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Article

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ISO 50002 and ITS Contribution to the Decarbonization of SMES: Case Study

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ABSTRACT

The decarbonization of all sectors of the energy system is essential to mitigate climate change. However, the existing barriers, mainly related to information, prevent the implementation of Energy Efficiency measures and energy management systems in SMEs to reduce carbon emissions. An energy audit is considered a critical step for businesses that want to increase their energy efficiency and reduce energy consumption cost-effectively. The present study addressed ISO 50002 and its contribution to energy management based on the ISO 50001:2019 standard through a case study applied to an SME in the non-metallic mineral sector, which allowed establishing the guidelines and the form to address an energy audit in an SME under ISO 50002, determining opportunities for improvement by eliminating unproductive times, correcting fleeting compressed air, eliminating energy losses due to operational variability, automating the start-up of the Hammer Mill and the feed band in gypsum grinding. Additionally, an annual energy and economic savings potential of 162,599 KWh and COP 49,360,442 was estimated; and 26,992 Kg CO2 stopped emitting.

Keywords: Decarbonization, ISO 50002, SMEs, Energy Management, Non-metallic Mineral Sector, Energy Efficiency
JEL Classifications: Q4, Q48, Q49, Q5

1. INTRODUCTION

Mitigating climate change is one of society's most significant challenges (Bhaskar et al., 2020). It is closely related to energy use which is responsible for almost 60% of greenhouse gas emissions (GWG) (Fiorini and Aiello, 2019). In addition to climate change, another factor of great importance in energy activity is that it is based on fossil fuels, which are finite resources (Lin and Zhu, 2019). The industrialization has been one of the main variables for the increase in GWG emissions, mainly as a consequence of electricity consumption and fuel burning (Fernando and Hor, 2017) On the other hand, energy consumption is one of the elements that most affect the competitiveness of the Colombian industry (Colombia productiva, 2021). The final energy of the Colombian sector, which in 2021 was 304 PJ, has significant participation in the national energy consumption of 22%, ranking second; however, there is an excellent opportunity to improve its use since the potential for Energy savings and avoided emissions for this sector are in the order of 21.67-39.3% and even 80% due to direct heat uses according to the report of the Indicative Energy Efficiency Action Plan-PROURE 2022-2030 (UPME, 2022)

SMEs play a crucial role in the transition with a high proportion of energy use (Manrique et al., 2018). Therefore, improving energy efficiency is key in the shift towards sustainable energy systems and net zero emissions (Johansson et al., 2022). In Colombia, the term SMEs according to Decree 957 of 2019 paragraph 13, refers to the group of small and medium-sized companies with values of income from annual ordinary activities that vary depending on the economic sector in question; this is the case in the manufacturing sector, the range is more significant than 23,563 UVT and less than or equal to 1,736,565 UVT, for the service sector the range is more significant than 32,988 UVT and less than or equal to 483,034 UVT and for the trade sector the range is more significant than 44,769 UVT and ≤2,160,692 UVT. This group of companies represents a potential dynamic element of the economy in Colombia since it has a high business representation of 96.4%, is responsible for approximately 80% of employment, and generates 35% of GDP (Ministerio del Trabajo, 2019).

Many studies find that small and medium-sized enterprises (SMEs) encounter more barriers to adopting energy efficiency measures than large companies. The most common barriers for SMEs appear to be more information (Schleich and Fleiter, 2019) on energy efficiency measures, lack of capital, and lack of staff time. When energy efficiency measures are associated with technological change, the barrier may be that the commercial technology offered needs to be adapted to the technical and economic scales of the processes involved (Manrique et al., 2018).

Other obstacles that prevent the implementation of Energy Efficiency measures in SMEs are related to lack of awareness, lack of skills (Kalantzis and Revoltella, 2019), and low priority to energy efficiency by management (Marchi et al., 2018) (Bosu et al., 2023).

Due to the above, it is vital to overcome the barriers and define an instrument based on a protocol to carry out the energy evaluation in Colombian SMEs that allows defining an action plan and determining measures to improve energy performance; one way to achieve this is through energy audits, 15. (Jochem and Gruber, 2007) (Andrei et al., 2021) (Lisauskas et al., 2022) (Majaty et al., 2023).

