot water. The polygeneration model is presented in Figure 1.

The polygeneration system was dimensioned starting from the thermal demands. Data from storage tanks and absorption chillers by Melo and colleagues [10] were used. The accumulation tanks have a 6% performance, a 1700 kW capacity for hot water, and 400 kW for cold water. The chosen absorption chiller is the EAW Wegracal 50, with a 71kW entrance power rating of 54kW, COP of 0.81, hot water entry temperature of 71oC to 86oC, and cold water exit of 9°C.

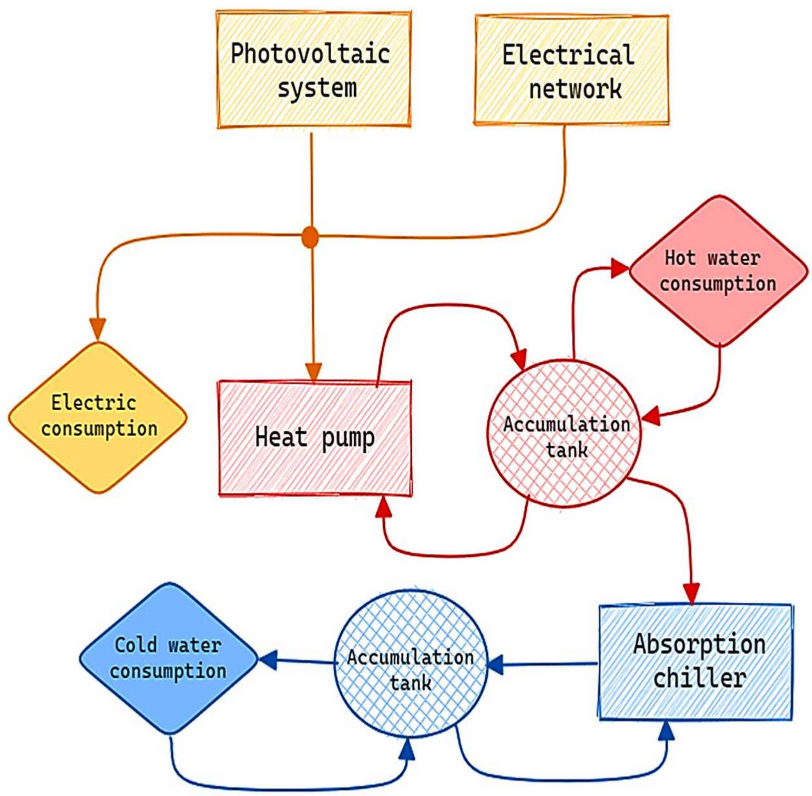
The heat pump was empirically dimensioned to supply the hot water thermal demands for consumption and the absorption chiller's need to provide the cold water demand.

For calculating the heat pump, the current peak of monthly cooling demand was 11,102.85 kWh, the chiller performance with COP was equal to 0.81, and the accumulation tanks had a 6% loss. As for the hot shower water, the peak demand considered was 713.00 kWh and a 6% loss from the accumulation tank. So, we calculated a pump generation demand of 15,340.66 kWh/month and a power of 21.31 kW. After analyzing the market's disponibilities, two heat pumps were selected: LG model HM121M. U33. The primary data from the heat pump are in Table 1.

Table 1. Primary data - Heat pump system LG HM121M.

Heat pump maker	LG
Module model	HM121M
Number of heat pumps selected	2
COP warming range (variation to entry/exit temperatures)	2.9 to 4.9
Thermal rated capacity - warming (kW)	12
Thermal rated capacity - cooling (kW)	14
COP cooling range (variation to entry/exit temperatures)	2.7 to 4.6
Domestic hot water temperature range (°C)	15 an 80
Compressor type	Scroll

Figure 1. Polygeneration system model.



After calculating the heat pump, the consumption adjustments were made due to its installation's predicted increase in efficiency. The hospital is situated in a high-temperature region with few variations, so the COP was considered as 4 for the heat pump. Therefore, comparing the pump's COP of 4 to a COP of 1 for the electric showers and COP of 3 for the air-conditioning units [10], considering the absorption chiller's performance losses, the electric energy consumption reduction calculated was approximately 11.22%.

From the results found in electric energy consumption, an on-grid photovoltaic system was dimensioned to supply the hospital's mean consumption. The system was empirically dimensioned by Excel sheets and generation and performance calculation guidance from the literature [11,12]. The system's dimensioning considered solar irradiation from the zone according to solarimetric data from CRESESB of 5.99 kWh/m^2, day [13], total system performance of 0.8 [11, 12]. Table 2 describes the photovoltaic generator.

After dimensionalizing the system, equipment market prices were consulted for photovoltaic and heat pumps [14,15]. The photovoltaic system projected has a foreseen value of R$ 91,312.63, and the two heat pumps have a total value of R$ 69,139.80. Based on the initial investment cost and calculating the economy of annual electric energy by the polygeneration system, the payback time and the value of VPL and TIR were calculated. For the energy economy calculus, the study considered the Brazilian law 14.300 for regulating the distributed generated energy and energy taxes indicated by ANEEL [16] for the place in concern. The annual loss predicted in performance was also considered for the modules, the country's inflation, and the energy inflation projected based on last year's average.

Table 2. Primary data – projected Photovoltaic System.

