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Artículo de Investigación

Gestión energética en la Empresa de Mantenimiento a Grupos Electrógenos Fuel-Oíl de Pinar del Río, Cuba

Energy management in the Maintenance Company for Fuel-Oíl Generator Sets in Pinar del Río, Cuba

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Resumen – El presente trabajo se trazó como objetivo realizar una caracterización energética en la Empresa de Mantenimiento a Grupos Electrógenos Fuel Oil de Pinar del Río, Cuba donde se detectó un elevado consumo de portadores energético en los motogeneradores Hyundai HIMSEM 9H25/33S. Se aplicaron herramientas matemáticas propuestas en la bibliografía acordes a este tipo de estudios (Diagrama de Pareto, Pruebas de Normalidad, Histogramas, entre otras). Los datos recolectados referentes al consumo de combustibles, lubricantes, agua y electricidad se procesaron mediante el software SPSS y una hoja de cálculo en Microsoft Excel. Se identifica como puestos clave la nave de motores, lugar donde se concentra el conjunto de equipos que consumen más del 80 % de portadores energéticos, siendo el Fuelóleo y Diesel los más representativos. Dentro de los equipos claves destaca el caso del Motor 7 pues presenta un bajo consumo en Toneladas Equivalentes de Petróleo (TEP), sin embargo, al estimar aproximadamente el consumo por hora se aprecia que presenta un valor de 5.85 TEP, el cual es muy superior a los demás motores que ronda una media de 2.91 TEP. Se concluye que la empresa debe seguir trabajando en el control sistemático del uso final de energía; aumentar la superación técnica de los operarios y responsables de áreas, además, durante el año 2021 el índice de consumo de combustible se comportó de manera homogénea, presentando poca variabilidad, pero se demostró que la media de la muestra de índice de consumo difiere de lo estipulado por el fabricante.

Palabras clave: eficiencia, energía, diagnóstico, línea base, puesto clave.

Abstract – The present work aimed to carry out an energy characterization in the Fuel Oil Generator Maintenance Company in Pinar del Río, Cuba, where a high consumption of energy carriers was detected in the Hyundai HIMSEM 9H25/33S generators. Mathematical tools proposed in the literature for this type of study were applied (Pareto diagram, Normality tests, Histograms, among others). The data collected regarding fuel, lubricants, water, and electricity consumption were processed using SPSS software and a Microsoft Excel spreadsheet. The engine room is identified as a key position, where the set of equipment that consumes more than 80% of energy carriers is concentrated, with Fuel Oil and Diesel being the most representative. Among the key equipment, the case of Motor 7 stands out because it has a low consumption in Equivalent Petroleum Tons (TEP), however, when estimating the consumption per hour, it is observed that it has a value of 5.85 TEP, which is much higher than the other engines that have an average of 2.91 TEP. It is concluded that the company must continue working on the systematic control of final energy use; increase the technical training of operators and area managers. Additionally, during 2021, the fuel consumption index behaved homogeneously, showing little variability, but it was demonstrated that the sample mean of the consumption index differs from what is stipulated by the manufacturer.

Keywords: efficiency, energy, diagnosis, baseline, key position.

Introduction

It is important that economic sectors implement energy efficiency measures to achieve significant savings and improve the sustainable use of resources. Climate change is a significant environmental problem and public policies are needed to mitigate greenhouse gas emissions and promote the use of renewable energies. Energy consumption worldwide tends to grow, so standards such as ISO 50001:2011 have been established to manage the use and planning of energy in all types of facilities and processes. (Gómez Rodríguez & Chou Rodríguez, 2019).

Many researchers have focused on the subject, coinciding in their definition of Energy Management, Borroto Nordelo & Monteagudo Yanes (2006) state that it is a subsystem of business management, covering in particular, the activities of administration and assurance of the managerial function, that give the entity the ability to efficiently meet its energy needs. (Monteagudo Yanes & Gaitan R, 2005). Another, equally relevant concept, is the term of Energy Efficiency, which has been defined by the Chilean Energy Efficiency Agency (AChEE) and the content of the ISO 50001:2011 standard as follows (NC-ISO 50001, 2011): "ratio or other quantitative relationship between a performance, service outputs, outputs of goods or energy and energy inputs."