An energy audit is a systematic approach to the inspection and analysis of the energy consumption of a plant, a building, a system, or an organization (Javied et al, 2015); it constitutes an instrument to improve energy efficiency in facilities (Yajima and Arimura, 2022) and is one of the most effective tools for energy management (Moya et al., 2016), whose main objective is to produce goods and provide services with the lowest energy cost and environmental effect (González, 2019). According to ISO 50002, the energy audit is defined as the energy performance analysis that can be carried out in any organization, process(es), equipment, or system(s), to identify and prioritize improvement opportunities, reduce waste energy and obtain environmental benefits, this standard constitutes a valuable tool to carry out a systematic analysis of energy use and energy consumption in an organization, building, equipment, system(s) or process(es), and is considered a substantial piece in the development of an energy review, since it allows identifying and prioritizing opportunities for improvement, reducing energy waste and obtaining other non-energy benefits such as environmental ones (ISO 50002, 2014). Additionally, in a comprehensive energy management plan, the first step that is carried out is usually an energy audit that includes the diagnosis, analysis, and improvement of energy use in a facility (Bosu et al., 2023).

Although energy audits are crucial to reducing energy consumption and emissions, problems can arise from a lack of methodology and information on energy efficiency practices (Choi et al., 2019) (Carlander and Thollander, 2022) and implementation costs as companies tend to place more value on investment costs than energy savings (Kapp et al., 2022). Furthermore, often a poor-quality energy audit is the result of non-standardized audit procedures and recommendations, which lead to a negative impact on the adoption rate of energy efficiency recommendations, thus demonstrating the economic value of a given recommendation it turns out to be vital for its final implementation (McLaughlin and Choi, 2023).

A well-structured energy audit is an essential first step for the success of energy management practices in industrial companies (Thollander et al., 2020) since it allows for overcoming information barriers to energy efficiency, facilitates the implementation of energy efficiency measures in SMEs and large companies (Kalantzis and Revoltella, 2019), and consequently contributes to the reduction of GWG emissions (Fernando and Hor, 2017). An energy audit is used to identify all energy streams in a facility, determine ways to reduce energy consumption per unit of product, or reduce operating costs. The energy audit is an effective tool for defining and developing a comprehensive energy management program and provides the basis for planning for more efficient energy use throughout the organization. (González, 2019) In an energy audit program in a vehicle store in Quito, the authors determined that the activities carried out established an energy baseline for the future implementation of the ISO 50001 standard (Briceño et al., 2022).

Some studies have shown that energy audits are more crucial for SMEs than larger organizations because they have the better internal knowledge and can more easily mobilize the necessary financial resources to implement investment recommendations from an audit to an Energy management System-SGE. (Jochem and Gruber, 2007), while the latter needs to prepare to carry out costly energy audits (3rd level) with many measurements; therefore, such companies should use a simplified methodology (Lisauskas et al., 2022).

Energy audits carried out in manufacturing SMEs in Sweden show that the calculated (mainly technical) potential to improve energy efficiency varies between 16% and 40% of the total end use of energy (Thollander et al., 2020). However, other studies have estimated the energy efficiency potential of industrial SMEs in the European Union and the EU at more than 20-25% (Andersson et al., 2018) (Kalantzis and Revoltella, 2019); said potential remains untapped mainly although many energy efficiency investments are financially profitable and generally require limited capital expenditure (Kalantzis and Revoltella, 2019).

Boharb A et al., 2016 when evaluating the impact of an energy audit carried out in an industrial facility in Morocco, concluded that the various actions proposed resulted in a reduction of energy consumption by 13.6% and 1.4%.

The energy audit is based on DIN EN 16247-1: 2012. It is a fundamental step for companies that want to improve their energy efficiency and reduce energy consumption (ISO 50002, 2014). As part of compliance with the requirements in Sweden, the Energy Audits in Large Companies Act (EKL) came into force in 2014 (SEA, 2019). According to EKL, large companies must carry out an energy audit every 4 years, which must be carried out by a certified energy auditor. However, if a company has implemented an energy management system certified to ISO 50001, it is possible to perform the energy audit internally as long as other requirements are met (Andersson et al., 2021).

Within the framework of the energy transformation of Colombia as a response of the energy sector to climate change, the regulatory framework is established through the issuance of (Law 697,2001), (Law 1715, 2014) and modified the latter (Law 2099, 2021) to promote the rational and efficient use of energy and provide a series of tax incentives such as VAT exclusion, income discount or deduction, tariff exemption, and accelerated depreciation; following the indicative goals of energy efficiency established in the PROURE Action Plan (UPME, 2022), the latter which considers the performance of an energy audit of buildings and production processes of any kind within the measures of efficient management of GEE energy, to access tax benefits in the 2022-2030 period, which represents an opportunity to overcome the cost barrier. Therefore, this study could serve as a guide to promote and drive the performance of energy audits in SMEs of other sectors.

