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ARTÍCULO DE INVESTIGACIÓN

Makariza Co-generation Power Plant - Environmental Feasibility Study

Central de Cogeneración Makariza - Estudio de Viabilidad Ambiental

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Abstract

This article studies the possibility of electrical energy generation using distributed generator in Makariza Company. According to the demand of heat in this company, the generators used in this study are simultaneous production of electricity and heat. According to the demand of electric, thermal load consumed by the company and the climate of Colombia province and according to the technical specifications of electricity and heat generation technologies in the world, the best technology is selected. Finally, energy saving and environmental pollution will be analyzed. The analysis shows that the use of the system of simultaneous production of electricity and heat in the company helps to save energy and also to reduce environmental pollution.

Keywords:

Feasibility study, Distributed generation, Simultaneous generation of electricity and heat, Makariza Company, environmental pollution

Resumen

Este artículo estudia la posibilidad de generación de energía eléctrica mediante generador distribuido en la empresa Makariza. De acuerdo a la demanda de calor en esta empresa, los generadores utilizados en este estudio son de producción simultánea de electricidad y calor. De acuerdo a la demanda de carga eléctrica, térmica consumida por la empresa y el clima de la provincia de Colombia y de acuerdo a las especificaciones técnicas de las tecnologías de generación de electricidad y calor en el mndo, se selecciona la mejor tecnología. Finalmente se analizará el ahorro energético y la contaminación ambiental. El análisis muestra que el uso del sistema de producción simultánea de electricidad y calor en la empresa ayuda a ahorrar energía y también a reducir la contaminación ambiental.

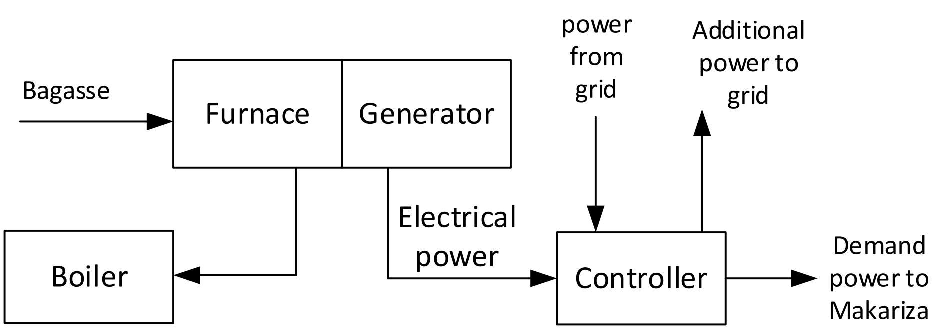
Palabras clave:

Estudio de viabilidad, Generación distribuida, Generación simultánea de electricidad y calor, Empresa Makariza, Contaminación ambiental.

Introduction

Due to the expansion of population and increasing energy consumption in recent years, various researches have been done to use distributed generation (DG) generators in the domestic sector and large administrative, scientific centers and etc. to provide the required energy in these sectors (Andoni, Robu, Früh, & Flynn, 2017; Bulatov & Kryukov, 2017; Odetayo, MacCormack, Rosehart, & Zareipour, 2017; van der Walt, Bansal, & Naidoo, 2018). The benefits of these power plants are lower initial energy consumption, reduced energy costs, reduced government responsibility for building the power plant and even the sale of electricity to the grid, and reduced environmental pollution. Due to the use of DG generators near load centers, transmission losses in these power plants are generally low (Al-Maghalseh, Odeh, & Saleh, 2017). Due to the low efficiency of these power plants compared to conventional power plants, in order to increase their efficiency and also use their heat, only the use of co-generators of electricity and heat has a technical and economic justification. The main components of this type of power plant are a primary power generator, electric power generator, heat recovery converter and hot water storage tank, which are shown in Figure 1. Co-generating power plants have the highest efficiency in energy and fuel consumption. For example, the average efficiency of a power generator is about 35% and the average efficiency of a boiler is 90% (Lisin, Shuvalova, Volkova, & Strielkowski, 2018). While a Combined Heat and Power (CHP) system with the production of both of these products has an efficiency of more than 85% (Arabkoohsar, 2020). Therefore, the efficiency of electrical generation part is about 35% and its thermal efficiency is about 50%.

