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Para o Desenvolvimento Ambiental, Cultural e Socioeconômico

Xosé Somoza Medina
(organizador)

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PRÓLOGO

El presente volumen de ***Ciencia y Tecnología para el Desarrollo Ambiental, Cultural y Socioeconómico*** reúne un conjunto diverso de trabajos que reflejan, desde distintas miradas, la importancia de la ciencia y la tecnología en la comprensión y transformación de los contextos actuales. A lo largo de sus páginas, se percibe un interés común por vincular el conocimiento con la realidad, abordando problemáticas concretas y proponiendo caminos posibles para su análisis y mejora.

Con el propósito de facilitar la lectura y dar coherencia al conjunto, los trabajos han sido organizados en dos grandes ejes, que dialogan entre sí: ciencia y tecnología. Esta división no pretende establecer fronteras rígidas, sino más bien destacar dos dimensiones complementarias del conocimiento.

En el eje de ciencia se reúnen investigaciones que parten de la observación, el análisis y la comprensión de fenómenos naturales, ambientales y sociales. Los estudios aquí incluidos abordan cuestiones como la producción agrícola, la microbiología, el emplazamiento urbano, la contaminación ambiental y la calidad de los ecosistemas, así como reflexiones sobre los fundamentos teóricos que han acompañado el desarrollo del pensamiento científico y económico. En conjunto, estos trabajos permiten dimensionar la relevancia del conocimiento científico como base para la toma de decisiones y la construcción de soluciones sostenibles.

Por su parte, el eje de tecnología concentra contribuciones orientadas al diseño, la aplicación y la innovación. Se presentan propuestas que van desde el desarrollo de dispositivos y sistemas técnicos hasta las tecnologías de tratamiento de aguas residuales industriales o el uso de herramientas digitales en contextos educativos, pasando por análisis vinculados al impacto de las tecnologías en la sociedad contemporánea. En este sentido, los trabajos evidencian cómo la tecnología no solo responde a necesidades concretas, sino que también transforma las formas de interacción, aprendizaje y producción de conocimiento.

En conjunto, este volumen pone de manifiesto que ciencia y tecnología no pueden pensarse de manera aislada. Ambas se entrelazan constantemente, nutriéndose mutuamente y contribuyendo al desarrollo ambiental, cultural y socioeconómico. Más allá de sus diferencias, comparten un mismo propósito: generar conocimiento significativo y aplicable, capaz de dialogar con los desafíos de nuestro tiempo.

Se trata, en definitiva, de una obra que invita a una lectura atenta y abierta, reconociendo la riqueza de enfoques y la diversidad de contextos desde los cuales se produce conocimiento.

Xosé Somoza Medina

Universidad de León, Espanha

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TOWARDS SELF-SUFFICIENCY: COGENERATION OPPORTUNITIES FOR THE HOTEL INDUSTRY IN PUERTO RICO

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ABSTRACT: Puerto Rico, with its significant tourism potential, positions hotels as promising business ventures and crucial contributors to the country's economy. As substantial consumers of utilities like energy, water, and gas, hotels face increasing interest in exploring sustainable alternatives, driven by current regulations promoting greenhouse gas reduction. This case study examines the consumption patterns of five hotels across different regions of the island. Based on these insights, we propose a Combined Heat and Power (CHP) system, evaluating its feasibility in terms of both requirements and economics. Our findings indicate that cogeneration system efficiencies surpass 60% in most cases, significantly outperforming independent thermal systems. Consequently, implementing cogeneration systems in the hotel industry proves not only viable but also advantageous.
KEYWORDS: Puerto Rico; cogeneration; hotels; combine heat and power and feasibility.

1. INTRODUCTION

The hotel industry in Puerto Rico, despite the natural challenges it has faced, has been a cornerstone of the country's economy. Hurricane Maria in September 2017 was a turning point in the lives of Puerto Ricans, causing total blackouts, telecommunication failures, and suspended water services for several months. This event had a substantial impact on tourism and the hotel industry, resulting in significant economic losses. However, since the beginning of 2021, lodging revenues have increased by 20%, demonstrating remarkable resilience despite all adversities (EFE S.A., 2023).

