A Review on The Panorama of Combined Heating, Cooling, and Power in Brazil

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Abstract: **Combined heating, cooling, and power (CHCP) systems are distributed power generation models that have several advantages over conventional, centralized power generation. A review of the panorama of CHCP in Brazil is presented herein, based on experimental and analytical studies. The focus of this research is to map and point out, through bibliographic research, the potential for CHCP in Brazil, according to the application and fuel employed. A bibliographic search was carried out on scientific papers and works published in scientific journals (databases: Periodicos Capes and Google Scholar) in the period 2010 – 2020. As a result, few studies were found on the subject. Despite the advantages of CHCP over conventional energy systems, there are barriers in Brazil for the technical feasibility of CHCP, such as the high capital costs, lack of subsidies, and tax incentives.**

I. Introduction

Integrated energy systems, such as CHCP, benefit from the energy integration of the processes in their equipment, extracting the maximum thermodynamic potential from the consumed resources [5]. The term trigeneration is often employed to refer to the combined production of three energy services – therefore, the terms "combined heating, cooling, and power" (CHCP) and "trigeneration" are used interchangeably. The concepts of combined production of energy services (e.g., polygeneration, cogeneration, and trigeneration) are directly related to DG. Additional equivalent term: "combined cooling, heating, and power" (CCHP). More comprehensive terms include polygeneration and integrated energy systems (IES) [3]. Figure 1 shows a general scheme for a CHCP system, fundamentally based on the coupling of a cogeneration module (prime mover) to an absorption chiller that produces cooling from the harnessed heat. Storage tanks can be inserted between the heating and cooling units and the final user.

There is no data on combined heat and power (CHP) or CHCP within the Brazilian energy matrix, but according to the Brazilian Association of Cogeneration Energy Industry [12], there was 18.5 GW of CHP installed in Brazil up to October 2019 (approximately 11% of the national generation park). Most of the energy systems used sugarcane biomass as fuel, followed by natural gas [13]. Figure 2 shows the progression in the development of the cogeneration market in Brazil.

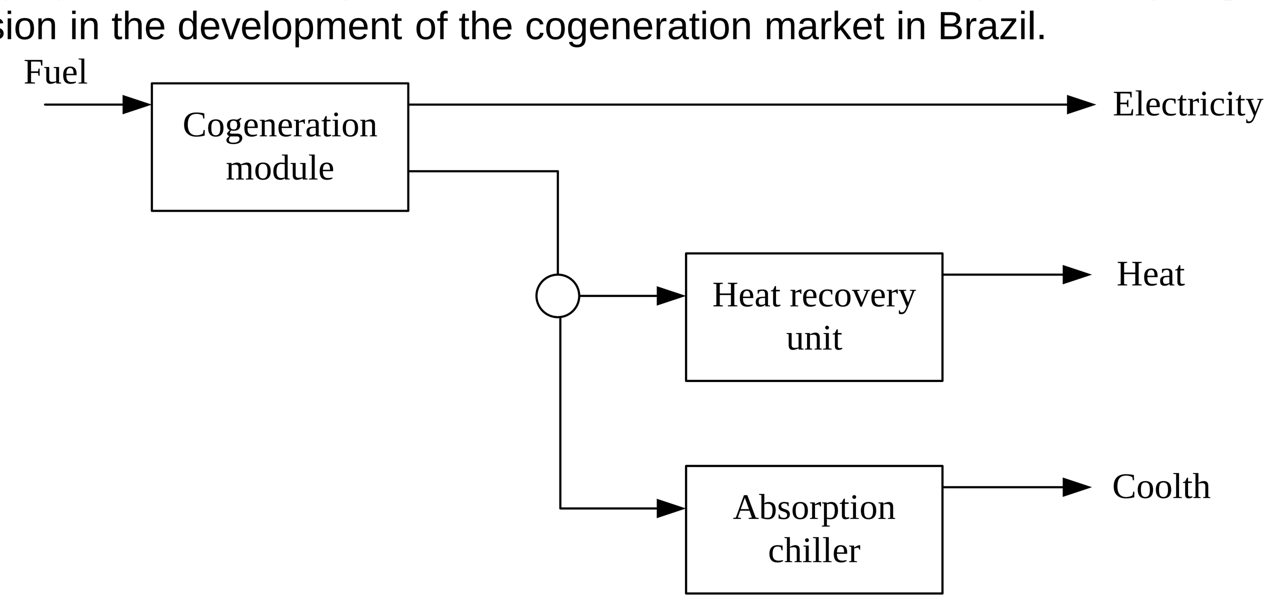

Figure 1 – General scheme of a combined heating, cooling, and power system.