Figure 1. Proposed CHP scheme for Makariza



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In the following, using the technical specifications and technologies of CHPs, the technical analysis of the use of these power plants and the type of generator used according to the climate of Makariza location (Bucaramanga) will be discussed. In addition, the amount of energy savings and the amount of reduction of environmental pollution in comparison with conventional power plants will be analyzed.

A brief look at CHP systems

By increasing awareness of the benefits of the co-generation power plants, the incentives to install these systems in various scientific, industrial, commercial and other applications have increased. The main characteristics of an ideal CHP system are the need for heat, stable and constant load patterns of thermal and electrical energy, and the long operating hours of the demand (Beiron, Montañés, Normann, &

Johnsson, 2020). The most common structures of cogeneration include gas turbines, piston engines, and micro-turbines (Ferreira, Teixeira, Teixeira, & Nebra, 2021). Gas turbines have high reliability, high-energy heat and low investment cost to generate output power (Wegener, Malmquist, Isalgué, & Martin, 2018). Gas turbines can operate permanently at low loads. In these systems, it is possible to use different fuels and it is even possible for a unit to run on multiple fuels, but if the unit is a gas burner, the pressure of the gas used must be high (Lion, Vlaskos, & Taccani, 2020). Other disadvantages of these systems are their limited production capacity and the need for long overhaul periods (Sung, Kim, & Kim, 2017). These engines also have advantages such as the ability to work with low-pressure gases, operating with several types of fuel including renewable sources. Micro-turbines are high-speed power generation systems with turbines, compressors, and generators. Micro-turbines are smaller than conventional reciprocating engines and have lower maintenance costs (Chahartaghi & Baghaee, 2020).

Electricity and heat demand

Knowing the real needs of the consumer unit for electricity and heat has a great impact on choosing the right size of CHP and how to use it. A CHP system is desirable in that it is active for at least 4,500 hours throughout the year (acceptable for micro-CHP sizes up to 3,000 hours) and as long as it can be on continuously and not disconnected and reconnected. This initial criterion is so effective in choosing the size of the CHP that non-observance of it imposes additional costs on the user, both for the purchase of the device and for maintenance. Usually the CHP system is not used alone, ie only CHP is not considered to meet all the needs of the unit. In terms of power generation, CHP is used when the cost of electricity generated is affordable compared to electricity purchased from the grid. Since it is possible to sell surplus electricity generated by CHP to the electricity grid, therefore the main criterion in choosing the size of CHP is a single heat dissipation, so as not to produce excess heat, but on the other hand, power consumption should not be less than 50% of the nominal load of the system because this issue leads to a sharp drop in efficiency. Generally, the main demand of electricity in the company is for use in lighting systems, office equipment, cooling systems, workshops and laboratories, and the demand for heat to produce hot water is required by the company. Generally, to choose a CHP system, the following must be clearly identified in order for the system to be profitable.

- Electricity and heat load profile required daily and annually, which shows the maximum, minimum and average electrical and thermal power required.
- Fuel price and its transportation and maintenance costs.
- It is possible to buy and sell electrical and thermal power. Since there is no heating network, the possibility of buying and selling heat is limited to the place of consumption.

In the following, we will deal with the amount of electricity and heat load required by the company.

Demand of electric charge

By examining the power consumption curves of the company during a year in the Figure 2, Figure 3, Figure 4 and Figure 5 which show the amount of electricity consumption for intermediate hours, low load, high load and average monthly consumption, respectively, which is the amount of electricity consumption in the months of the year due to the hot and dry climate of the province. Furthermore, the hours or company holidays are different and by examining the company equipment and also to respond to company development plans and increase the demands in the future, the company's electricity consumption is about 100 to 120 kwh taken into consideration.