This study presents the current practices and requirements for a profitable energy audit (so that the expected benefit of the improvement practices is less than the cost) in SMEs based on the ISO 50002 standard and its connection. -contribution to energy management and the reduction of carbon emissions; likewise, the findings of an energy audit carried out in an SME in the non-metallic mineral sector are exposed, which includes energy analyses adopted to improve energy efficiency, the expected energy savings, and the evaluated benefits of the proposed energy management practices through a case study applied to an SME in the non-metallic mineral sector.

2. MATERIALS AND METHODS

In the present study, a descriptive and exploratory analysis is carried out considering the guidelines or requirements of the ISO 50002 and its application in energy management based on the ISO 50001:2019 standard and reducing carbon emissions. As a practical way of connecting the theory or premise raised, the application is carried out *in situ* in an SME in the Non-Metallic Minerals sector. The scope established in the energy audit was the gypsum and mix processing area, and the Limit determined was the natural gypsum grinding and calcination processes; however, preliminary analysis and evaluation of energy consumption are carried out at a general level in the SME, which provides helpful information for planning the energy audit, in order to meet the objective of improving energy performance fixed in the organization.

2.1. Calculation of CO_2 Emissions

The CO_2 emissions were estimated according to the energy saving potential and using the following equation 1. The emission factor used for electricity corresponded to 0.166 KgCO2/KWh; which was taken from UPME.

$$CO_2 \textit{ dejado de emitir } (KgCO_2) = \textit{Ahorro energético } (Kwh) \times \textit{Factor de emission } (KgCO_2/Kwh) \quad (1)$$

2.2. Data

Information corresponding to the year 2019 was collected; additionally, teams carried out exhaustive tests, which contributed significantly to the analysis and evaluation of energy performance; and improvement opportunities.

The three shifts correspond to the following time slot; Shift 1: From 6:00 a.m. to 1:00 p.m.; Shift 2: From 2:00 p.m. to 9:00 p.m.; and Shift 3: From 10:00 p.m. to 11:00 p.m. of the same day and 12:00 a.m. to 5:00 a.m. of the following day.

For the economic valuation of the economic savings calculated from natural gas and electricity, the average energy price of the year 2019, which corresponded to \$1,950/m3 and \$367/KWh.

2.3. Selection of the SME in the Non-metallic Minerals Sector

The SME selected to carry out the energy audit corresponds to the non-metallic mineral sector, which plays a vital role in the development of society; since it provides the critical materials for the construction of the infrastructure and both its production and consumption of energy are driven by urbanization (Choi et al., 2019). Additionally, this sector constitutes the second sector of the industry that most impacts energy consumption in Colombia with 19%, according to the study "First Balance of Useful Energy for Colombia and Quantification of Related Energy Losses and the Energy Efficiency Gap." This type of sector's most significant energy uses corresponds to direct heat and motive power. Furthermore, it is estimated that the savings potential in this sector is 1.4 TWh/year (García et al., 2017).

The company under study has more than 50 years of experience in the Colombian market, is dedicated to the production of finishing systems and mortars for construction, non-metallic industrial minerals, and functional pigments derived from calcium carbonate and barite, and it is positioned nationally as a leading company in the supply of finishing products for construction.

3. RESULTS AND ANALYSIS

Next, a descriptive analysis is presented where the ISO 50002 standard for energy audits and its role in energy management is based on ISO 50001 studied. Finally, the application case is presented.

3.1. ISO 50002 and its Application in Energy Management in SMEs

The ISO 50002 standard helps develop an energy audit by establishing a minimum set of requirements to identify opportunities to improve energy performance, reduce energy losses and obtain environmental and financial benefits. An energy audit is the key to a systematic approach to decision-making in energy management, and its effectiveness varies with the organization's size. For example, some studies have established that audits may be less effective for larger organizations because information barriers are lower (Schleich and Fleiter, 2019). In SMEs, high-level audits are less effective due to the application costs given the limited financial resources that this type of organization presents. Based on the premise established by Cañizares et al., that the best energy management can be achieved through an energy management system (Cañizares et al., 2014), the latter defined as a systematic and continuous approach to sustainable energy improvement (Javied et al., 2015), and that such energy management can be implemented following ISO 50001:2019 guidelines of ISO 50002 can contribute to the implementation, maintenance, and continuous improvement of an energy management system based on ISO 50001 supporting: energy review, energy baselines, energy indicators, energy performance evaluation, and internal audit, given that this standard provides guidelines or relevant information for data collection, monitoring, measurement and analysis of: energy use and consumption; and energy efficiency, as well as in the identification of opportunities to improve energy performance, as specified in Figure 1.

