Revista Facultad de Ingeniería, Universidad de Antioquia, No.118, pp. x-xx, xxx-xxx 2026

L. Álvarez *et al*.; Revista Facultad de Ingeniería, No. xx, pp. x-x, 20xx

Revista Facultad de Ingeniería

Title: **Exergoeconomics in energy systems: Evaluating technological and economic costs of an AHT**

Authors: Lailani Álvarez, Mayra Harumi Bello-Guadarrama , Nanci Isamar Ortega-Mojica, Arianna Parrales, José Alfredo Hernández, Javier Delgado-Gonzaga and David Juárez-Romero

DOI: **10.17533/udea.redin.20250370**

To appear in: *Revista Facultad de Ingeniería Universidad de Antioquia*

Received: November 20, 2024

Accepted: March 28, 2025

Available Online: March 28, 2025

Please cite this article as: L. Álvarez, M. H. Bello-Guadarrama , N. I. Ortega-Mojica, A. Parrales, J. A. Hernández, J. Delgado-Gonzaga and D. Juárez-Romero. Exergoeconomics in energy systems: Evaluating technological and economic costs of an AHT, *Revista Facultad de Ingeniería Universidad de Antioquia*. [Online]. Available: https://www.doi.org/10.17533/udea.redin.20250370

Exergoeconomics in energy systems: Evaluating technological and economic costs of an AHT

Exergoeconomía en sistemas energéticos: Evaluación de los costos tecnológicos y económicos de un AHT

Lailani Álvarez [1*] https://orcid.org/0000-0001-5559-9063 , Mayra Harumi Bello-Guadarrama[1] https://orcid.org/0009-0007-1202-2900 , Nanci Isamar Ortega-Mojica[1] https://orcid.org/0000-0001-9843-2044 , Arianna Parrales[1] https://orcid.org/0000-0001-8554-8777, José Alfredo Hernández[1] https://orcid.org/0000-0002-2107-3044 , Javier Delgado-Gonzaga [2] https://orcid.org/0000-0003-2243-0290 and David Juárez-Romero[1] https://orcid.org/0000-0003-0942-9738

[1]Centro de Investigaciones en Ingeniería y Ciencias Aplicadas-CIICAp, Universidad Autónoma del Estado de Morelos. Av. Universidad 1001 Col. Chamilpa, C. P. 62209, Cuernavaca, Morelos, México.
[2] Instituto de Energías Renovables, Universidad Nacional Autónoma de México. Xochicalco s/n, Azteca, C. P. 62588. Temixco, Morelos, México.

Corresponding author: Lailani Álvarez
E-mail: lalvarezb16@gmail.com

KEYWORDS
Exergonomic; exergy analyses; systems optimization; absorption heat transformer; exergetic efficiency
Exergonomía; análisis exergéticos; optmización de sistemas; transformador térmico por absorbción; eficiencia exergética

ABSTRACT: The increasing awareness about energy conservation and its implications for a company's profitability has led to the creation of several models that combine energy processes with cost-accounting methods. Consequently, the industry has centered its endeavors on identifying economically viable, technologically possible, and environmentally acceptable alternatives. An approach to addressing the above issues is to conduct an exergoeconomic analysis of the energy systems implemented during operations to maximize resource use. The present research evaluates the use of exergonomic analysis in an Absorption Heat Transformer (AHT) to identify areas for improvement in system operation and to optimize the essential parameters for improved technological efficiency. The study also found possible ways to make the generator (GE), economizer (EC), and absorber (AB) better for future research, while still reaching up to 98% technical efficiency in some parts. Considering cost as a measure of used resources provides a thorough insight into the energy systems adopted by the industry. Thanks to the fact that exergonomics considers costs as a measure of resource consumption, this approach offers a comprehensive view of the energy systems adopted by the industry. These results are relevant for understanding the potential impact of integrating technical, economic, and environmental efficiency into energy management practices within the industrial sector.

RESUMEN: La creciente preocupación por la conservación de energía y sus implicaciones en la rentabilidad de una empresa ha llevado a la creación de muchos modelos que combinan procesos energéticos con métodos de contabilidad de costos. En consecuencia, la industria ha centrado sus esfuerzos en identificar alternativas económicamente viables, tecnológicamente posibles y ambientalmente aceptables. Un enfoque para abordar las alternativas propuestas es realizar análisis exergonómicos de los sistemas energéticos implementados durante las operaciones para maximizar el uso de recursos. El presente trabajo de investigación evalúa el uso de un análisis exergoeconómico de un Transformador Térmico por Absorción (AHT, por sus siglas en inglés) para identificar áreas de mejora en la operación del sistema y, así, optimizar los parámetros esenciales para una mayor eficiencia tecnológica. Además, el estudio sugirió áreas de mejora en el generador (GE), economizador (EC) y absorbedor (AB) para futuros estudios, logrando eficiencias técnicas de hasta el 98% en ciertos componentes. Por lo tanto, considerar el costo como una medida de los recursos utilizados proporciona una visión profunda de los sistemas energéticos adoptados por la industria. Gracias a que la exergonomía considera los costos como una medida del consumo de recursos, este enfoque ofrece una visión integral de los sistemas energéticos adoptados por la industria. Estos resultados son relevantes para comprender el impacto potencial de integrar la eficiencia técnica, económica y ambiental en las prácticas de gestión energética dentro del sector industrial.

1. Introduction

In response to the growing concern regarding energy conservation and its economic ramifications for enterprises, many methods have been developed to integrate energy processes with accounting.

Therefore, it is important to ascertain the particular elements included in the principles of economic management. One of the elements is “cost”, which represents the number of resources necessary for the production of a service or product. In the context of energy accounting, however, “cost” is associated with the environmental impact of an energy process in addition to the resources generated and consumed during its operation [1].