In view of this reality, numerous studies have been carried out in order to mitigate as much as possible the destructive effects of this new challenge. One of the most widely accepted alternatives has been the implementation of Energy Management Systems, which generally require little investment and are aimed at achieving efficiency by applying good practices.

Noriega Angarita *et al.* (2019) conduct their study with the objective of improving energy performance in a battery factory in Colombia by introducing the energy management approach defined in ISO 50001. The main energy consumptions were identified in the battery formation, the compressed air system and the large electric motor network. Different actions were proposed to improve energy efficiency. As a result, a 3.48% reduction in electricity consumption was achieved during the implementation of the proposed measures.

From the point of view of Espinosa *et al.* (2018), analyzing worldwide efforts to reduce the energy demand of residential buildings, is significant to increase the Energy Efficiency of the sector. They highlight the opportunities for energy savings in heat, ventilation, air conditioning and lighting that they detect in Ecuador. The authors believe that current government regulations and policies are not sufficient to promote energy audits and the adoption of modern technologies. In agreement, Ramos Males & Bautista Segovia (2022) analyze energy efficiency as a strategy for the domestic economy. They raise the importance of promoting the use of renewable energies in homes, such as the installation of solar panels or the use of efficient heating and cooling systems. They show in their study that the residential sector plays a crucial role in energy markets, and household energy consumption represents an important part of the household budget.

Likewise, Ladeuth *et al.* (2021) state that energy consumption in Colombia has increased due to industrial and population growth, which has led the government to invest in improvement alternatives and adopt international standards. In the educational field, the study was conducted at the Universidad de La Guajira in Riohacha, where the need to implement energy efficiency measures and raise awareness in the educational community to reduce energy consumption and costs was concluded. In addition, it is suggested to work together with government entities and private companies to implement clean and renewable technologies in energy generation.

On the other hand, Laayati *et al.* (2022) develop a new hardware, software, and data processing infrastructure for open pit mines that uses artificial intelligence to improve energy efficiency and decision making. They test a peak load monitoring and forecasting system at an experimental open pit mine in Benguerir, which uses a fast forest quantile regression algorithm to predict energy demand response, thereby minimizing energy consumption and improving the efficiency and profitability of the mining industry.

According to Urteneche *et al.* (2022) public hospitals are structures that consume a lot of energy, so it is necessary to implement energy efficiency measures to reduce consumption. They apply a methodology in La Plata, Argentina, allowing to propose specific improvement alternatives by area, oriented to the recycling of the building envelope with passive design techniques. The results obtained showed that intervening the building envelope from the outside improves the thermal behavior and the stabilization of spaces, without altering the external image of the building.

According to Caceres Espinoza *et al.* (2022) the Peruvian electricity sector has been going through several modifications regarding its energy matrix, use of renewable energies, biofuels, energy efficiency. They propose the use of smart grids to improve efficiency and environmental care in the electricity sector, using an Arduino MEGA 2560 meter and a liquid LCD display to encourage electricity savings.

Andrade Zambrano & Real Perez (2021) state that Small and Medium Enterprises (SMEs) contribute about 13% of annual energy consumption globally. Considering energy efficiency can strengthen SMEs by helping them to reduce energy costs with the possibility that these savings can be invested in actions that allow them to be more competitive. Accordingly, Navarrete Baez & Labelle (2023) conducted initial research on the practices of small and medium-sized enterprises (SMEs) in Jalisco, Mexico regarding their sustainable energy management policies. They apply a questionnaire to SME owners on sustainable development practices focused on energy management. As a relevant result, only one third of the SMEs interviewed carry out sustainable energy management practices, demonstrating that it is not a priority for them to increase efficiency through the application of improvements and good practices.

Given the importance of aviation, the study by Baxter (2022) examines airports located around the world that have implemented an ISO 50001-certified Energy Management System (EMS). The study found that airports located in China, Cyprus, Hong Kong, Europe, India, Turkey, Sweden, the United Kingdom and the United States of America have implemented ISO 50001 certified Energy Management Systems since the inception of this standard in 2011. Among the measures they implement for energy conservation, including the use of light emitting diode (LED) systems, electrification of ground service equipment and vehicles, installation of electric vehicle charging stations, installation of solar photovoltaic (PV) systems, optimization of building heating and cooling systems, and energy optimization for plant and equipment.