The energy audit process based on ISO 50002 involves a series of steps that encompasses: The energy audit planning, the opening meeting, the data collection that can be done before or after the measurement plan, the measurement that can be reviewed before the start of the audit or during the site visit based on the auditor's findings, completion of the site visit, analysis of current performance data, identification of opportunities for improvement with a cost-benefit assessment and an action plan to reduce energy consumption, the audit report and the closing meeting. When the cost of energy and the opportunities for reduction in SMEs are proportionally small, the energy audit cost must be appropriate for the application. Therefore, the methodology and the way of approaching an energy audit will determine the effectiveness of its implementation, especially for SMEs where not all the requirements of the standard will be applicable; some of the requirements will be too expensive and will not be relevant for the objective of the audit, aware of the above, it is presented in the following Table 1. the guidelines and the degree of information to carry out an audit in SMEs according to ISO 50002.

3.2. Case Study

Next, Figure 2 presents the methodology adopted in SMEs, in which it is possible to assert that the energy audit process proposed by ISO 50002 contributes to the planning for the collection of data applicable to energy, the performance of the energy review, and the evaluation of the energy performance of the ISO 50001 Standard.

3.2.1. Energy data collection plan

Data collection constitutes the starting point for developing an exhaustive study of the use and consumption of energy and energy efficiency in any system, area, equipment, or process. According to the NTC ISO 50001 standard, the organization must ensure that the key characteristics of operations that affect energy performance are identified, measured, monitored, and analyzed at planned intervals. The data to be collected includes electrical energy consumption of the local equipment, measurements to be made, production data, energy costs, information corresponding to the description, mode of operation and equipment operation (technical data sheet of the equipment), maintenance plans, energy indicators, project(s) currently or future development(s) that may affect energy performance, energy audits or previously developed studies, electrical plans, process diagrams, company philosophy, Objectives set by the organization that is related to energy aspects (for example environmental or sustainability plans that mention energy aspects or initiatives of specific divisions that are related to energy performance), the legal framework applicable to the organization related to energy efficiency, use and consumption of energy. Table 2 presents the proposal for the data collection plan. Other aspects to consider if performance evaluation is carried out are data to evaluate the effectiveness of action plans when to monitor and measure, variables to establish energy performance indicators-EnPIs, actual vs. expected energy consumption, and when to analyze and evaluate the results.

3.2.2. Analysis of energy use and consumption based on measurement and other data

As the first step of the energy review of ISO 50001, An analysis of energy use and consumption was carried out initially globally and then in the Plaster and Stucco area delimited in the scope.