An example of such energy accounting is exergoeconomics, which integrates the ideas of the Second Law of Thermodynamics (namely, the concept of exergy) with economic principles (specifically, the concept of cost) [2]. The adoption of this sort of method enables us to gain insights into the three key aspects of energy systems [3]: 1) the allocation of resources, 2) the amount of resources consumed, and 3) potential enhancements to the system's design and configuration.

The origins of this discipline (exergoeconomics) can be traced back to studies into the techno-economic improvement of various energy systems. El-SAyed and Evans [4] presented a first example in which they introduced a novel framework for analyzing the notions of "exergy" and "internal economy." Their research facilitated the resolution of complex energy challenges through an analysis of interconnected systems, thus offering an enhanced viewpoint on the effective use of renewable energy.

Regarding the performance optimization of a combined power plant, Tsatsaronis and Winhold [5] proposed a method that took into account cost-benefit analysis and technological efficiency. In order to demonstrate the internal economy and optimal performance of an energy system, Von Spakovsky [6] developed a model of it. This model included an engineering functional analysis that decentralized the process of optimizing or enhancing the components of a system, while also considering their isolated behavior.

Frangopoulos [7] applied a nonlinear programming approach to optimize a cogeneration system's technical and economic aspects. The main aim of the Specific Exergy Costing (SPECO), Exergy Economics Approach (EEA), First Exergoeconomic Approach (FEA), and Extended Exergy Accounting (EEA) methodologies is to assess the economic costs associated with the exergy efficiency of an energy system [8-11].

Current exergonomic analyses also use the determination of exergetic cost based on irreversibility criteria. For their application, Mendez et al. applied their hypothesis to a combined cycle of three levels of pressure. In this case, they calculate the cost of waste using the Gouy-Stodola theorem to assign those costs to the components that produce such waste. This new perspective identifies waste, enabling its reduction or disposal [18].

Various disciplines have employed exergonomic analysis to comprehend the effects of thermodynamics and economics. The study by Qi et al. [19] applies exergy accounting to analyze the agriculture industry in Hebei province, China, to comprehend its evolution in the region. Their analysis revealed reduced energy resource utilization; however, the sector remains reliant on substantial natural resource consumption. A key part of the study is the diminished investment in technology, infrastructure, and commodities. The results indicated a reduction in environmental damage that aligns with the implemented strategies.

Marques et al. [20] utilized exergy thermodynamics in a microcogeneration unit, which consists of an internal combustion engine and an ammonia-water absorption refrigeration system. This analysis revealed that the absorber component spent the largest exergy cost, whilst the electrical consumption of the pump exhibited the lowest cost within the refrigeration system. It also identified the generator, absorber, evaporator, and regenerator as areas for enhancement, which would facilitate improved overall efficiency.

Afterward, Valero and Lozano [12] introduced the Theory of Exergetic Cost (TEC), which addresses evaluating and optimizing energy systems via cost allocation. Hence, this paper showcases the use of the TEC on an Absorption Heat Transformer (AHT) to understand the expenses linked to energy conversion and the enhancement of the process. The primary arguments put forth are as follows:

a) Determine and measure the expenses related to the procedures inside the AHT.
b) Offer analysis on areas that might be enhanced in the energy process in order to achieve more optimization.
c) Use the TEC as a tool for assessing cost and efficiency concerns.

2. Experimental Setup

The Absorption Heat Transformer (AHT) is a type of heat pump, which has the ability to take advantage of the design heat of an industrial process or a low-quality source and bring it to a higher temperature in order to use it for a specific purpose [16].

The heat exchangers that make up the AHT are of different types, shapes and perform specific purposes: converting liquid to vapor (Evaporator), vapor to liquid (Condenser), producing thermal energy (absorber), and capturing waste heat (Generator).

The AHT studied in this article is built with two duplex components and an economizer: an Evaporator-Absorber (EV-AB) which works at high pressure, and a Generator-Condenser (GE-CO) which works at low pressure.

The AHT process hinges on an exothermic reaction triggered by the Lithium Bromide (LiBr) absorbent mixture. This reaction's heat output distills impure water introduced into the system.

Low thermal level waste heat (Q_{GE}) is added to vaporize the refrigerant from the weak solution (low concentration of the absorbent mixture). The vaporized refrigerant goes to the condenser where it condenses and delivers a quantity of heat (Q_{CO}) at low ambient temperature. The refrigerant leaving the condenser is pumped to the evaporator where it is evaporated by an amount of low thermal waste heat (Q_{EV}). Then the refrigerant vapor goes to the absorber where it is absorbed by the solution with a high concentration of absorbent coming from the generator, delivering an amount of heat at a higher temperature (Q_{AB}). Finally, the solution with a low concentration of the absorbent mixture returns to the generator, preheating the solution in the economizer, and beginning the cycle again [17].

For the analysis of this article, 5 experimental tests of the installed AHT were considered, which were taken under stable operating conditions. The operating parameters that the AHT allows to measure according to its limited instrumentation are: mass flow ($\dot{m}$), pressure (P), temperature (T), and concentration (X), which are shown in **Table 1**.

Table 1. Operation parameters of Absorption Heat Transformer.