Maria's arrival on the island completely destroyed the electrical distribution infrastructure, prompting the enactment of Law 17-2019 (U.S. Department of Energy [DOE], a). This law mandates the Puerto

Rican Government to reduce the use of fossil fuels, minimize gas emissions, and support initiatives focused on mitigation and resilience (DOE, a). All requirements of this law represent necessary steps to initiate an energy transformation seeking more efficient solutions and favoring renewable technologies.

The commercial sector in Puerto Rico, comprising hotels, restaurants, offices, among other business buildings, accounted for 47% of the energy consumption in 2018, the highest percentage of any sector in the country (Shah et al., 2021). Hotels, due to services like air conditioning, hot water, spas, saunas, pools, etc., are structures with high energy consumption. Understanding the needs of the country and the world in an energy transformation, it is imperative to reduce the energy consumption of the hotel industry.

Cogeneration is a technology for the rational use of energy, defined as the simultaneous generation of two or more forms of energy from a single source (Lee et al., 2022). This technology will be the focus of analysis within the hotel industry in Puerto Rico to explore its potential in reducing energy consumption and economic viability, thus supporting the reduction of fossil fuel usage and enhancing energy efficiency.

2. LITERATURE REVIEW

Cogeneration can be defined as the simultaneous production, in a sequential process, of mechanical and/or electrical energy and useful thermal energy (Instituto para la Diversificación y Ahorro de Energía, 2020). Although the beginnings of cogeneration date back to the early 1880s, it is only in the last couple of decades that these systems have gained momentum in global implementation due to the impacts of greenhouse gases generated by the burning of fossil fuels (Vourdoubas, 2021). Cogeneration processes can increase overall system efficiencies, exceeding 80%, and reduce the emission of pollutants such as NOX, SO2, and CO2. These factors have been decisive in positioning cogeneration as one of the best alternatives in the industry today.

The use of cogeneration in the hotel sector has been studied worldwide, demonstrating significant performance and corroborating the aforementioned benefits. In Malta, Magro & Borg (2023) studied the implementation of cogeneration systems in 3 to 5-star hotels, achieving efficiencies of 81.4% using a combined heat and power (CHP) system. Uydur & Imamoglu (2023) studied the implementation of such a system for a 3,200 m^2 facility in Istanbul, reaching an efficiency of 88%. In Veracruz, Mexico, the implementation of a trigeneration system (CCHP) for a hotel complex was studied, concluding that this implementation was valid and would generate economic savings due to its efficiency (Camacho Ceballos et al., 2020). Xu et al. (2023) studied the use of microcogeneration with a heat pump implemented in a large-scale hotel, finding that it can reduce the annual peak energy demand by up to 37% and additionally decrease NOX, SO2, and CO2 emissions by 73.5%, 73%, and 64.8%, respectively.

3. METHODOLOGY

3.1. DATA COLLECTION

Analysing the energy, water, and gas demands of five hotels across various regions of Puerto Rico over a year is crucial for understanding their resource consumption patterns and identifying areas for potential efficiency improvements or cost savings. By utilizing billing receipts from the respective utility providers, such as LUMA for electricity, the Authority of Aqueducts and Sewers for water, and individual gas providers, this study aims to provide a comprehensive overview of resource usage trends in the hospitality sector. The synthesized information presented in tables 1 through 5 will aid in understanding the principles guiding the selection of the best technology for cogeneration purposes to maximize efficiency and reduce environmental impact.

Table 1: summary of consumption hotel 1.