Figure 1: Diagram of the contribution of the NTC-ISO 50002 in the ISO 50001

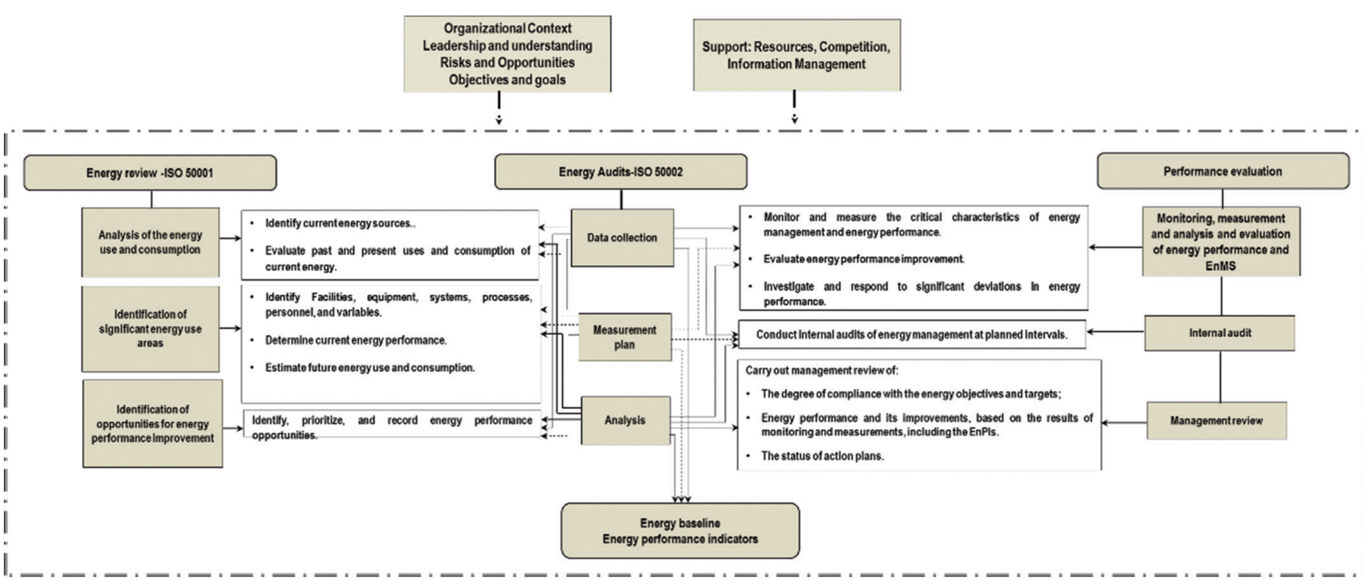


Table 1: Process and requirement to carry out an energy audit according to ISO 50002 in SMEs

	Audit Planning	Opening Meeting	Data collection	Measurement Plan	Conducting the site visit	Analysis	Report and Closing Meeting
Energy Audit in SMEs	The stage that contemplates: 1. The scope, limits, and objectives of the audit. 2. Needs and expectations to achieve the objectives. 3. Commitments of the organization in time and other resources. 4. Representative of the organization responsible for the audit process. 5. Period to carry out the audit. 6. Technical, economic, human resource, and relevant information requirements. 7. Evaluation criteria and classification of opportunities for improvement. 8. The process to agree on any change in the scope of the energy audit. 9. Expected deliverables and report format.	Whose purpose is to socialize the auditor to the stakeholders, the objective (s), scope, limits, and methods of the energy audit; additionally, the agreements for the audit must be reviewed.	Collect energy data appropriately and supports the audit objectives.If it is the first audit, it will be necessary to consider the following: 1. General or daily energy data according to the sources, systems, or equipment, including load profiles. 2. Detailed characteristics of energy uses. Covering single. line diagrams or graphic representations of flows or relationships between elements such as production, emissions, reprocessing, and waste, among others, that interact in the process. 3. Determination of relevant variables for energy; for example, production and employment, among others. 4. Current value of energy rate. 5. list of equipment, including nameplate data, operation scheme, and estimation of load factors.	It is how the magnitudes to measure are quantified and examined to identify and evaluate energy performance and compliance with the audit. The considerations to take into account in the measurement plan are: 1. Methodology of the measurements, including the calculation methods, the range of applicability, validity of results, and their precision, repeatability, and uncertainty level. 2. Personal competencies to measurement. 3. Check proper installation and operation of the measuring equipment. 4. Representative intervals of data to be measured. 5. Relevant variables that correspond to operating parameters and production data, among others. 6. Relevant measurement points, identification of additional measurement and associated measurement processes and equipment, and installation feasibility.	During the site visit, the energy auditor (s) must: 1. Observe, understand, compare, and evaluate energy uses and consumption from the information collected against the limit, objective (s), and agreed methods of the energy audit and others associated with energy performance (DE). 2. List processes and areas for analysis and get preliminary ideas and opportunities to improve Energy performance. 3. Ensure the procedures, measurements, observations, and representative data. 4. Immediately report any unexpected difficulties. Additionally, the energy auditor must agree with the organization: 5. Identify the people to provide access or accompany the visit. 6. Give the energy auditor access to relevant documents such as plans,	For an energy audit to be effective, the energy auditor must consider three aspects: 1. Analysis of current energy performance that includes knowing the energy consumption by use and source; considering historical patterns of energy performance; reviewing consumption profiles to identify anomalies; comparing performance with benchmarks of similar processes; studying energy performance and relevant variables; and assessing existing performance indicator (s) to distinguish inefficiencies; and if it is essential, a proposal for a new energy performance indicator (s). If any action to improve energy performance associated with equipment, processes, or systems was established, carry out the respective evaluation. 2. Identification of low.cost improvement opportunities to confirm feasibility or suitability with energy savings and obtain some non. energy benefits based on the previous analysis, design, and configuration options to address the system's needs. (The minimum energy consumed by a system to deliver a product or service), the operational useful life, condition, operation, and level of maintenance of the audited objects, the technology of existing energy use compared to the most efficient on the market, best practices, including operational controls and behaviors, future energy use, and changes in operation. 3. Evaluation of improvement opportunities focused on energy, economic savings, and other non.energy benefits such as environmental, productivity, or maintenance, among	The audit report shall include the following topics: Executive Summary, Back.ground, Audit Details, Energy, Opportunities to Improve Energy Performance, Conclusions and recommenda. tions. In the closing meeting, the results achieved in the energy audit are explained in a way that facilitates decision. making for the organization; it is established whether or not another additional analysis or follow.up by the energy auditor is required.