Line	$\dot{m}$ (kg/s)	P (kPa)	T $(°C)$	X $(\% wt)$
1	0.000863-0.00145	6.46-8.22	233.00-399.00	0
2	0.000863-0.00145	6.46-8.22	29.42-33.26	0
3	0.0008-0.0009	24.92-34.27	33.53-38.41	0
4	0.00089-0.007	24.92-34.27	53.55-72.20	0
5	0.0054-0.017	81.9	83.23-86.20	49.69-52.61

6	0.0054-0.017	81.9	75.43-78.54	49.69-52.61
7	0.0054-0.017	81.9	74.31-77.05	49.69-52.61
8	0.004-0.016	81.9	70.21-76.52	52.22-55.54
9	0.004-0.016	81.9	78.59-82.73	52.22-55.54
10	0.004-0.016	81.9	75.42-79.88	52.22-55.54
A	0.12-0.13	81.9	83.00-88.55	0
B	0.12-0.13	81.9	79.97-85.25	0
C	0.144-0.146	81.9	30.52-35.76	0
D	0.144-0.146	81.9	34.74-40.56	0
E	0.12-0.14	81.9	30.52-35.76	0
F	0.12-0.14	81.9	72.02-79.89	0
G	0.03-0.05	81.9	93.92-96.95	0
H	0.03-0.05	81.9	96.95-99.61	0

There is a variation between the parameters shown in **Table 1** because, for each of the experimental tests, different initial operating conditions are considered, which make changes in the marked ranges.

3. Mathematical model

As is well-known, the amount of energy entering and leaving each component and the entire system can be determined through analysis based on the First Law of Thermodynamics. Nevertheless, this analysis needs to provide details regarding the energy quality or irreversibilities within the components and the system as a whole.

By performing energy balances on each main component of the system shown in **Figure 1**, **Equations 1-13** are obtained.

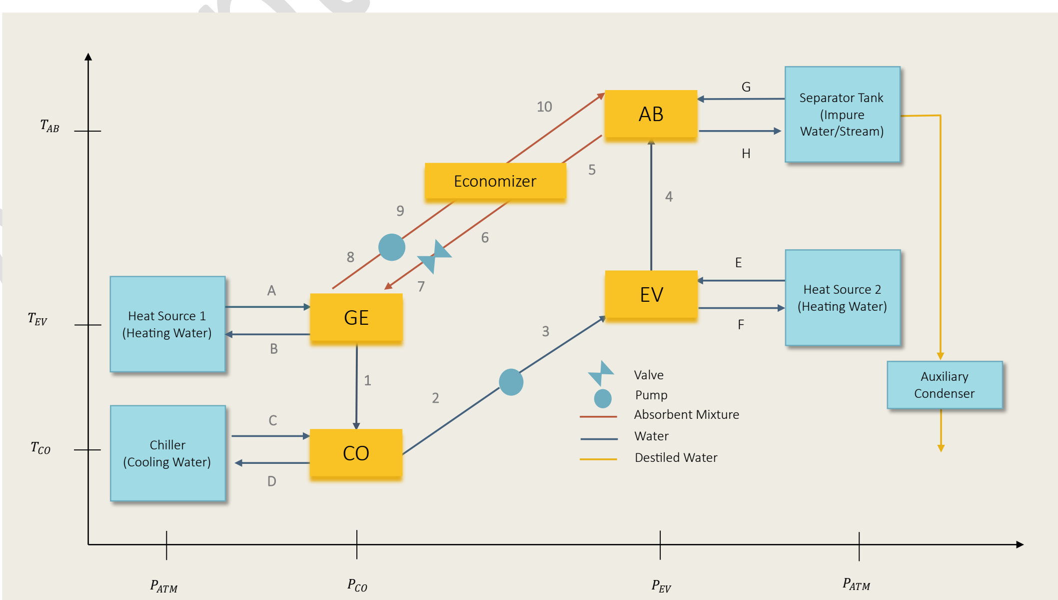

Figure 2. Schematic diagram of the AHT with dual components.

Generator

$$\dot{m}_7 = \dot{m}_1 + \dot{m}_8 \tag{1}$$

$$\dot{m}_7 X_7 = \dot{m}_1 X_1 + \dot{m}_8 X_8 \tag{2}$$

$$\dot{m}_1 (h_A - h_B) = \dot{m}_1 h_1 + \dot{m}_8 h_8 - \dot{m}_7 h_7 \tag{3}$$

Condenser

$$\dot{m}_1 = \dot{m}_2 \tag{4}$$

$$\dot{m}_{CO} (h_D - h_C) = \dot{m}_1 h_1 - \dot{m}_2 h_2 \tag{5}$$

Evaporator

$$\dot{m}_1 = \frac{Q_{EV}}{(h_4 - h_3)} \tag{6}$$

$$\dot{m}_{EV} (h_E - h_F) = \dot{m}_1 (h_4 - h_3) \tag{7}$$

Absorber

$$\dot{m}_5 = \dot{m}_4 + \dot{m}_{10} \tag{8}$$

$$\dot{m}_5 X_5 = \dot{m}_4 X_4 + \dot{m}_{10} X_{10} \tag{9}$$

$$\dot{m}_{AB} (h_H - h_G) = \dot{m}_4 h_4 + \dot{m}_{10} h_{10} - \dot{m}_5 h_5 \tag{10}$$

$$\dot{m}_H h_H = \dot{m}_L h_L + \dot{m}_V h_V \tag{11}$$

Auxiliary condenser

$$\dot{m}_I h_I + +\dot{m}_V h_V = \dot{m}_J h_J + \dot{m}_K h_K \tag{12}$$

Economizer

$$\dot{m}_6 h_6 + \dot{m}_8 h_8 = \dot{m}_7 h_7 + \dot{m}_9 h_9 \tag{13}$$

Where,

h represents enthalpy.

4. Methodology: Theory of Exergetic Cost

One of the exergetic models that use cost as a basis to determine the origin of the production process and quantifies it is the TEC. Dr. Antonio Valero's introduction of this model aimed to allocate expenses by the thermodynamic principle of exergy. The TEC establishes that with higher irreversibility (I), the system will always consume a greater number of resources from the plant (F) as long as the products (P) remain constant. Therefore, it is necessary to establish the relationship between the variation in local irreversibilities (ΔI) and the increase in consumed resources [12]. In a more general sense, the entire procedure is illustrated in **Figure 2**.