Month/Year	Gallons of Propane Gas	Electricity In kW- Hours	Water Consumption in Gallons*	Occupancy Rate
may-22	1,938.20	176,864.00	938,867.29	76.00%
jun-22	2,007.20	160,283.00	772,703.10	83.00%
jul-22	2,287.30	206,237.00	890,787.98	76.00%
ago-22	1,891.40	219,986.00	951,811.72	67.00%
sep-22	2,288.90	165,894.00	851,690.53	61.00%
oct-22	1,267.20	117,040.00	957,623.50	70.00%
nov-22	1,906.80	179,520.00	811,272.21	68.00%
dic-22	2,347.20	169,400.00	1,077,557.59	74.00%
ene-23	2,132.02	153,006.00	802,554.54	77.00%
feb-23	1,487.00	130,794.00	749,984.31	86.00%
mar-23	1,786.00	160,600.00	885,504.54	89.00%
abr-23	1,561.35	144,320.00	822,367.44	86.00%

Table 2: summary of consumption hotel 2.

Month/Year	Gallons of Propane Gas	Electricity In kW- Hours	Water Consumption in Gallons*	Occupancy Rate
jun-22	1,515.20	260,700.00	1,213,870.34	73.00%
jul-22	1,736.00	267,300.00	1,073,066.66	88.00%

ago-22	1,656.00	260,040.00	826,065.84	89.00%
sep-22	1,515.20	265,320.00	784,590.84	80.00%
oct-22	1,963.40	247,632.00	668,355.16	76.00%
nov-22	1,186.80	250,668.00	567,441.46	77.00%
dic-22	1,355.20	262,680.00	649,598.95	71.00%
ene-23	1,788.50	279,840.00	1,129,335.30	64.00%
feb-23	1,328.60	251,460.00	670,204.36	66.00%
mar-23	1,702.90	262,020.00	681,035.42	83.00%
abr-23	1,399.30	280,500.00	911,393.40	77.00%
may-23	1,454.50	250,140.00	598,349.58	70.00%

Table 3: Summary of consumption hotel 3.

Month/Year	Gallons of Propane Gas	Electricity In kW-Hours	Water Consumption in Gallons*	Occupancy Rate
jun-22	977.00	123,420.00	752,890.20	92.00%
jul-22	1,314.80	133,980.00	907,430.82	96.00%
ago-22	1,148.20	147,840.00	517,248.78	88.00%
sep-22	1,115.00	145,200.00	505,625.21	74.00%
oct-22	935.60	127,380.00	529,929.03	92.00%
nov-22	980.80	121,440.00	531,249.89	80.00%
dic-22	974.30	122,100.00	508,795.27	77.00%
ene-23	1,084.70	121,440.00	635,597.83	80.00%
feb-23	894.20	102,300.00	381,200.20	72.00%
mar-23	935.60	111,540.00	546,307.70	70.00%
abr-23	957.70	125,400.00	840,859.48	69.00%
may-23	874.90	119,460.00	671,525.22	69.00%

Table 4: Summary of consumption hotel 4.

Month/Year	Gallons of Propane Gas	Electricity In kW-Hours	Water Consumption in Gallons*	Occupancy Rate
may-22	2,082.27	177,760.00	1,324,822.58	75.00%
jun-22	2,425.76	195,140.00	1,142,543.90	84.00%
jul-22	2,532.38	205,260.00	1,296,556.18	75.00%
ago-22	2,262.26	223,080.00	1,409,357.62	67.00%
sep-22	1,890.84	192,500.00	1,217,040.40	56.00%
oct-22	2,228.50	184,140.00	1,282,555.06	66.00%
nov-22	1,551.21	190,080.00	1,038,460.13	61.00%

dic-22	1,703.79	190,740.00	1,466,154.60	67.00%
ene-23	2,127.20	168,080.00	488,718.20	63.00%
feb-23	2,059.80	154,000.00	425,845.26	81.00%
mar-23	2,368.00	149,820.00	499,813.42	82.00%
abr-23	1,682.70	158,840.00	995,928.44	83.00%

Table 5: Summary of consumption hotel 5.