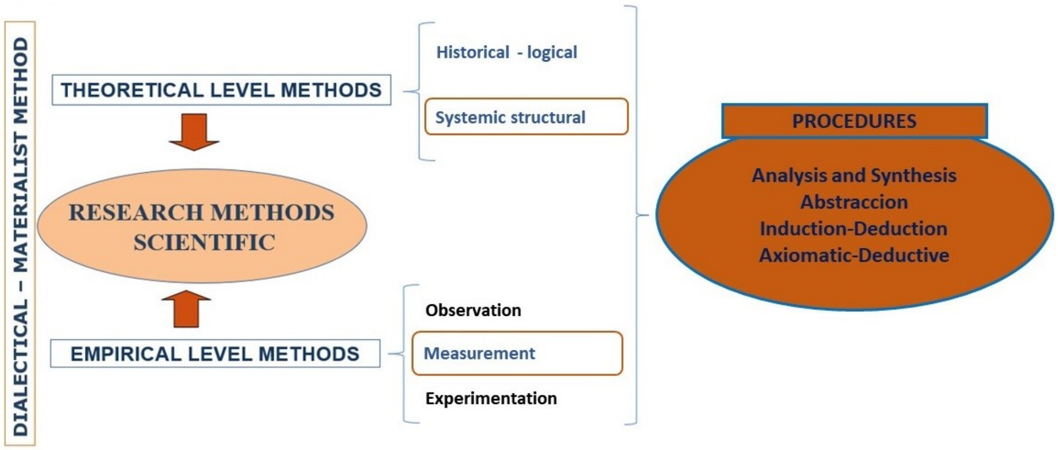
In Cuba, there have been many researches on the mentioned subject, Álvarez Cancio *et al.* (2021) apply energy management in rum and beverage factories, specifically in the Basic Economic Unit (UEB) rum "Luis Arcos Bergnes" of Cienfuegos. They make an energy characterization of the Cienfuegos Rum UEB, identifying the most energy-consuming equipment and areas were determined, and an improvement project was proposed in order to increase the energy efficiency of the rum manufacturing process. Likewise, Crespo Sánchez *et al.* (2019) raise the need for management systems that allow better energy performance in the manufacture of balanced animal feed. Obtaining and using the energy performance indicator and the baseline concept for daily control, made it possible to decrease from 12.8 kWh/t on average to values below 10 kWh/t.

The 30 MW "Antonio Briones Montoto" Fuel-Oil ICE Power Plant located in the municipality of Pinar del Río, does not have an Energy Management System, which constitutes a brake for the correct management of energy carriers and other saving potentials; there are procedures that regulate the use of energy carriers, technological fuel and fuel cards. Therefore, the objective of this research is to perform an energetic characterization and establish the current state of Energy Management

Materials and Methods

The methods and materials used in the research are described below. Based on the dialectical materialist method, a fundamental pillar for the theoretical-methodological foundation and understanding of the problem posed: business energy management, and within it the study of the application of different mathematical tools, the data processing was carried out using a Microsoft Excel spreadsheet in its 2019 version and the SPSS Software (Hernández Sampieri *et al.*, 2014). A complex interaction of different research methods (empirical and theoretical) is used as can be seen in figure 1.

Figure 1. Used methods



Source: own elaboration

Theoretical methods:

Historical and logical method: it was used to determine the trends of the energy management process, particularly in the different Energy Management Systems currently used. Its application was given that there is a national and international experience on the subject.

Empirical methods:

Measurement method: was used to establish the baseline, i.e., to obtain information on the existence or not of potential savings with the application of the management system. For this purpose, techniques such as documentary analysis and interviews were used, the results of which were processed to arrive at the conclusions presented.

The following procedures were used in conjunction with the theoretical and practical methods:

1. Analysis and synthesis method: it was used in function of the decomposition of the functioning of the object in its various components and the establishment of the relationships between them. Each of its parts was investigated in their reciprocal relationship, identifying the place and significance of each one and how they reveal the dialectic contradiction that arises in it and the way to resolve it. Once this has been achieved, the synthesis is in charge of mentally recomposing the totality having now a clear vision of the laws that govern or govern such totality.

2. Abstraction method: it was used for the analysis of the possible determinants and relationships that can be created in the decomposition of the object of study.