Heat to electricity ratio

The heat generated in the CHP system must correspond to the amount of heat required by the company. For this reason, in choosing the correct capacity of the cogeneration system and heating, it is necessary to know the ratio of heat demand to electricity. Due to the difference in heat demand in cold and hot seasons according to the climate of province, in this study, the amount of heat demand for hot water is provided by CHP system and heat demand for space heating in cold seasons is provided by a support boiler. By examining the boiler and water heaters used to supply hot water used in the company, the amount of heat load for hot water is about 648500 btu/hr.

Figure 2. Load diagram in normal demand situations

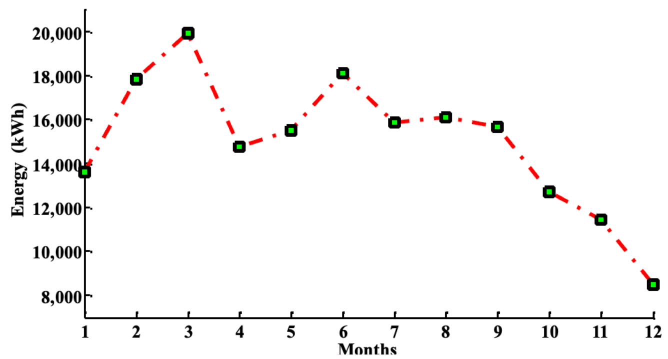

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Figure 3. Load diagram in low demand situations

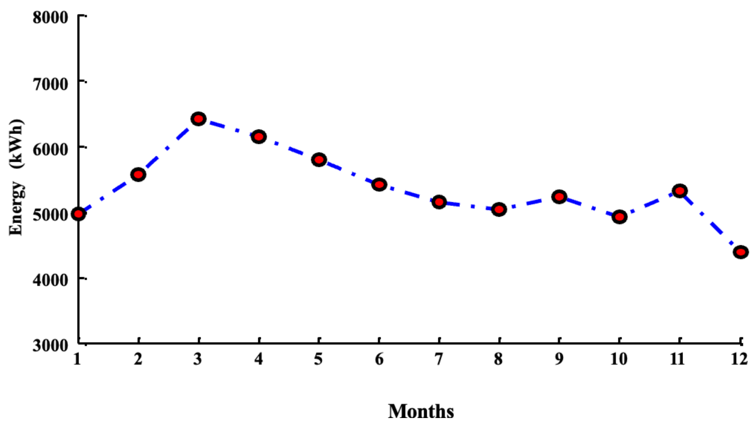

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Figure 4. Load diagram in high demand situations