Month/Year	Gallons of Propane Gas	Electricity In kW-Hours	Water Consumption in Gallons*	Occupancy Rate
ago-22	1,145.00	246,180.00	783,798.32	56.20%
sep-22	911.00	296,340.00	691,602.30	57.60%
oct-22	1,234.00	306,220.00	611,558.18	85.70%
nov-22	1,075.00	312,451.00	663,071.72	84.00%
dic-22	1,213.00	315,011.00	647,749.74	84.40%
ene-23	1,119.00	326,357.00	842,708.68	85.30%
feb-23	1,067.00	313,876.00	687,111.37	90.30%
mar-23	1,240.00	314,939.00	651,976.50	91.20%
abr-23	1,279.00	278,784.00	668,090.99	90.40%
may-23	1,471.00	58,001.00	1,146,506.48	86.00%
jun-23	1,140.00	63,743.00	728,058.03	93.50%
jul-23	1,263.00	59,624.00	847,463.78	92.70%

3.2. DATA ANALYSIS

To analyse the consumption data collected and begin examining cogeneration opportunities within the sector, all the information was synthesized into graphs shown in Figures 1 and 2. These graphs allow a clear view of which sectors are consuming the most energy and gas. Understanding which sectors are utilizing the highest amount of resources provides perspective on the approach that should be taken when evaluating cogeneration potential. Once these graphs are available, factors can be defined to consider when selecting criteria to assist in evaluating the various existing cogeneration systems.

Figure 1. Average distribution of energy consumption from the five analyzed hotels.

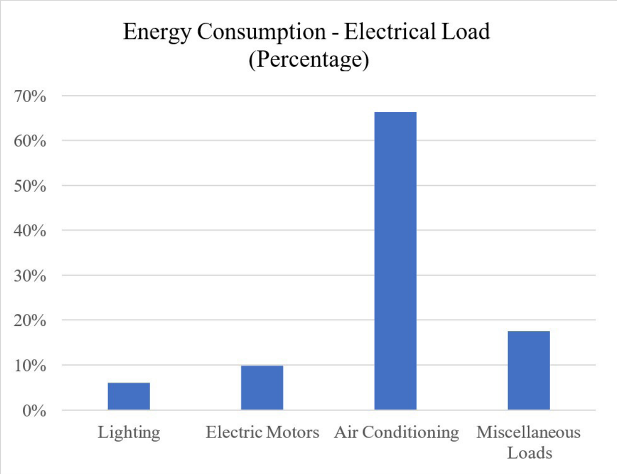
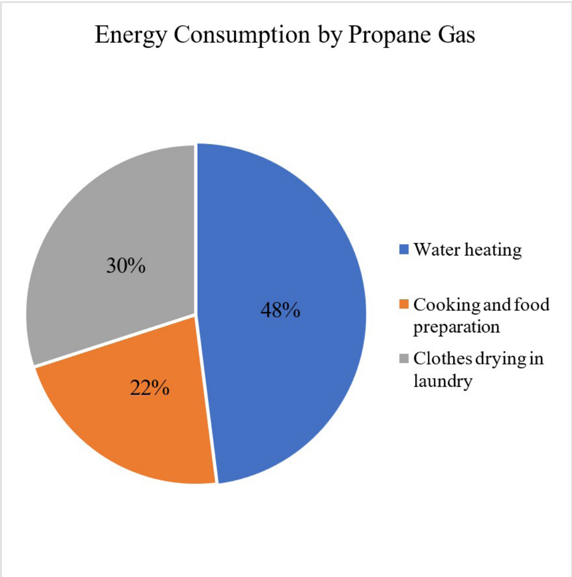


Figure 2. Average distribution of propane gas consumption from the five analyzed hotels.



3.3. TECHNOLOGY SELECTION

The following considerations were made for selecting the cogeneration technology that fits into the hotel's requirements (Pelaez-Samaniego et al., 2020):

1) The proposed cogeneration system must align with the current heat requirements to ensure cogeneration plants with a high capacity factor.