3. Induction – deduction method: made it possible to determine the generalities and regularities of the energy management process.

Results and Discussión

Analysis of the energy carrier consumption structure in the company.

The identification of the most-consumed energy carriers during the year 2021 is shown in the table 1.

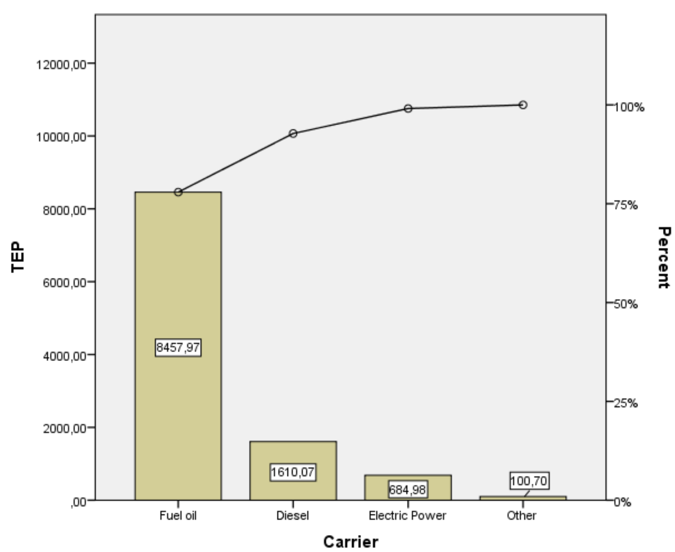
Table 1. Distribution of energy consumed during 2021

Energy Carrier	Unit	Expenditure	Convection factor	Equivalent Tons Oil	Percentage (%)	Cumulative Percentage (%)
Fuel oil	t	8543,41	0,99	8457,97	77,93	77,93
Diesel	t	1529,03	1,05	1610,07	14,83	92,76
Electric Power	MWh	1826,60	0,38	684,98	6,31	99,07
Lubricants	t	100,70	1,00	100,70	0,93	100,00
Total				**10853,72**	**100**	

Source: own elaboration, from data processing in SPSS and Microsoft Excel

The figure 2 shows the distribution of energy using the Pareto Diagram. It is highlighted that the energy carriers with the highest incidence on the plant's overall consumption are Fuel Oil and Diesel (77.9 % and 14.8 % respectively). These carriers represent more than 90% of the total energy expenditure, thus arising the need to look for the causes of the high consumption in order to propose measures to increase the efficiency and rational use of these fuels.

Figure 2. Pareto diagram



Source: own elaboration, based on data processing in SPSS

After an exhaustive bibliographic search, no studies on energy management at ice power plants using fuel oil as fuel for continuous electricity generation were found; however, Pino Morales (2009) carried out an "Energy diagnosis in the of diesel ice power plant in Moa", the most consumed energy in this type of installation is diesel, representing 97.52% of total consumption; and the rest corresponds to electricity and lubricants.

Similarly, Crespo Sánchez (2020) in his work "Implementation of the Energy Planning stage of the ISO 50001 Standard, in the ice power plant of the Cienfuegos Oil Refinery" identified diesel as the most consumed energy source, representing 97.7% of the total consumption of energy carriers of the Diesel Power Plant (CDE). Both studies were carried out in similar generation technologies; a determining factor to obtain similar results, but, unlike the Fuel technology, object of the study, the results do not coincide with the current research.

The study by Madrigal *et al.* (2018) conducted an energy planning for fuel oil savings in an industrial laundry, after analyzing its energetics, it was determined that fuel oil is the most consumed, representing 72.02 % of the total. Similarly; de la Rosa Andino (2017) in his work "Energy evaluation of the fruit and vegetable canning factory in Yara municipality in the province of Granma" identified said energy as the most consumed with 72 %. Both studies show similarity with the results of the present research, even though they are companies with very different social objects.

Crespo Sánchez *et al.* (2019) in their work "Energy management in the manufacture of balanced animal feed in Cienfuegos" determined that electrical energy represents 74.24 % of the annual energy consumption, a result that agrees with the technology of the plant, since it presents a high number of electrical consumers to achieve the manufacture of feed; however, it does not coincide with the results of the current research, where the carrier "electricity" only represents 6.31 %.