Electric energy average consumption. (kWh/day)	200.18
Average HSP (CRESESB) - (kWh/day)	5.99
Assumed performance	0.80
Theoretic power of the photovoltaic generator	41.77
Module power (kWp)	0.55
Minimum number of modules	76
Total power of Photovoltaic Inverters (kW)	37.5
Total power with the modules (kWp) - updated	41.8
Number of modules	76

Results and Discussion

According to developed calculations, the proposed system can supply the current hospital demand for electric, hot, and cold thermal energy from the macro module of polygeneration.

The heat pump was dimensioned to meet the maximum thermal load of the electric showers, although it has a COP value of 4 times the estimated COP for electric showers. It enables supplying the thermal load demanded and projected but with an electric energy consumption of only 25% of that electric showers consume.

The heat pump can elevate the water temperature to 80°C, which is compatible with the operating range of the absorption chiller. The assumed absorption chiller power of 50 kW is also superior to the hospital's thermal peak of 31.66 kW in February, which indicates the possibility of meeting the peak power with a relative operating slack. The total COP calculated for the cold thermal set was 3.24, considering the series connection of the heat pump, the absorption chiller, and the accumulation tanks. The set COP is approximately 8% bigger than the current air-conditioning units' COP.

By calculating the predicted energy generation for the photovoltaic system throughout the year, according to the solar irradiation variability during the year, a mean generation of 6097.51 kWh/month was determined, which is larger than the mean has foreseen hospital consumption of 6088.67 kWh/month with the polygeneration system. That indicates that the system can supply to the maximum its energetic compensation through the distributed generation, bringing the hospital an investment financial return. The hospital can operate with a concessionary network during low solar generation hours. Figure 2 below shows the generation consumption curves over the year.

An investment return curve was calculated for the leading equipment through the foreseen energy economy for the year and considered the annual inflation adjustments, energy inflation, TUSD - FIO B tax charging adjustments, and performance loss from the photovoltaic modules predicted by the supplier. The payback time found was 3.14, and the financial gain after 25 years was R$ 2,258,438.92. Taking the average of last year's inflation, the VPL value calculated was R$ 1,173,312.52, and the TIR was 33.75%. Figure 3 shows the returning income of the two main analyzed components.

Conclusion

The present study aimed to project a polygeneration system model for a hospital unit. According to the available parameters and developed calculations, the system can meet the hospital's energetic demands - electric, warm, and cold heat. The system presented promising results for energetic efficiency value and a reliability degree superior to the current energetic structure in the hospital. After analyzing the central polygeneration system's cost, it was possible to identify that the project is viable and thrilling regarding financial investment, with significant payback time, VPL, and TIR values.

Figure 2. Generation curve and monthly consumption.

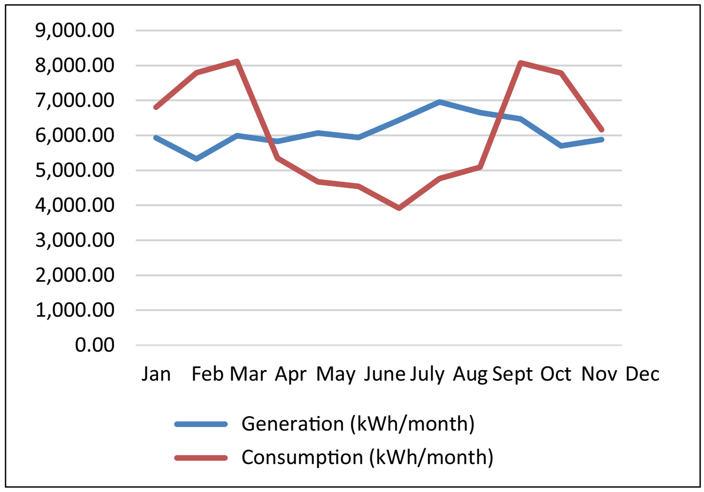
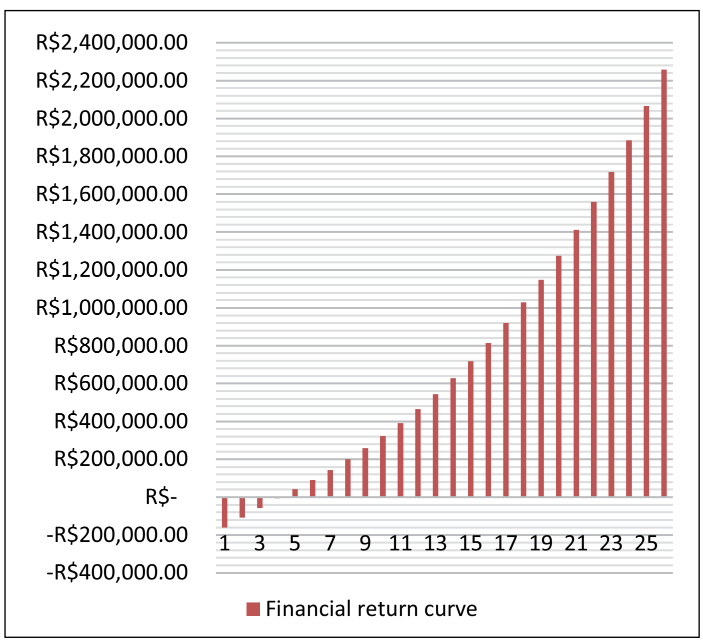


Figure 3. Financial return curve.



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