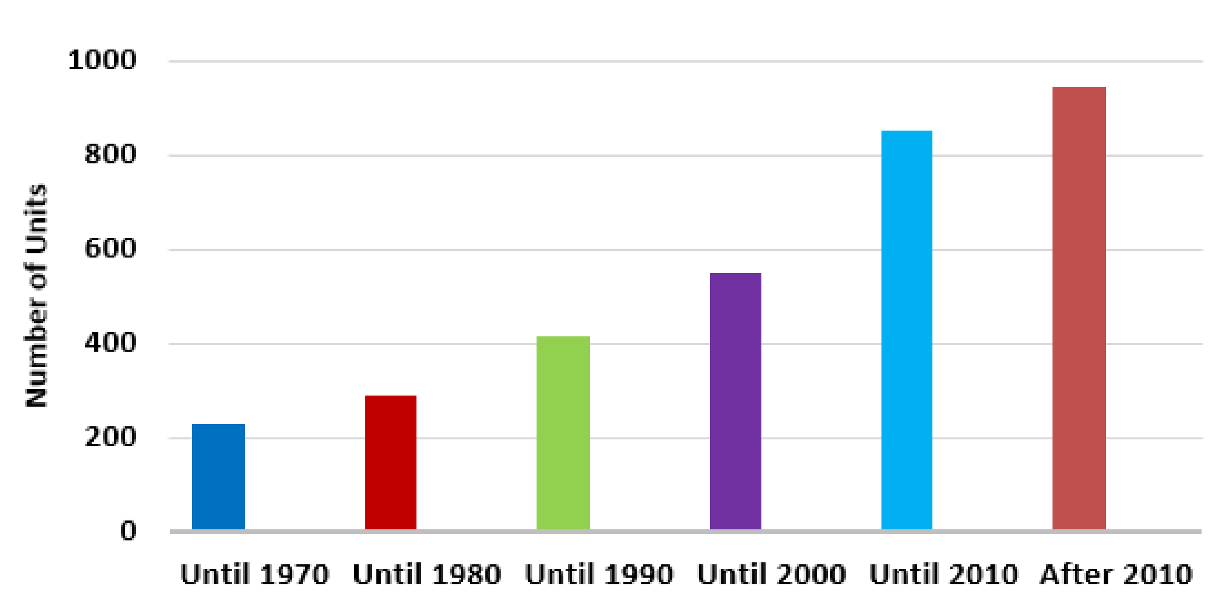

Figure 2 – Cogeneration units in operation.

The objective of this study is to carry out a systematic literature review, to identify studies that addressed CHCP systems in Brazil, listing the sectors involved and fuels used, presenting a panorama of studies that have been developed over the past ten years. The overarching aim is to verify the feasibility of implementing these systems, and what are the most favorable conditions.

II. Methodology

A bibliographic research is presented herein, focusing on research papers and studies (MSc. and PhD. Theses) published between 2010 and 2020. The databases consulted were *Periódicos CAPES* and Google Scholar, using the descriptors: Trigeneration, CHCP, Brazil, Combined heating, cooling and power, as well as their synonyms and equivalents in Portuguese, in various combinations. Databases of Brazilian associations were also consulted: Energy Research Company (EPE), Association of the Energy Cogeneration Industry (COGEN), and Ministry of Mines and Energy (MME).