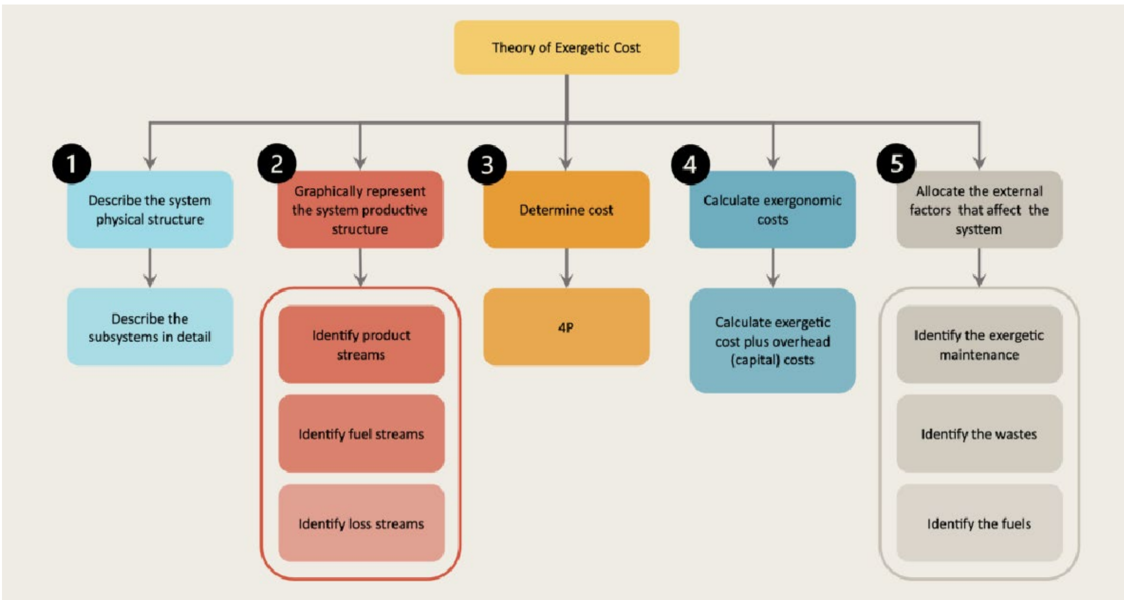

Figure 1. TEC procedure.

To implement this model within an energy system, the information required to construct the exergetic model is important. This information consists of [3]:

1. The physical structure. Offers a detailed description of the physical elements and their interconnections, encompassing boilers, turbines, heat exchangers, pumps, and other related components—**Figure 3**.

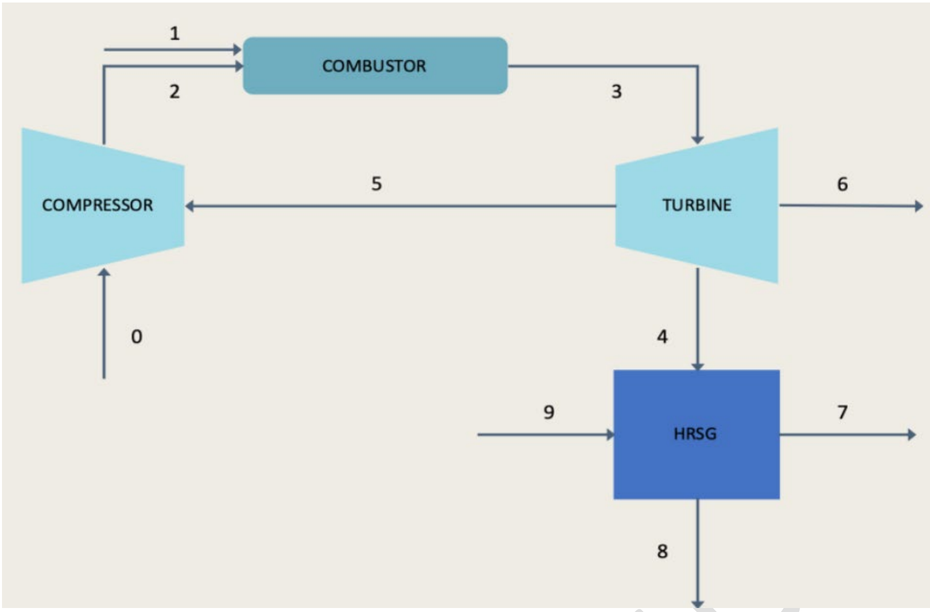

Figure 3. Physical structure of a cogeneration plant [12].

2. Thermodynamic model. The interplay of each mass flow stream, heat, and work within the plant's physical structure is characterized by a series of equations, specifically the mass, energy, and entropy (s) balances. **Equation 14** is used to compute the physical exergy (e) of a stream (i) for a given state.

   $$e_i = h_i - h_0 - T_0(s_i - s_0) + \sum_i(\mu_i c_i - \mu_0 c_0) \quad (14)$$

   Where,
   h_0 y T_0 they are properties that are taken from a selected reference state.
   $\sum_i(\mu_i c_i - \mu_0 c_0)$ It constitutes chemical exergy.

3. Economic model. The cost of the equipment, measured in dollars per hour, is determined by multiple variables such as size, materials, operational range, annual working hours, inflation rates, installation cost, and maintenance expenses. **Figure 4** also takes into account the commercial prices of fuels such as natural gas and coal, measured in US dollars per kilowatt-hour (US$/kW·h).