2) The selected primary mover will be capable of covering total or partial energy requirements. In the event of an energy deficit, and as long as thermal requirements are met, importing energy from the local grid (LUMA) is preferable. In case of overgeneration, excess energy will be sold to the local grid. The buying or selling of hot or cold fluids was not considered.
3) The yearly average of thermal energy requirements (not the peak requirement) was used to size the cogeneration plant.
4) Trigeneration projects are viable due to high air conditioning loads. In this case, both air conditioning and/or cold fluid will be produced from the waste heat of the primary mover. The Trigeneration system will primarily operate on LiBr (Lithium Bromide) absorption chillers for air conditioning.

Based on the consumption data gathered from the five hotels, we have compiled a summary of annual average consumption shown in Table 6, which will serve as the foundation for sizing the proposed systems.

Table 6: Summary of annual average consumption.

Yearly Hours	Yearly Average Energy Consumed (kWh)	Yearly Average Energy Consumed in gas (MMBTU)	Yearly Average Energy Consumption for Hot Water and Laundry (MMBTU)
8,760	2,436,232.80	1,697.63	1,324.15

4. RESULTS AND DISCUSSION

The aim of this study is to select a cogeneration system suitable for implementation in the hotel sector in Puerto Rico. Once the criteria were selected based on the collected data, the discussion of the selected system and its generation capacity is carried out as the main outcome of the study.

4.1. COMBINE HEAT AND POWER SYSTEM (CHP)

Despite the high utilization of electrical resources for air conditioning, the primary criterion is to meet heating needs. Therefore, the selected system is a combined heat and power system rather than a trigeneration system. To size this system, we will employ a reciprocating engine with a heat output sufficient to meet 78% of the annual energy requirement used by gas, as indicated in Table 6.

Table 7: Reciprocating engine performance characteristics (natural gas fuel).

Characteristic	CHP Reciprocating Engine (Stoichiometry and Gross Power)[a]							
	Rich Burn			Lean Burn				
	35 kW	100 kW	250 kW	500 kW	1 MW	2 MW	3 MW	4.5 MW
Net Power (kW)[b]	34.7	99.0	247.5	495	990	1,980	2,970	4,455
Fuel Input (MMBtu/hr, HHV)[c]	0.43	1.14	2.58	4.65	9.18	16.80	25.10	37.40
Electric Efficiency (%, HHV, net power basis)	27.7%	29.7%	32.7%	36.3%	36.8%	40.2%	40.4%	40.6%
Thermal Recovery Based on 180°F Hot Water (HW)								
HW Capacity (MMBtu/hr)	0.23	0.57	1.21	1.95	3.85	6.45	9.65	14.40
HW Thermal Efficiency (%, HHV)	54.0%	50.0%	47.0%	41.9%	41.9%	38.4%	38.4%	38.5%
HW Power to Heat Ratio	0.52	0.60	0.70	0.87	0.89	1.06	1.06	1.07
CHP Efficiency (%, HHV)[d]	81.7%	79.7%	79.7%	78.2%	78.7%	78.6%	78.8%	79.1%
Thermal Recovery Based on Steam (125 psig sat) and Hot Water (180°F)								
Jacket Cooling HW Capacity (MMBtu/hr)	Steam recovery is less common in rich burn engines compared to lean burn engines.			1.05	2.15	3.70	5.48	8.85
Exhaust Steam Capacity (MMBtu/hr)				0.85	1.42	2.16	3.27	4.20
HW Efficiency (%, HHV)				22.6%	23.4%	22.0%	21.8%	23.7%
Steam Efficiency (%, HHV)				18.3%	15.5%	12.9%	13.0%	11.2%
Steam + HW Efficiency (%, HHV)				40.9%	38.9%	34.9%	34.9%	34.9%
CHP Efficiency (%, HHV)[e]				77.2%	75.7%	75.1%	75.3%	75.5%

Source: U.S. Department of Energy, 2023, http://energy.gov/CHP/

Using data from the DOE (2023) for reciprocating engines, we have selected a nominal power engine of 100 kW with a useful heat output for heating of 0.57 MMBTU/hr. Considering the continuous operation of hotels around the clock, every day of the year, this results in a total of 8,760 hours annually, yielding an available annual energy capacity of 4,993 MMBTU when the engine operates at full load.