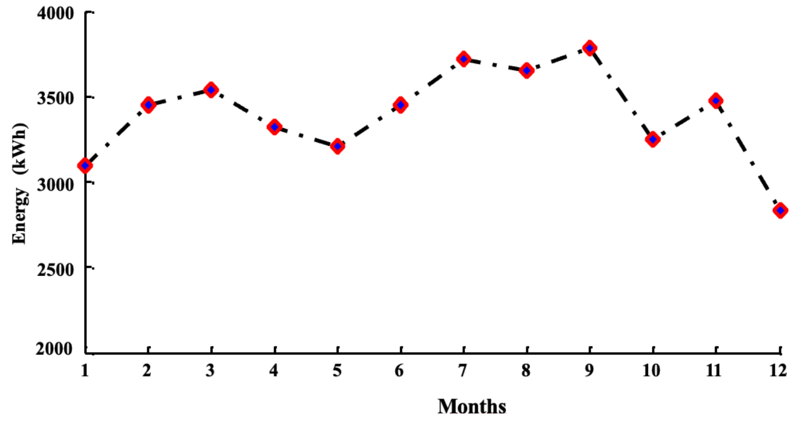

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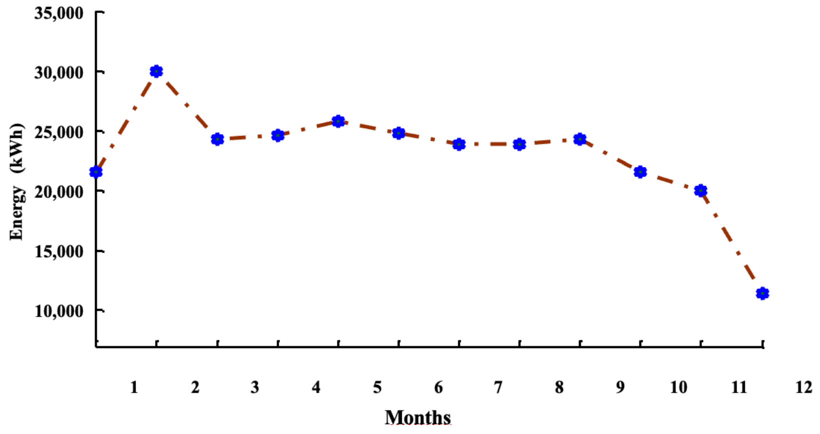
Figure 5. Average load demand



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Ratio to heat ratio

The ratio of heat demand to electricity is an important parameter for selecting and designing CHP. Due to the seasonal nature of heat demand for heating, the selection of CHP for the company is based on the base heat load (heat to produce hot water). Thus, the amount of heat generated by CHP is used for use in the hot water production system and energy loss is prevented due to not using heat in summer. It should be noted that the ratio of electricity demand in hot seasons to cold seasons in cold climate is 4.1 times, hot and dry climate is 2 times, hot and humid climate and temperate and humid climate is 4 times. As can be seen in Table 1, the minimum ratio of heat demand to power in each climate occurs in summer and this minimum is considered in the choice of CHP system.

Table 1. Heat to electricity ratio in different seasons

Climate	Electricity from heat in non-summer seasons	Electricity from heat in summer seasons
Cold	4.1	2.9
Hot and dry	4.3	2.2
Moderate and moist	4.5	1.1
warm and wet	1.1	0.8

Source: Author

Technical analysis and technology selection

After extracting the demand for electricity and heat consumption of the company and also the ratio of heat to electricity of the company, in this section we will analyze the technical potential of each of these CHP technologies for use in the company, which is shown in Table 2. Where only small-scale hot water is needed, reciprocating engines are the best option, and turbine steam is the best option. However, reciprocating motors can also be used for small-scale low-pressure steam, which is more suitable for combination with a suction chiller system. Heat requirement for use in air conditioning systems changes throughout the year according to different seasons and temperature changes. Therefore, the best places to stabilize the heat used for home and office are places that have less temperature changes during the year. The effect of increasing temperature and decreasing pressure on the performance of gas turbines is very significant and leads to a decrease in their efficiency. In addition, in comparison with the studied CHPs, in hot and dry climates, the best option in this climate is the internal combustion gas engine with indoor combustion engine and the best technology is for private use in a micro-CHP residential unit with a sterling engine that has the highest slope increase. For the function of net present value (2NPV) and the rate of return on investment for the increase in operating hours. Due to this, the reciprocating motor co-production system is suitable for small consumers who need more electrical energy or need low thermal energy quality (low-pressure steam or hot water). Hospitals, commercial buildings, and academic centers are examples of customers of the reciprocating engine co-production system. The reciprocating engine co-production system has low initial investment costs and flexibility in the use of different fuels. In addition, in this system, unlike gas turbines, ambient temperature and climate have no effect on it. For this reason, it is quite suitable for countries with hot climates. The joint production system of steam turbine in sugar industry, wood factories, food industry, etc. has more position and feasibility. In these factories, even the fuel of this joint production system can be supplied from domestic biomass (production waste) (Di Fraia, Massarotti, Prati, & Vanoli, 2020; Fytili & Zabaniotou, 2018; Safarian, Unnthorsson, & Richter, 2020; Uris, Linares, & Arenas, 2017).