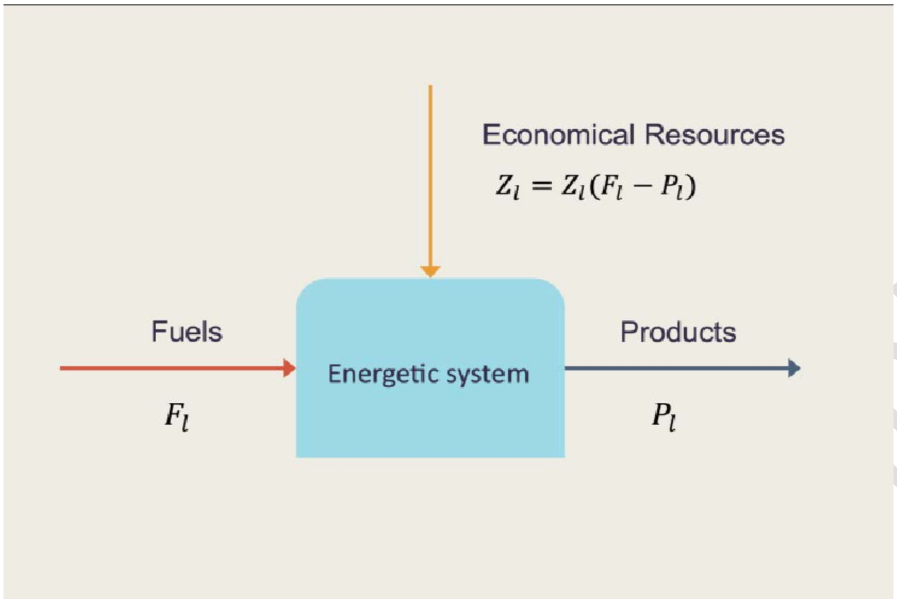

Figure 4. Economic resources scheme.

4. The productive structure of the plant. As one of the model's central concepts, this relates to the rationale behind the tangible placement of the system's components. In other words, it is a visual depiction of how resources are distributed within the system.

According to Valero, the goal of doing these analyses using the proposed model is to achieve efficiencies in both the components and the overall operation of the system. The efficiencies (η_{ex}) mentioned above can be used to measure the quality of the process, as indicated by **Equation 15**.

$$\eta_{ex} = \frac{P}{F} = \frac{Product}{Fuel} \quad (15)$$

Valero [12] represents his model in what he calls "Uniqueness matrix" as can be seen in **Figure 5**, which makes it possible to calculate both the exergetic and economic costs of an energy system.

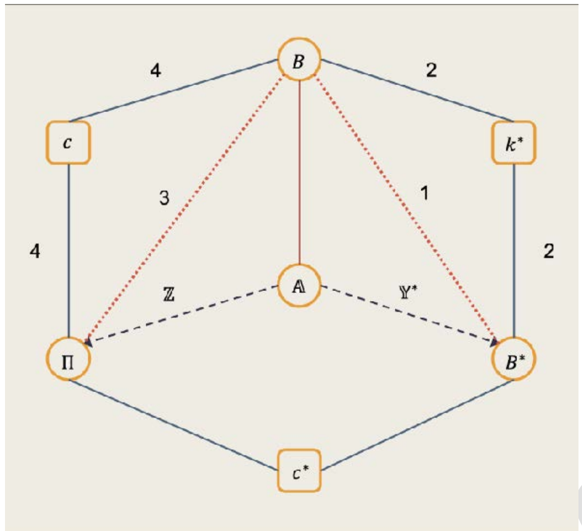

Figure 5. Uniqueness matrix [12].

Where,

(1) $B^* = \mathbb{A}^{-1} * \mathbb{Y}^*$, with B^* being the representation of the exergy cost (kJ), $\mathbb{A}^{-1}$ being the cost matrix, and $\mathbb{Y}^*$ being the vector of external allocations to the system.

(2) $k_i^* = B_i^*/B_i$ where k_i^* is the unit exergy cost (kJ/kJ), B_i is the current exergy.

(3) $\prod = \mathbb{A}^{-1} * \mathbb{Z}$ where $\prod$ is the exergonomic cost and Z are all external economic allocations, such as maintenance expenses, waste expenses, and fuel expenses.

(4) $c_i = \prod / B_i$, where c_i is the exergonomic unit cost for each unit of exergy.

To carry out the cost allocation procedure, Valero [12] is based on 4 propositions and represented by **Equations 16-17**:

P1: The exergetic cost is a conservative property, meaning that the cost of the inputs is equal to the cost of the outputs for each component.

$$A * B^* = 0 \qquad (16)$$

P2: The exergetic cost will be related to the system limits. That is, the exergetic cost of each flow that enters the plant is equal to its exergy.

$$B_i^* = B_i \qquad (17)$$

P3: If a component's fuel stream has an output stream that is not exhausted, the exergetic unit cost of the component remains the same as its input stream.

P4a: If a component's product stream has many flow outlets, the unit exergy cost will be assigned to all of them.

P4b: The total expenses spent during the production process, that involve the expenses related to waste, need to be assessed in relation to the cost of the end products.

5. Results

Once the TEC methodology was applied to the AHT and based on the physical structure outline shown in **Figure 6,** the following notable results were obtained.

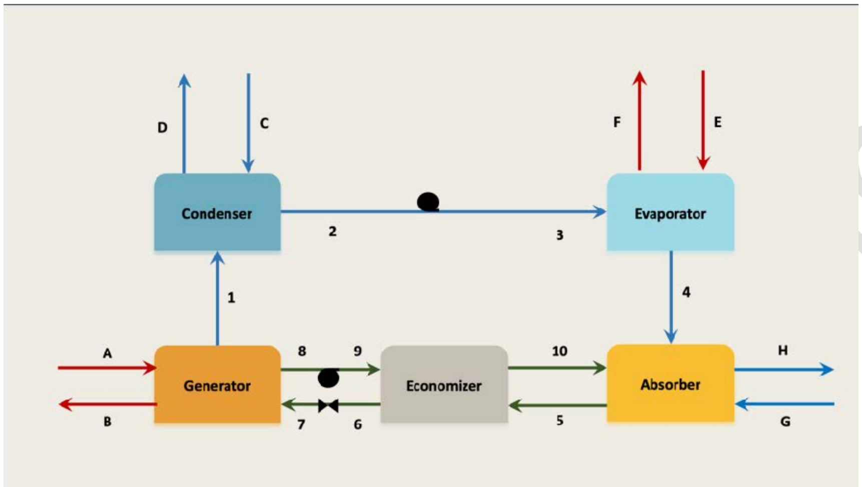

Figure 6. Physical structure of the AHT.