These data are based on the use of natural gas as the engine fuel; however, in the case of Puerto Rico, which is not a natural gas-producing country and lacks reserves of this fuel, the optimal scenario would be to use propane as the primary fuel. The use of reciprocating engines as primary mover in cogeneration is highly versatile, as these engines exhibit good efficiencies even at partial loads and can burn a wide range of fuels.

Propane has a much higher calorific value than natural gas; therefore, the propane consumption of the engine would be much lower than the consumption of natural gas. We could estimate propane consumption as the ratio between the High Heating Values (HHV) of natural gas and propane multiplied by the current consumption of natural gas:

$$Propane\ Consumption = \frac{HHV\ of\ Natural\ Gas}{HHV\ of\ Propane} * Natural\ Gas\ Consumption. \quad (1)$$

Using the HHV of natural gas as 1000 BTU/ft³ and the HHV of propane as 2,500 BTU/ft³, the estimated propane consumption would be approximately 0.46 MMBTU/hr. Considering the thermal efficiency of this engine is 50%, it would result in a useful heat output of 0.23 MMBTU/hr. Considering the same 8,760 hours per year, this equates to around 2,014 MMBTU/year available. With these approximate calculations, we continue to meet the required thermal capacity in the hotels.

The implementation of this system will not only reduce the electrical consumption drawn from the grid but also meet thermal needs, achieving overall efficiencies in the CHP system ranging from 50% to 79.7%, which is the maximum efficiency the engine will reach when utilizing all the thermal energy output.

5. FINANCIAL CONSIDERATIONS

In order to assess the economic considerations of this project, it is crucial to consider two fundamental factors. The first involves comparing the cost of the generated energy with the purchasing cost from the grid operator. The second factor entails evaluating the project's return on investment. To achieve this, it is essential to be acquainted with the costs associated with equipment, installation, and ongoing operation and maintenance (Provenzano, 2021).

Table 8: Reciprocating engine capital and O&M costs (typical).

Cost Element	CHP Reciprocating Engine (Stoichiometry and Gross Power)							
	Rich Burn			Lean Burn				
	35 kW	100 kW	250 kW	500 kW	1 MW	2 MW	3 MW	4.5 MW
CHP Equipment Cost ($/kW)	$2,250	$1,900	$1,700	$1,500	$1,300	$1,150	$1,050	$900
Installation Cost ($/kW)	$2,000	$1,800	$1,750	$1,650	$1,500	$1,400	$1,300	$1,100
Total Installed Cost ($/kW)	$4,250	$3,700	$3,450	$3,150	$2,800	$2,550	$2,350	$2,000
Non-Fuel O&M (¢/kWh)	3.0	2.5	2.2	2.0	1.7	1.5	1.4	1.3
Total Installed Cost for SCR ($/kW)	NA	NA	NA	$375	$300	$230	$180	$130
O&M Costs for SCR (¢/kWh)	NA	NA	NA	0.25	0.25	0.25	0.25	0.25

Source: U.S. Department of Energy, 2023, http://energy.gov/CHP/

Utilizing information from the DOE (2023), one can estimate all expenses related to implementing a cogeneration project in one of the studied hotels. All costs for implementation, operation, and maintenance are summarized in Table 9. Energy prices per kWh and propane prices per gallon were calculated as the annual average from billing receipts analyzed across the five hotels.

Table 9: Summary of project-associated costs.