Table 1: ***(Continued)***

Audit Planning	Opening Meeting	Data collection	Measurement Plan	Conducting the site visit	Analysis	Report and Closing Meeting
		Additionally, if it is not the first audit to address: 6. Audits or previous studies related to energy or energy performance. 7. Future plans that may affect energy performance. and 8. Maintenance programs.	7. Duration and frequency of measurement, e.g., individual data points or continuous monitoring. 8. Calibration and traceability of the measuring equipment	manuals, and other technical or historical documentation. 7. Allow the installation of energy monitoring equipment and data loggers.	others, calculated using technology improvement opportunities compared to the energy baseline and considering the return of investment, expected operating lifetime, necessary investments, standardized costs or supplier information, prioritization of opportunities to improve energy performance; and other criteria agreed in the audit plan.	

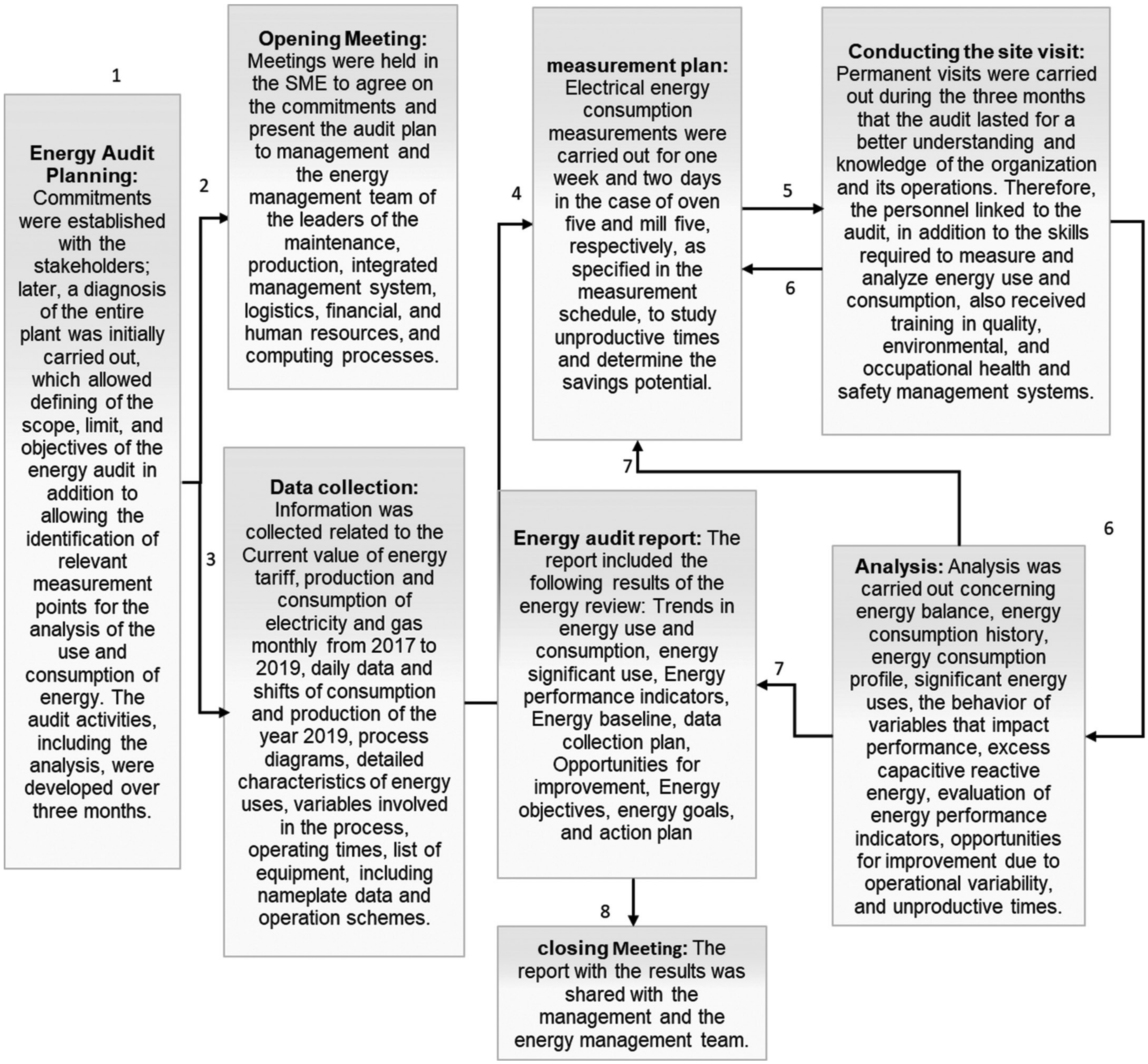
Table 2: Data collection plan SME

Collection Objective: Improve energy performance and management in the Plaster and Mix area.											
Data or variables to collect	So that? (Analyze energy use or consumption, evaluate the performance)	Where to collect the data or variable	Frequency	required resources		Where will the information be stored	Other aspects to consider if measurements are made				
				Responsible staff	Equipment and calibration certificate		When to measure	Relevant variables	Operational Criteria (If Applicable)	*Static Factors (If Applicable)	**Data treatment