Table 2. Different technologies of Co-generation of electricity and heat

Technology	Fuel cell	Micro turbine	gas turbine	Steam turbine	Reciprocating engine
Available capacities	5KW-2MW	30KW-250KW	50KW-250MW	50KW-250MW	Lower than 5MW
Electrical efficiency	30-63%	22-28%	24-36%	15-38%	27-41%
Total CHP efficiency	55-80%	63-70%	66-71%	Near to %80	77-80%
Accessibility	More than %95	98-99%	93-96%	Nearto %100	96-98%
Start-up time	2 days – 3 hrs	6 secs	1hr -10 mins	1 day – 1 hr	10 secs

Source: Author

CHP potential in reciprocating engines

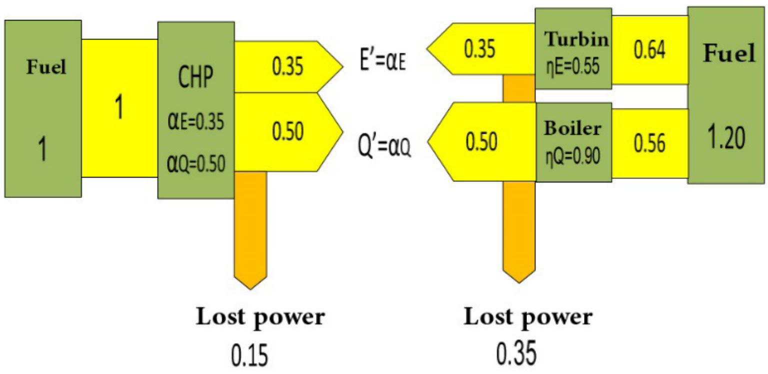
Economic consideration of using reciprocating engines (whose capacity to supply power is from 5 kW to 8000 kW) depends on the amount of thermal energy used in the exhaust gas and the exhaust of their cooling systems. This energy is usually 60 to 70% of the input fuel energy. Most of the heat is recovered from the exhaust gases and from the cooling of the shell and the heat recovery from the cooling of the oil and turbocharger is low. Recycled engine heat is used to produce hot water or low pressure steam for use in processes or to heat a space and produce hot water or absorption cooling. The cooling temperature of the engine shell is up to 30% of the input energy and it can produce hot water of 200 to 210 degrees Fahrenheit. Some engines, such as engines with boiling or high-pressure cooling systems with cooling water, have a shell temperature of up to 256 degrees Fahrenheit. The heat of the hot exhaust gases of the engine accounts for 30 to 50% of the heat loss. Exhaust gas temperatures are usually 850 to 1200 degrees Fahrenheit. With heat recovery, approximately 60 to 70 percent of fuel energy is used to generate electricity and useful thermal energy. However, a co-production system with a piston engine has advantages such as high efficiency, flexibility in operation with part of the capacity, fast start-up, relatively low investment cost, can be used independently of the network, the ability to adjust the total production load, adjustable In place with normal operators and operation with low pressure gas and disadvantages such as high maintenance costs, limited to use at lower temperatures, relatively high air pollution, must be constantly cooled even if the exhaust heat is not used and creates noise pollution (Ahmadi & Gaona, 2021; Tan & Shi, 2021).

System analysis

In the following, energy saving analysis and reduction of CO2 emission for CHP production unit with reciprocating engine technology are discussed. To obtain the ratio of energy storage and reduce CO2 emissions, a comparison is made with separate heat and power generation. A boiler with 90% efficiency is considered for heat production. Therefore, for different scenarios in which CHP is compared with reciprocating engine technology with combined cycle and fossil fuel power plants in Colombia, the average efficiency of these power plants in Colombia is as follows:

1- Electricity generated by a combined cycle power plant in Colombia, whose average efficiency is about 44%.