Total Installed Cost ($/kW)	3,700
Non-Fuel O&M ($/kWh)	0.025
Total kW	100
Total kWh	867,240
Total Installed Cost ($)	370,000
Total, Non-Fuel O&M ($)	21,681
Energy Rate ($/kWh)	0.27

Total Propane Consume (MMBTU)	4,030
Total Gallons/year of Propane	44,039
Gas Rate ($/gal)	2.01

One of the key criteria for assessing the feasibility of energy self-generation for self-consumption instead of purchasing energy from an external operator is undoubtedly the comparison between the current purchase price from the external operator and the estimated self-consumption generation price. According to Duffy et al. (2022), to calculate the cost of energy production for self- consumption, the following Levelized cost of energy (LCOE) can be used:

$$\left(\frac{\$}{kWh}\right) = \frac{Total\ Installed\ Cost\ (\$) * (\%\ of\ Annuity) + Total\ O\&M\ Cost + Fuel\ Cost}{Total\ Energy\ Produce\ (kWh)} \quad (2)$$

In this case, the annuity will be assumed as 5% of the total installation cost of the project, as cogeneration projects often benefit from reductions in pollutants and energy efficiency. With this annuity percentage, we obtain an energy cost of 0.15 $/kWh, comparing this value with the current purchase cost of 0.27 $/kWh from the grid operator is a very promising figure.

The second factor to evaluate is the simple rate of return, for which we need to calculate annual savings and compare them with installation costs. Annual savings will be calculated as the difference between energy and gas expenses before implementing the project and those after project implementation, those values are presented in Table 10 as No Cogeneration scenario (Before) and Cogeneration scenario (After).

Table 10: Annual savings implementing cogeneration.

No Cogeneration	
Total Energy Used From the Grid (kWh)	2,436,232.80
Price ($/kWh)	0.27
Total Price of Energy ($)	**657,782.86**
Total Gas Used (gal)	18,553.33
Price ($/gal)	2.01
Total Price of Gas ($)	**37,292.20**
Sum of Energy and Gas ($)	**695,075.06**
Cogeneration	
Total Energy Used From the Grid (kWh)	1,568,992.80

Price ($/kWh)	0.27
Total Energy Produced (kWh)	867,240.00
Price ($/kWh)	0.15
Total Price of Energy ($)	**552,328.14**
Total Gas Used (gal)	48,121
Price ($/gal)	2.01
Total Price of Gas ($)	**96,723.37**
Sum of Energy and Gas ($)	**649,051.50**
Annual Estimated Savings ($)	**46,023.55**

$$Simple\ Payback = \frac{Total\ Installation\ Cost\ (\$)}{Annual\ Estimated\ Savings\ (\$)} \tag{3}$$

Using the total installation cost of $370,000 and the calculated savings, we arrive at a simple payback of 8.04 years. In comparison with the cost of energy production, this payback value is unattractive for project implementation if the capital expenditure is provided by the hotels. Since the implementation of CHP strategies will indeed reduce the cost of energy alternatives can be explored thru Power Purchasing Agreements with third parties where the third party will produce and sell the energy and heat to the hotel at lower prices than the utility for a fixed period. This type of arrangement has been the basis for the proliferation of CHP in Puerto Rico and the hotel industry can benefit from this alternative (DOE, b).

6. CONCLUSIONS AND FUTURE WORK

Cogeneration projects continue to be part of studies and implementations worldwide. The potential for cogeneration in hotels is feasible due to their consumption profiles (Ma et al., 2023). It is of great interest to explore the future use of Combined Cooling, Heat, and Power (CCHP) systems where the output of the reciprocating engine reaches an absorption chiller, thus significantly reducing energy expenses.

In this studied case, the use of a reciprocating engine was analyzed to meet thermal needs, primarily to increase system efficiency, ranging from 50% to 79.7%, depending on the amount of heat output used to heat water. Due to fuel availability, propane was proposed as the primary resource for the engine. The cost of generating energy is competitive with current prices from the grid operator (0.15 $/kWh compared to 0.27 $/kWh). However, the simple payback is not as promising, therefore it uses should be thru third-party power purchasing agreements (PPA).