Mohamed Arreh *et al.* (2016) in their study of the application of total efficient energy management technology in the Pinar del Río Hydro energy Company, carried out an energy characterization by consumer elements, the creation of key workstation and the identification of key personnel involved in the consumption processes of the different energy carriers (Operators and Key Managers), it resulted that the Diesel fuel used in the service transport and production assurance, is the carrier with the highest incidence in the UEB representing 52.82 %; the same is distributed according to the consumption indexes of each vehicle, taking every month the real consumption index of each one of them. These results do not correspond to the present study where the diesel carrier only represents 14.83 %.

Table 2. Statisticians for the population. Consumption index variable

Statistics	Sample
Media	215,76
Median	212,60
Standard desviation	21,44
Asymettry	1,476
Standard error of asymmetry	1,212
Kurtosis	6,854
Standard error of kurtosis	0,422

Source: own elaboration, based on data processing in SPSS

IPSA Scientia, revista científica multidisciplinaria, 8(3), 48-62.

Fuel-Oil fuel is used in the continuous work of the engines, it is the most consumed fuel in the entity, it is stored in tanks of 1000 m^3. The tanks are gauged, so measurements are taken three times a day to see the variation in the fuel level, thus estimating the consumption during the day. Once the generated electricity readings are taken, the fuel consumption index is calculated. This indicator is controlled on a daily basis, constituting an important reference of the efficiency in the electricity generation process. The table 2 shows an analysis of the behavior of the fuel consumption index in the year 2021, it is composed of 130 measurements.

In order to demonstrate the normality of the data, the Kolmogorov-Smirnov test is performed at 95% significance. As shown in table 3 and figure 3 the data conform to a normal distribution.

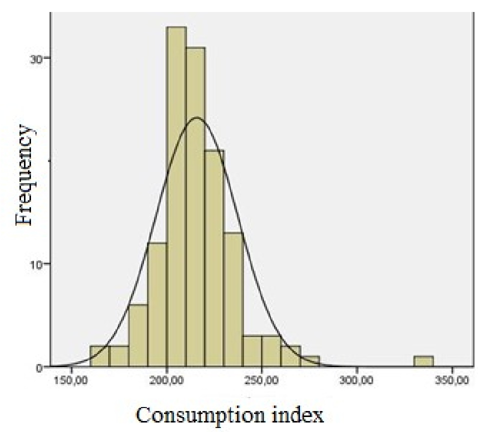
Table 3. Kolmogorov-Smirnov test

		Consumption index
Sample		130
Normal parameters[a,b]	Media	215,7621
	Standard deviation	21,44368
Z for Kolmogórov-Smirnov		1,275
Sig. asymptotic (bilateral)		,077

a. The contrast distribution is the Normal distribution.
b. They have been calculated from the data.

Source: own elaboration, based on data processing in SPSS

Figure 3. Histogram



Source: own elaboration, based on data processing in SPSS

Comparing the Fuel Consumption Index with an average of 212 g/kW given by the manufacturer gives the results shown in table 4. Starting from the hypothesis that: H_0: $\mu = 212$ g/kW; H_1: $\mu \neq 212$ g/kW

Table 3. Test for one sample

	Test Value = 212					
	t	gl	Sig. (bilateral)	Difference in averages	95% Confidence interval for the difference	
					Inferior	Superior
Consumption index	2,000	129	,048	3,76208	,0410	7,4832

Source: own elaboration, based on data processing in SPSS

As the bilateral significance is less than 0.05 it can be stated that H_0 must be rejected, so we assure with sufficient evidence that the sample mean differs from that stipulated by the manufacturer with a significance level of 95%.

Determination of key positions

With regard to the definition of "Key workstation " given by Borroto Nordelo & Monteagudo Yanes (2006) refers to a piece of equipment or set of equipment that has a great influence on energy consumption in a specific place, representing approximately 85% of the consumption of the energy carriers in question. The Fuel-oil Generator Maintenance Company uses Hyundai HIMSEM 9H25/33 internal combustion engines coupled to a 2.5 MW generator to generate electricity. This research identifies the engine shed as a key location since it is the place that contains the key equipment, where the bulk of energy is consumed. The Table 5 and Figure 4 show information regarding fuel consumption by key equipment (engines) and the time each one worked.