Experimental and simulation studies were included, which aimed to evaluate the performance of CHCP systems in Brazil, considering the fuels used in the plants and the sectors or locations of application. The first step of the review consisted of reading the titles and abstracts of all documents identified in the searches (manual and in databases), selecting only those that focused on the subject and type of study. Duplicated studies were removed. The second step of the review encompassed the full reading of the documents, with extraction of relevant data. Manual search was also carried out by reading the references listed in the studies, for possible inclusion of other studies that were not identified initially in the electronic search.

III. Results

The studies were then screened by reading the titles and abstracts, and all 18 publications were considered relevant to the research scope established, fulfilling the inclusion and exclusion criteria. The studies were published between 2010 and 2020, with 10 experimental studies and eight simulations. There were five MSc. theses, one PhD. thesis, and 12 research papers. Regarding the geographic location of studies, nine were carried out in the Southeast region, four were carried out considering the Northeast region, one considered the South region, one considered the North region, one did not specify its location within Brazil, and two did not specify neither the consumer center or the location. Tables 1 and 2 shows the summary of the panorama of the studies covered, highlighting the object of study and the fuel used for experimental, modeling and simulation studies.

Table 1. Panorama of experimental studies.

Reference	Type of Study	Study Object	Fuel
Marques et al., 2020	Energy, exergy, and exergoeconomic assessments	University laboratory + adjacent biodiesel production plant (Northeast Brazil)	Natural gas
Alcântara et al., 2019	Economic and energy analysis	Ice cream industry (Brazil)	Natural gas
Cavalcante et al., 2017	Energy analysis of three configurations	University laboratory (Northeast Brazil)	Natural gas
Pérez et al., 2015	Energy and exergy analysis	Laboratory setup (Southeast Brazil)	Liquefied petroleum gas
Lovati, 2015	Optimization of operation (exergoeconomics)	Research center (Southeast Brazil)	Natural gas/Diesel oil
Silva, 2015	Thermoeconomic analysis and optimization of process utility consumption(pinch analysis)	Soluble coffee industry (South Brazil)	Coffee and woodchip biomass
Espirito Santo, 2014	Performance simulation and evaluation	Hospital (Southeast Brazil)	Natural gas
Rocha et al., 2012	Energy analysis of two configurations	Laboratory setup (Southeast Brazil)	Natural gas
Jaramillo, 2011	Optimization of configurations (Genetic algorithm)	Dairy industry, hospital, and beverage industry (Southeast Brazil)	Natural gas
Preter et al., 2010	Energy analysis: theoretical vs. experimental results	Laboratory setup (Southeast Brazil)	Natural gas

Table 2. Panorama of modeling and simulation studies.

Reference	Type of Study	Study Object	Fuel
Leite, 2019	Exergoeconomic assessment	Resort hotel (Northeast Brazil)	Diesel
Pina et al., 2018	MILP-based optimization with Pinch analysis	Hospital (Southeast Brazil)	Natural gas
Givisiez et al., 2018	Economic analysis (energy tariffs): trigeneration vs. conventional system	Hospital (Southeast Brazil)	Natural gas
Givisiez, 2018	Economic analysis: trigeneration vs. conventional system	Hospital, residential building, university building, and hotel (Southeast Brazil)	Natural gas
Ochoa et al., 2017	Technical and economic feasibility	Unspecified consumer center and location	Natural gas
Silva, 2017	Thermodynamic and environmental analysis	Unspecified consumer center and location	Diesel oil/ Biodiesel
Malagueta et al., 2014	Technical feasibility based on thermal parity	Hospital (Northeast Brazil)	Natural gas
Cruz et al., 2011	Feasibility analysis	Thermoelectric power plant (North Brazil)	Diesel oil

IV. Conclusion

This review study demonstrate how trigeneration systems have been explored so far in Brazil, considering the period 2010-2020. Few Brazilian studies were identified on trigeneration. Experimental studies are concentrated in research, teaching and development institutes. The configurations of the trigeneration systems varied according to their different applications, which included hospitals, industrial facilities, and residential and university buildings. The majority of studies utilized natural gas as the main fuel. Although the Brazilian energy matrix is predominantly renewable and Brazilian energy policies favor advances in the use of biomass, wind and solar photovoltaic energy, these resources are still underexploited and were not expressive in the results herein obtained.

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