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SOBRE O ORGANIZADOR

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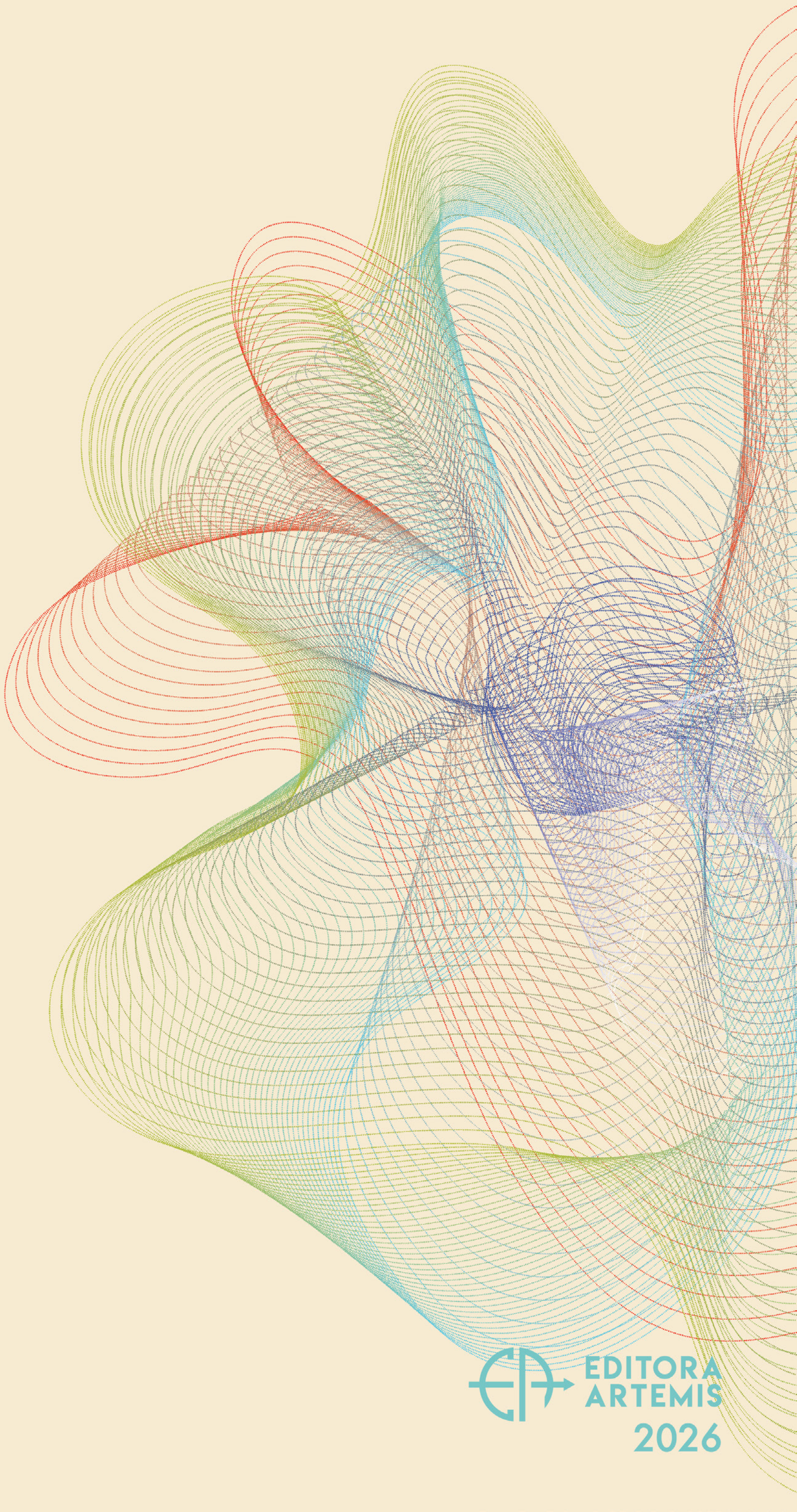

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