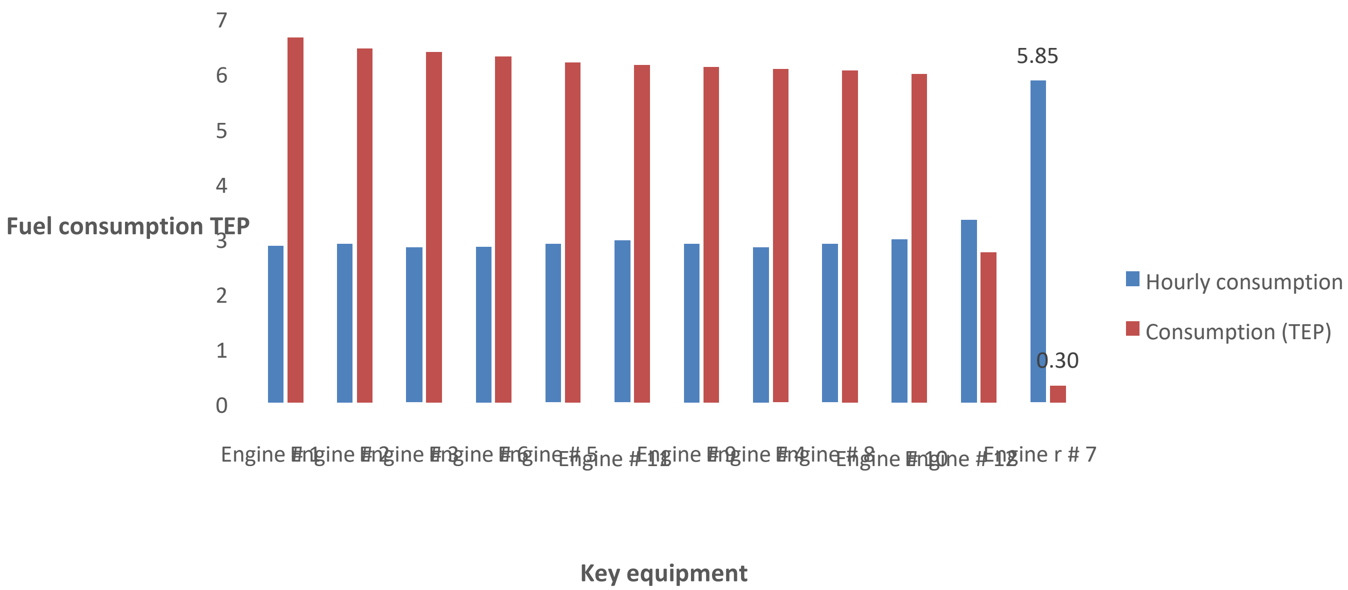
Table 5. Energy consumed in key positions

Engine	Fuel consumption (TEP)	Percent (%)	Percent Accumulated (%)	Time (horas)	Equivalent consumption (TEP)	Estimated hourly consumptio n n
Engine # 1	662.66	10.10	10.10	1889.00	6.63	2.85
Engine # 2	643.61	9.80	19.90	1855.00	6.44	2.88
Engine # 3	636.83	9.70	29.60	1788.00	6.37	2.81
Engine # 6	628.38	9.60	39.20	1772.00	6.28	2.82
Engine # 5	617.41	9.40	48.60	1773.00	6.17	2.87
Engine # 11	612.99	9.40	58.00	1802.00	6.13	2.94
Engine # 9	610.04	9.30	67.30	1759.00	6.10	2.88
Engine # 4	605.45	9.20	76.50	1704.00	6.05	2.81
Engine # 8	603.62	9.20	85.70	1736.00	6.04	2.88
Engine # 10	596.98	9.10	94.80	1769.00	5.97	2.96
Engine # 12	272.31	4.10	98.90	905.00	2.72	3.32
Engine # 7	30.27	0.40	99.30	177.00	0.30	5.85
Total	**6520.55**					

Source: own elaboration, from Microsoft Excel data processing

The figure 4 shows the fuel consumption of the engines in TEP where 10 engines have a homogeneous behavior, this behavior may be based on the fact that all of them had a similar regime and operating time during the period (on average with 1784 working hours each one), engine 12 with less working time (905 hours). The case of Engine 7 stands out because it has a low consumption, in direct correspondence with its 177 working hours; however, when including the fuel consumption per hour, it can be seen that it has a value of 5.85, which is much higher than the other engines.