Among the 5 tests analyzed in this study, the system exhibits an exergetic efficiency ranging from 30% to 50% (see **Figure 7)**. This is due to the fact that the subsystems or components of the GE, AB, and EC show low efficiencies during their operation because these components contain the lines that carry the LiBr mixture. In other words, the destruction of exergy in these components is greater than the production of exergy.

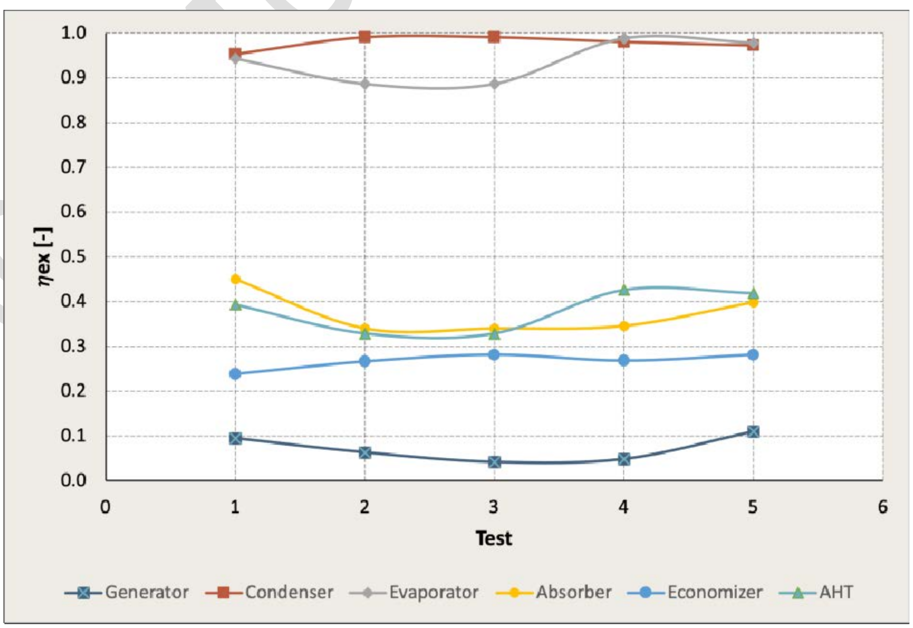

Figure 7. Efficiency exergetic of the AHT.

Particularly, the evaporator stands out as the component with the highest exergetic efficiency, with efficiencies ranging from 89% to 98.8%. On the other hand, the generator has a lower exergetic performance, meaning it has higher irreversibilities in its process, causing most of the useful energy produced in it to be almost immediately destroyed.

This is corroborated by **Figure 8**, which shows the exergetic unit consumption of AHT. It is observed that the highest energy consumption occurs in the devices mentioned. The GE consumes between 8 and 15 kW for each unit of exergy produced, demonstrating that the start of the process within the AHT requires more resources to continue the energy process.

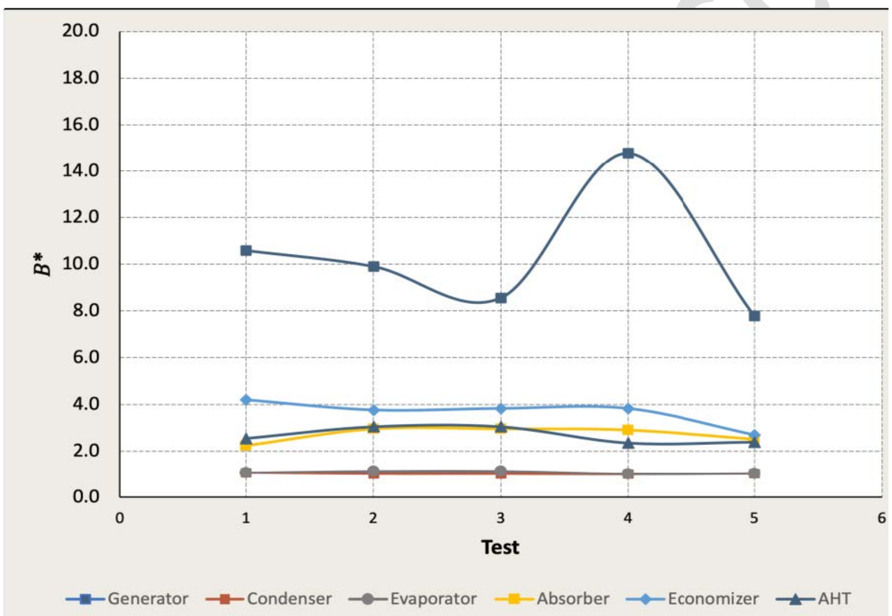

Figure 8. Exergetic unit cost of the AHT.

From an exergetic perspective, the fuels for the plant's operation consume between 45 and 90 US$/kW. On the other hand, the products generated within the system consume between 15 and 45 US$/kW. Specifically, the generator, economizer, and absorber consume most of the fuels necessary for the AHT's operation, as shown in **Figure 9** and **Figure 10**.