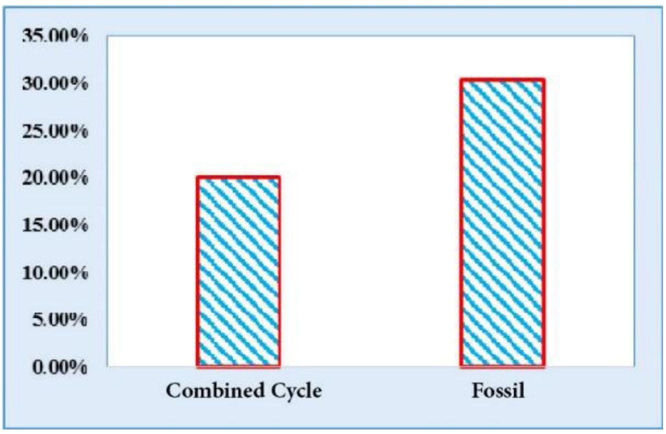
Figure 6. The schematic shows the energy balance between the CHP unit and the separate production unit



Source: Author

2- Electricity generated by a fossil fuel power plant in Colombia, whose average efficiency is about 2.35% (Strambo & González Espinosa, 2020).

Figure 7. Analysis of the overall energy savings of reciprocating engine technology compared to conventional power plants



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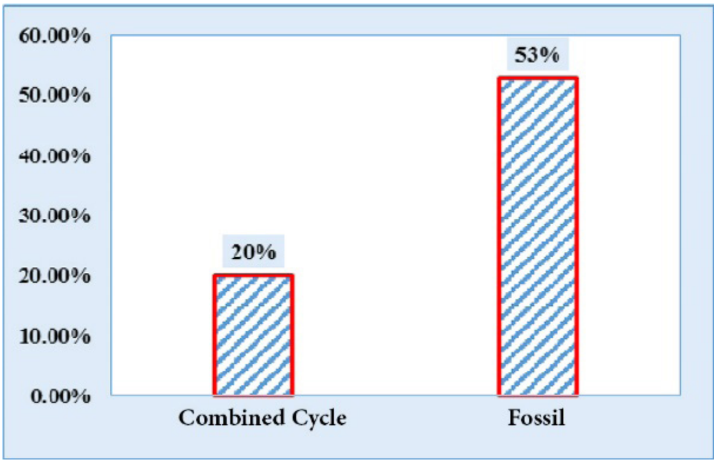
Overall energy saving of unit CHP

Heat and electricity generation using a CHP unit is very different from that of a separate boiler and a power plant, as shown in Figure 7, where αE and αQ are electrically efficient, respectively. In addition, the heat of the CHP, ηE and ηQ units are the electrical efficiency and the heat of the separate unit, respectively, and also E and Q are the useful size of the electricity and heat generation, respectively. Figure 7 shows the energy savings of the CHP unit compared to combined cycle and fossil fuel power plants for both types of power plants (Iora, Beretta, & Ghoniem, 2019).

Environmental aspects of CHP unit

CHP is a process with high energy efficiency and reduces the amount of combustion products per unit of energy consumed compared to heat and power generating systems. The performance of the CHP method usually increases the fuel consumption of the site somewhat (compared to a single heat generator such as a boiler with the same output power), but compared to the fuel consumption of both generators and heat separately, about 20 to 30% It seeks to save on consumption. It is clear that the size and type of equipment of the CHP system will affect its environmental impact. The most important of these effects include the emission of combustion products, noise and system effluent, in addition to its effect on the landscape of the building and the storage and maintenance of spent fuels. CO_2 is the most important combustion product that is effective in greenhouse phenomena and climate change. The amount of production of this gas depends on the type and amount of fuel consumed and therefore by using the CHP system and reducing fuel consumption, CO_2 production is also reduced. Based on the studies, it can be concluded that greenhouse gas emissions are a function of several factors, such as the type of fuel used, the technology used for both CHP and 3SHP units, greenhouse gas emissions and system efficiency. As can be seen in Figure 8, after analysis, the rate of reduction of CO_2 emissions from CHP power plant to combined cycle power plant and fossil fuel power plant, respectively, is about 20% and 53% that shows the role of CHP power plants in reducing CO_2 pollution.