Figure 4. Carrier consumption by key equipment



Source: own elaboration, from plotting data in Microsoft Excel

The concept of "Key Point" will be intrinsically linked to the corporate purpose of each company, hence each one has different equipment with influence on energy consumption in a specific place. In this regard, Hidalgo Suárez (2010) in his work observed that electricity represents 56.45 % and Fuel-Oil 42.65 % respectively of the consumption of carriers. The company's corporate purpose is the production of meat products, thus identifying the refrigeration area as the maximum consumer, which differs from the present investigation.

Delgado (2020) The Pareto diagram shows that the Refrigeration and Conservation, Climate and Lighting sectors are the ones that use 65.7% of the electrical energy, which does not coincide with the results of the current study. Crespo Sánchez *et al.* (2019) in their study determined as a result of the stratification by areas and equipment, from the installed energy capacity, that the energy consumption of the mills was 85% of the energy destined to the area, that the presses and cyclones consumed 75% of the energy destined to the pressing area, that in dosing and mixing, the mixer, elevator and screen consumed 70% of the energy destined to the area and that in the reception of cereals, the elevators and main conveyors, required 70% of the energy consumption of the area. These results do not coincide with those of the present investigation.

Álvarez Cancio *et al.* (2021) analyzed from the point of view of energy management the Basic Economic Unit (UEB) rum "Luis Arcos Bergnes" of Cienfuegos. When the energy characterization of the UEB Ron of Cienfuegos was carried out by analyzing the consumption of the main energy carriers, the most energy consuming equipment and areas were determined, where it was established that electricity represented more than 90% in the last two years. Air compressors constituted the set of key equipment, which does not correspond to the present study.

The study conducted by Ladeuth *et al.* (2021) in order to determine the areas that generate the highest consumption of electrical energy at the University of La Guajira, Riohacha (Colombia), the energy consumption corresponding to each block was established, based on the years 2015, 2016 and 2017. From their study it resulted that the areas that demanded the highest electrical energy consumption were the blocks and the laboratories. It is stated that these two areas were the most influential because these infrastructures are necessary and need optimal air conditioning for the effectiveness of service provision, knowing that the academic offerings that present greater student demand support their activities in the laboratories.

Results of Energy Efficiency Indicators

Generating Groups are a company that establishes production criteria and goals, where economic indicators are defined to evaluate their compliance. However, locking into these indicators without making changes can be counterproductive. The chain reaction principle suggests that a continuous reduction of errors can lead to lower costs, less waste of resources and an increase in productivity. Therefore, it is important to identify and eliminate potential causes of energy inefficiency to improve the process and reduce the consumption of energy carriers. The key control indicators are the physical consumption indexes, which relate the energy consumed to the production or service performed. The table 6 shows the consumption of the most consumed energy carriers during the year 2021.