*The static factor is an identified factor that significantly impacts energy performance and does not change routinely, e.g., facility size, product variety, number of shifts, and installed equipment design.

**Data processing includes graphs and tables drawn from the measurement results, the methods used, and any assumptions made, including the range of applicability of the calculations and the appropriate quality and validity checks of the results. E.g., mass balance and energy, among others.

Figure 2: Energy audit process according to ISO 50002 in SMEs



3.2.2.1. Energy description of the SME

In its organizational and energy structure, the SME has two production areas: Plaster and Stucco and Carbonates, with installed capacities of 644 HP and 1118 HP respectively, in addition to this are the administrative teams and other services that are subdivided into four circuits, the first two are a main compressor and a backup one with a total installed power of 226 HP; the third is single-phase, the latter is made up of two circuits: (a) Single-phase Carbonates: it has all the lighting loads, unregulated sockets, from the areas of Mill 6, Mill 7, Micronized, Maintenance Workshop, Water Plant, Grinding 1, Shredded 2, Logistics Office and Warehouse; and (b) Single-phase Mortars: includes the charges of Mixing Tower 2, Mixing Tower 3, Mixing Tower 4, Mixing Tower 5, Furnace 3, Furnace 5, Maintenance and Production Offices, Laboratory, Casino, Storage Warehouses and Mill 5; and the fourth office circuit where, according to measurements carried out in this circuit, most of the load is air conditioning equipment with 67%, followed by 27% of unregulated loads such as lighting and loads other than computers. Moreover, finally, regulated charges such as computer equipment contribute 6%.