Figure 8. CO_2 pollution reduction analysis of reciprocating engine technology compared to conventional power plants

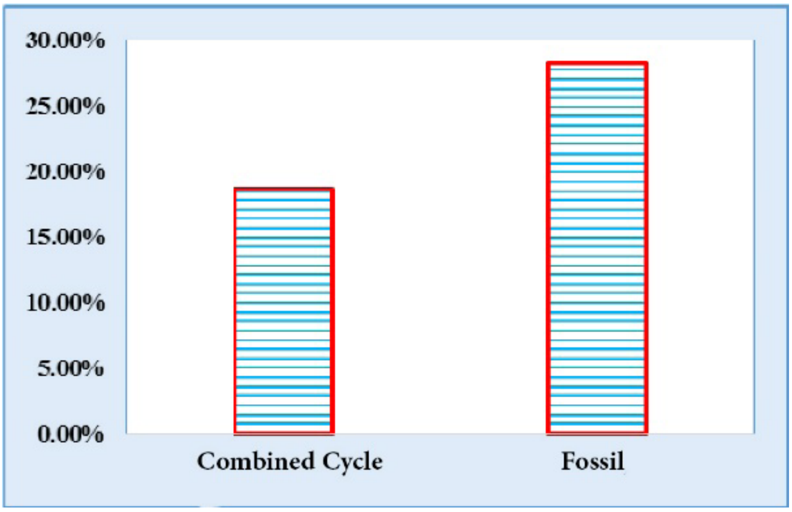


Source: Author

Energy saving in the company

Considering the demand for electric charge and heat load of the company, the analysis of the energy saving rate in the company in relation to combined cycle power plants and fossil fuels is as shown in Figure 9. As can be seen, the use of CHP unit in the company, the amount of energy consumption compared to the combined cycle power plant is reduced by about 18% and fossil power plant by about 28%, which saves the country's energy resources for the next generation.

Figure 9. Energy saving analysis using CHP unit in university in comparison with conventional power plants



Source: Author

Conclusion

This article studies and potentials for the establishment of a power plant for simultaneous production of electricity and heat in Makariza Company. In order to create a power plant for the simultaneous production of electricity and heat, the amount of electrical and thermal demand required by the company has been studied and then by examining the existing technologies in the world of technology. Reciprocating motors are selected as the best option for this project according to the geographical location and the amount of heat output. Analysis of energy savings and also analysis of CO_2 pollution reduction in relation to combined cycle power plants and fossil fuels in Colombia were studied. The results of increasing energy savings and also reducing CO_2 pollution, show the benefits of these power plants.

References

Ahmadi, T., & Gaona, S. S. (july 2021). *Designing a Mathematical Model and Control System for the Makariza Steam Boiler.* Paper presented at the International Conference on Swarm Intelligence. https://doi.org/10.1007/978-3-030-78811-7_50

Al-Maghalseh, M., Odeh, S., & Saleh, A. (2017). *Optimal sizing and allocation of DGs for real power loss reduction and voltage profile improvement in radial LV networks.* Paper presented at the 2017 14th International Conference on Smart Cities: Improving Quality of Life Using ICT & IoT (HONET-ICT).

Andoni, M., Robu, V., Früh, W.-G., & Flynn, D. (2017). Game-theoretic modeling of curtailment rules and network investments with distributed generation. *Applied energy, 201*, 174-187. https://doi.org/10.1016/j.apenergy.2017.05.035

Arabkoohsar, A. (2020). Combined steam based high-temperature heat and power storage with an Organic Rankine Cycle, an efficient mechanical electricity storage technology. *Journal of Cleaner Production, 247*, 119098. https://doi.org/10.1016/j.jclepro.2019.119098

Beiron, J., Montañés, R. M., Normann, F., & Johnsson, F. (2020). Combined heat and power operational modes for increased product flexibility in a waste incineration plant. *Energy, 202*, 117696. https://doi.org/10.1016/j.energy.2020.117696

Bulatov, Y. N., & Kryukov, A. (2017). *A multi-agent control system of distributed generation plants.* Paper presented at the 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM). DOI:10.1109/ICIEAM.2017.8076128

Chahartaghi, M., & Baghaee, A. (2020). Technical and economic analyses of a combined cooling, heating and power system based on a hybrid microturbine (solar-gas) for a residential building. *Energy and Buildings, 217*, 110005. https://doi.org/10.1016/j.enbuild.2020.110005