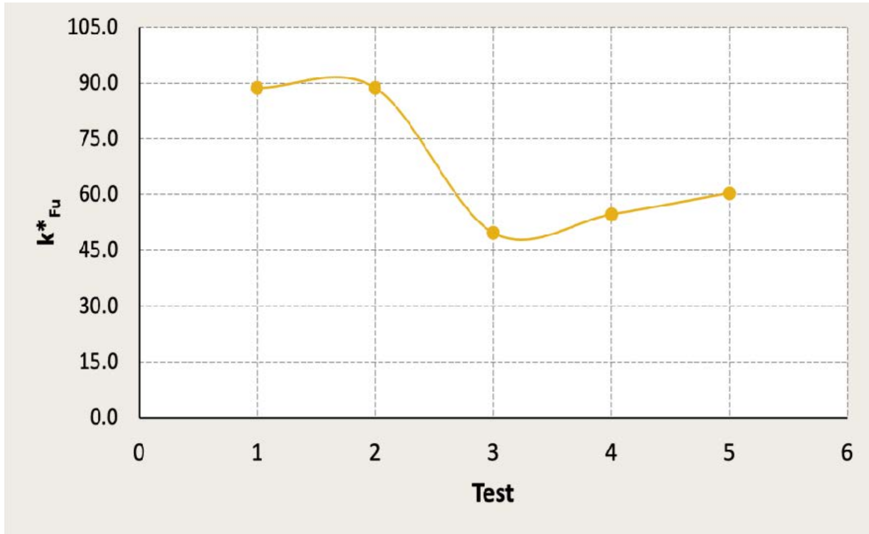

Figure 9. Exergonomic cost of fuels.

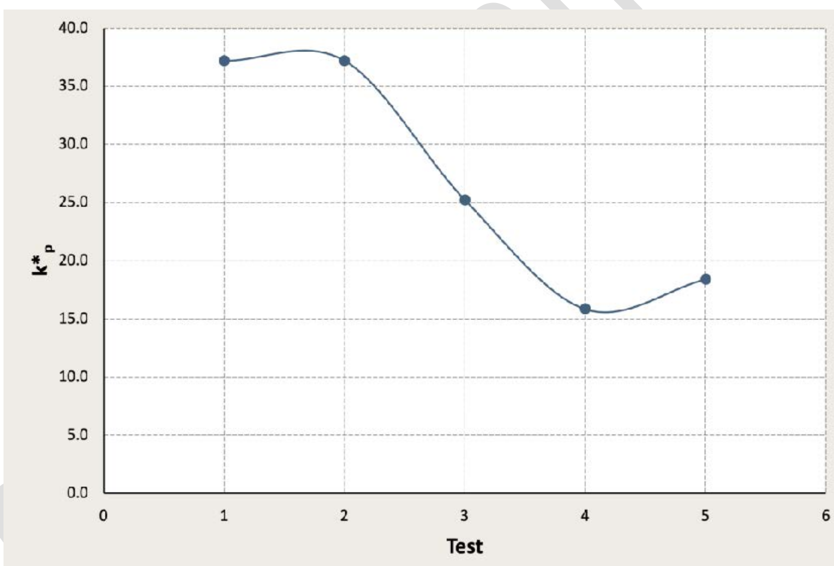

Figure 10. Exergonomic cost of products.

Overall, the exergetic profitability ranges from 29% to 50%, understanding that there is a positive relationship between the system's investment and its capacity for efficient work in energy production and transformation. It is important to note that the exergetic profitability test is performed for the system as a whole since it is considered a comprehensive investment project shown in **Figure 11**.

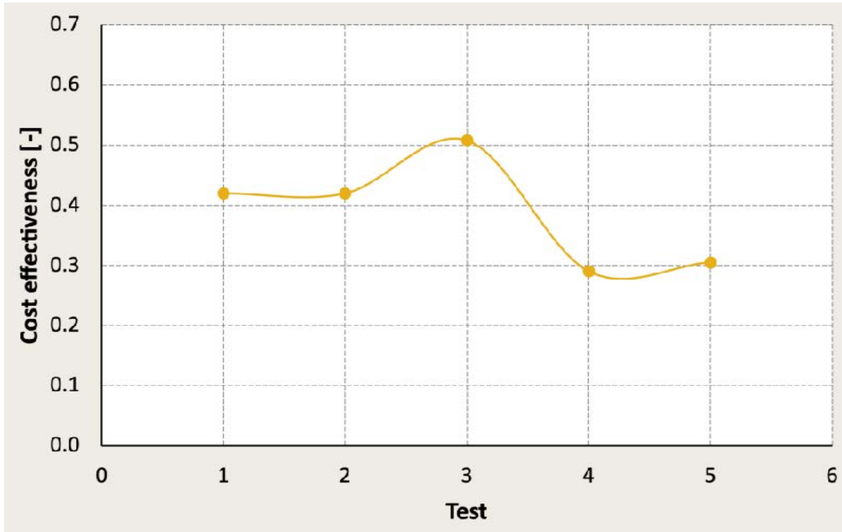

Figure 11. Exergonomic cost-effectiveness.

6. Conclusions

The use of the TEC technique enabled a thorough assessment of the system through the accurate allocation of expenses and the identification of resource depletion and areas of inefficiency. Furthermore, this program offers pertinent information regarding the system, including not just exergetic efficiency but also the associated expenditures entailed in the energy process.

The study emphasized notable disparities among the key constituents of the AHT, revealing that EV exhibited the highest level of efficiency, ranging from 89% to 98.8%, while GE had the lowest level of efficiency, ranging from 4.1% to 10.9%. Regarding the consumption of exergy, it has been determined that the components GE, EC, and AB exhibit the highest resource utilization levels within the process, with power consumption ranging from 8 to 15 kW, 2.7 to 4.2 kW, and 2.2 to 2.9 kW, respectively. Hence, these aspects might be deemed worthy of further enhancement in further research endeavors.

Despite its ability to enhance the Coefficient of Performance (COP) of the AHT, the EC was shown to have a significant energy and economic resource consumption, rendering it exergonomically impractical based on the conducted analysis. It is recommended to perform this study in the absence of this equipment in order to achieve a full evaluation and comparison of the outcomes.