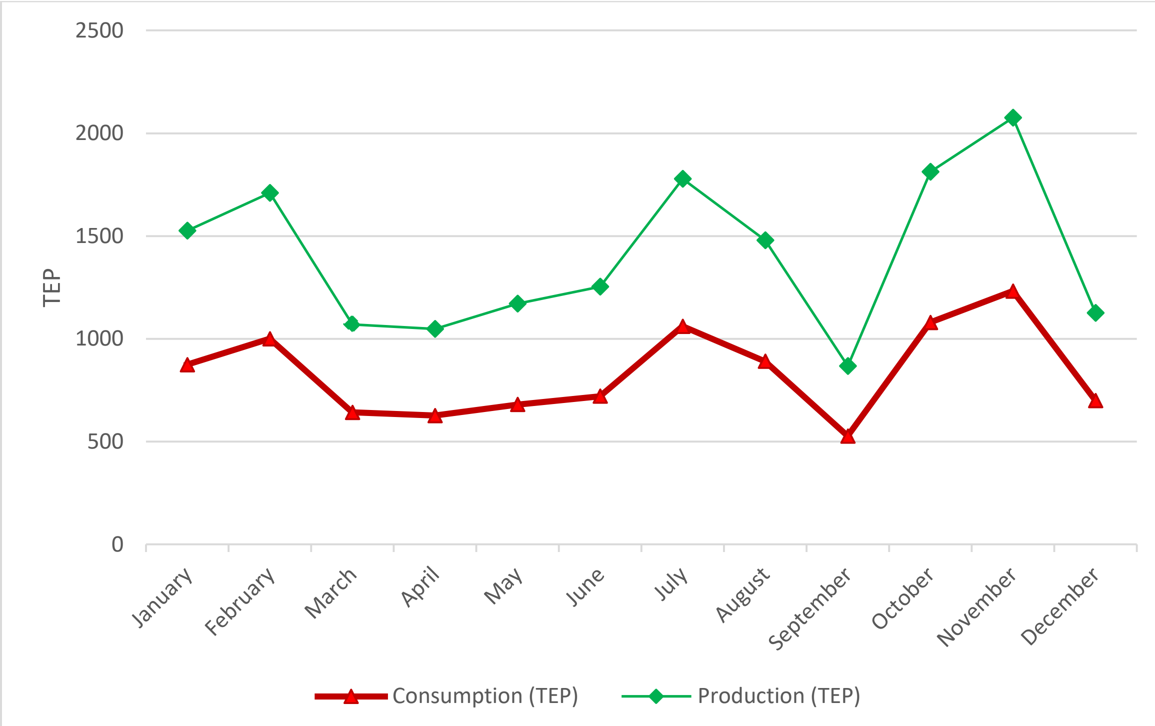
Table 6. Fuel consumption vs. electricity generation

	Consumption (TEP)			Production (TEP)
Months	**Fuel-Oíl**	**Diesel**	**Total Consumed**	**Electricity**
January	773,87	100,58	874,45	1526,25
February	927,96	72,39	1000,36	1709,59
March	598,92	43,12	642,04	1070,03
April	438,13	188,23	626,36	1048,88
May	625,96	54,74	680,70	1171,43
June	660,71	60,51	721,22	1253,21
July	926,52	134,47	1060,99	1778,96
August	651,95	238,39	890,34	1478,74
September	353,36	173,31	526,67	866,85
October	925,05	154,43	1079,48	1812,38
November	1073,16	159,31	1232,47	2076,41
December	502,37	197,52	699,89	1126,73

Source: own elaboration

The figure 5 shows the correlation between electricity production and fuel consumption; it is notable that increases in consumption lead to higher production. One possible cause may be that during these winter months the engines can work at higher loads (85% or more), since the lower ambient temperature acts positively on the temperature parameters in the cylinders of each engine.

Figure 5. Consumption-Production vs. Time diagram



Source: own elaboration, from plotting data in Microsoft Excel

Measures to increase Energy Efficiency

- Implement a system for the management and control of energy carriers, especially fuel.
- Implement fuel flow meters in each engine.
- Strict control of the activity performed by energy carrier consuming equipment.
- Completely disconnect blown or burned-out lamps or bulbs in the room containing the motors.
- Turn off and disconnect equipment in empty offices.
- Reduce the use of equipment during peak hours without affecting production.
- Increase staff awareness of the importance of improving energy efficiency.

In summary, to achieve energy efficiency and energy carrier savings, it is necessary to establish production criteria and goals with economic and physical indicators, identify and eliminate potential causes of energy inefficiency, improve organization and technological discipline, and involve workers. Management must apply science and technology, take advantage of advanced technologies, and transform concepts, approaches, habits and methods of dealing with this issue.

It is important to have indicators and indexes that allow analysis and show deviations in consumption in order to detect problems and make timely decisions. The main problems affecting energy savings and efficiency are related to lack of analysis, lack of knowledge, lack of identification, insufficient dissemination, lack of information and lack of appreciation of energy efficiency as an important source of energy.

Conclusions

After processing and analyzing the results, the following conclusions can be drawn regarding the current state of energy management: 1) the company is energetically characterized providing a starting point or baseline, which can be used in the evaluation of impacts once the measures to improve energy efficiency are implemented; 2) the company should continue working on the systematic control of the final use of energy carriers; 3) attention should be paid to the technical improvement of operators and those responsible for each key area; 4) during the year 2021 the fuel consumption index behaved homogeneously, presenting little variability, but it was shown that the average of the consumption index sample differs from that stipulated by the manufacturer.

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