Di Fraia, S., Massarotti, N., Prati, M., & Vanoli, L. (2020). A new example of circular economy: Waste vegetable oil for cogeneration in wastewater treatment plants. *Energy Conversion and Management, 211*, 112763. https://doi.org/10.1016/j.enconman.2020.112763

Ferreira, A. C., Teixeira, S., Teixeira, J. C., & Nebra, S. A. (feb 2021). Application of a cost-benefit model to evaluate the investment viability of the small-scale cogeneration systems in the Portuguese context. *International journal of Sustainable Energy Planning and Management, 30*. https://doi.org/10.5278/ijsepm.5400

Fytili, D., & Zabaniotou, A. (2018). Circular economy synergistic opportunities of decentralized thermochemical systems for bioenergy and biochar production fueled with agro-industrial wastes with environmental sustainability and social acceptance: a review. *Current Sustainable/Renewable Energy Reports, 5*(2), 150-155. https://doi.org/10.1007/s40518-018-0109-5

Iora, P., Beretta, G. P., & Ghoniem, A. F. (2019). Exergy loss based allocation method for hybrid renewable-fossil power plants applied to an integrated solar combined cycle. *Energy, 173*, 893-901. https://doi.org/10.1016/j.energy.2019.02.095

Lion, S., Vlaskos, I., & Taccani, R. (2020). A review of emissions reduction technologies for low and medium speed marine Diesel engines and their potential for waste heat recovery. *Energy Conversion and Management, 207*, 112553. https://doi.org/10.1016/j.enconman.2020.112553

Lisin, E., Shuvalova, D., Volkova, I., & Strielkowski, W. (2018). Sustainable development of regional power systems and the consumption of electric energy. *Sustainability, 10*(4), 1111. https://doi.org/10.3390/su10041111

Odetayo, B., MacCormack, J., Rosehart, W. D., & Zareipour, H. (2017). A sequential planning approach for distributed generation and natural gas networks. *Energy, 127*, 428-437. https://doi.org/10.1016/j.energy.2017.03.118

Safarian, S., Unnthorsson, R., & Richter, C. (2020). Performance analysis and environmental assessment of small-scale waste biomass gasification integrated CHP in Iceland. *Energy, 197*, 117268. https://doi.org/10.1016/j.energy.2020.117268

Strambo, C., & González Espinosa, A. C. (2020). Extraction and development: fossil fuel production narratives and counternarratives in Colombia. *Climate Policy, 20*(8), 931-948. https://doi.org/10.1080/14693062.2020.1719810

Sung, T., Kim, S., & Kim, K. C. (2017). Thermoeconomic analysis of a biogas-fueled micro-gas turbine with a bottoming organic Rankine cycle for a sewage sludge and food waste treatment plant in the Republic of Korea. *Applied Thermal Engineering, 127*, 963-974. https://doi.org/10.1016/j.applthermaleng.2017.08.106

Tan, Y., & Shi, Y. (july 2021). *Advances in Swarm Intelligence: 12th International Conference, ICSI 2021, Qingdao, China, July 17-21, 2021, Proceedings*: Springer Nature. https://doi.org/10.1007/978-3-030-78811-7

Uris, M., Linares, J. I., & Arenas, E. (2017). Feasibility assessment of an Organic Rankine Cycle (ORC) cogeneration plant (CHP/CCHP) fueled by biomass for a district network in mainland Spain. *Energy, 133*, 969-985. https://doi.org/10.1016/j.energy.2017.05.160

van der Walt, H. L., Bansal, R. C., & Naidoo, R. (2018). PV based distributed generation power system protection: A review. *Renewable Energy Focus, 24*, 33-40. https://doi.org/10.1016/j.ref.2017.12.002

Wegener, M., Malmquist, A., Isalgué, A., & Martin, A. (2018). Biomass-fired combined cooling, heating and power for small scale applications–A review. *Renewable and Sustainable Energy Reviews, 96*, 392-410. https://doi.org/10.1016/j.rser.2018.07.044