The current research provides an economic analysis that identifies the components with the highest costs, especially those that require the greatest amount of energy resources while evaluating exergetic efficiency. On the other hand, the direct influence of exergy consumption on operating costs is highlighted, indicating that certain components, especially the generator and the condenser, are fundamental aspects in which improvements could reduce expenses. The present study has the ability to guide future investments toward a more efficient cost structure by optimizing the energy performance and economic viability of cogeneration and trigeneration systems. This is achieved by relating these costs to the exergetic efficiency of each component.

Declaration of competing interest

We declare that we have no significant competing interests including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

Acknowledgement

In carrying out this investigation, the authors express gratitude to CONAHCyT. They also express gratitude to UAEM-CIICAp for facilitating the execution of essential experimental tests and serving as a cornerstone of applied science. Notably, this work was presented during the VI Ibero-American Congress of Smart Cities.

Author contributions

L. Alvarez: Exergonomic Analysis and interpretation. M. J. Bello-Guadarrama: Energy analysis and interpretation. N. I. Ortega-Mojica: System and data collector description. J. Delgado-Gonzaga: Experimental development. A. Parrales: Argumentation of the problem and interpretation of data. J. A. Hernández: Conceptualization and provided statistical data analysis tools. D. Juárez- Romero: Experimental methodology design.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

References

[1] C. Torres and A. Valero, “The exergy cost theory revisited,” Energies, vol 14, 1594, 2021.
[2] G. Tsatsaronis and J. Pisa, “Exergoeconomic evaluation and optimization of energy systems. Application to the CGAM problem,” Energy, vol. 19, pp 287-32, 1994.
[3] A. Valero et al., “Theory of Exergy Cost and Thermo-ecological Cost,” Thermodynamics for Sustainable Management of Natural Resources, W. Stanek (ed), Springer Cham, 2017, pp.167-202.
[4] M. El-Sayed and B. Evans, “Thermoeconomics and the design of Heat Systems,” Journal of Engineering for Gas Turbings and Power, vol. 92, no.1, pp.27-35, 1970.

[5] G. Tsatsaronis and M. Winhold, "Exergoeconomic analysis and evaluation of energy-conversion plants—I. A New General methodology," Energy, vol. 10, no. 1, pp. 69-80, 1985
[6] M. Von Spakovsky, "A Practical Generalized Analysis Approach to the Optimal Thermoeconomic Design and Improvement of Real-world Thermal Systems," Ph.D dissertation, Georgia Institute of Technology, USA, 1986.
[7] C. Frangopoulos, "Application of the thermoeconomic functional approach to the CGAM problem," Energy, vol. 19, no. 3, pp.323-342, 1994.
[8] A. Lazzaretto and G. Tsatsaronis, "SPECO: A systematic and general methodology for calculating efficiencies and costs in thermal systems," Energy, vol. 31, no. 8-9, pp. 1257-1289, 2006.
[9] R. Gaggioli and W. Wepfer, "Exergy economics: I. Cost accounting applications," Energy, vol. 5, pp. 823-837, 1980.
[10] G. Tsatsaronis, "Thermoeconomic analysis and optimization of energy systems," Progress in energy and combustion science, vol. 19, pp.227.257, 1993.
[11] E. Sciubba, "Beyond thermoeconomics? The concept of extended exergy accounting and its application to the analysis and design of thermal systems," Exergy, an international journal, vol. 1, no. 2, pp. 68-84, 2001.
[12] M. Lozano et al., "Theory of exergetic cost and thermoeconomic optimization," in Energy systems and ecology, J. Szargut (ed), Cracov, Poland: OPAKOWR, 1993, pp. 339-350.
[13] S. Seyyedi, "A New Method for the Residues Cost Allocation and Optimization of a Cogeneration System Using Evolutionary Programming," Journal of Applied Dynamic Systems and Control, vol. 2, pp. 48-60, 2019.
[14] L. de Araújo *et al.*, "On the effects of thermodynamic assumptions and thermoeconomic approaches for optimization and cost allocation in a gas turbine cogeneration system,", Journal of the Brazilian Society of Mechanical Sciences and Engineering, vol. 42, no. 323, 2020.
[15] P. Rosseto de Faria *et al.*, "The environment as a thermoeconomic diagram device for the systematic and automatic waste and environmental cost internalization in thermal systems," Renewable and Sustainable Energy Reviews, vol. 171, 2023.
[16] J. Pospisil and M. Balas, "Working Characteristics of Small-scale Absorption Unit with Two-Cylinder Design," Wseas Transactions on Heat and Mass Transfer, Vol. 3, pp. 77-86, 2009.
[17] I. Smith, "Bombas de calor por absorción,". Seminario sobre conservación de energía y aplicaciones industriales y comerciales de las bombas de calor, Mexico, 1990.
[18] LMH Denise, TGE Vicente, CH Sergio, SP Martín, LA Teresa, LL Raúl, "An irreversibility-based criterion to determine the cost formation of residues in a three-pressure-level combined cycle". Entropy 22.3 (2020) 299.

[19] H. Qi, Z. Dong, X. You, Y. Li, Y. Zhao, and X. Sun, "Extended exergy accounting for assessing the sustainability of agriculture: A case study of Hebei Province, China," Ecological Indicators, vol. 150, p. 110240, Apr. 2023, doi: 10.1016/j.ecolind.2023.110240.

[20] A. Marques, Y. Benito, A. Ochoa, and M. Carvalho, "Thermoeconomic analysis of a microcogeneration system using the theory of exergetic cost," Thermal Science, vol. 27, no. 5 Part A, pp. 3579–3589, Jan. 2023, doi: 10.2298/tsci220806023m.