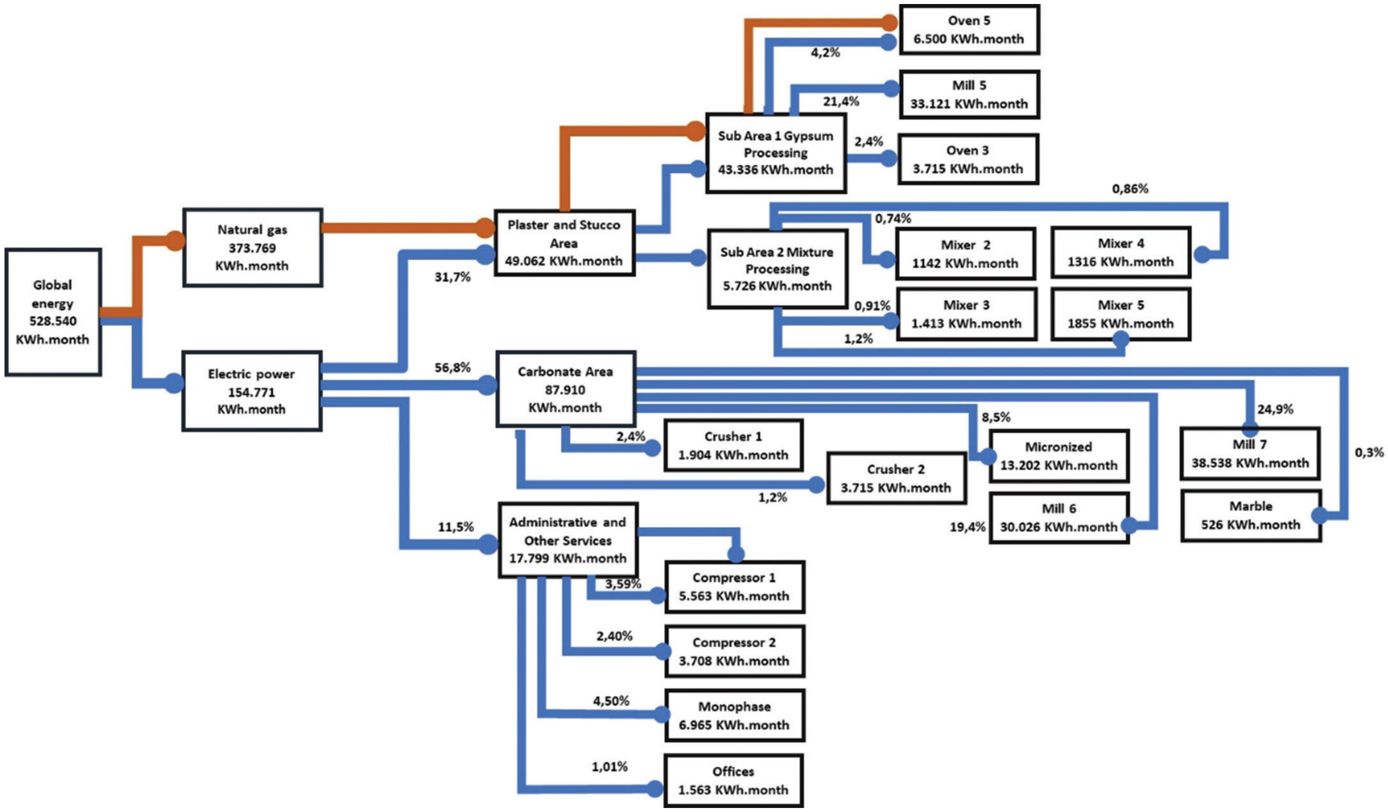
In the energy diagram shown in Figure 3; The uses and types of energy used in the different production processes are presented, and the energy flows and the input and output energy of the SME for each process are detailed.

3.2.2.2. Identification of the types of energy used in the plant

The type of energy used in the plant are:

- Electrical energy is used in equipment such as pendulum mills, compressors, bucket elevators, feeding belts, endless screws, fans, mixers, crushers, classifiers, computer and office equipment, lighting, and air conditioning.

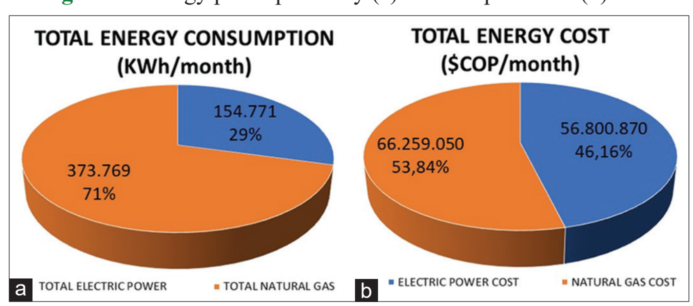
Figure 3: Energy diagram of the SME



- Natural gas is required only in kiln 5 for the natural gypsum calcination process.

Figures 4a and b show the monthly average energy consumption and costs. Again, it is evident that the energy with the highest consumption is natural gas; however, concerning total costs, energy participation is close to half.

Figure 4: Energy participation by (a) Consumption and (b) Cost



3.2.2.3. Evaluation of past and current uses and consumption of electrical energy

In the period analyzed from 2017 to 2019 (Figure 5), there was evidence of an increase in electricity consumption of 13% and 7% in the years 2018 and 2019, according to 2017, while natural gas presented a significant decrease of 42 % in the year 2018 because some modifications were made in the process such as the change of the raw material and the raw material was covered, which reduced the impact exerted by the environment, which is observed from July (Figure 36) and in 2019 there was an increase of 4%.

In the analysis of the consumption of electrical energy in the plaster and stucco area in the period from July to December of the year 2019, where the measurement was installed, variations in consumption from 1 month to the next are reflected, ranging from 7%-8% up to 53% considering that the months with the highest energy demand were November and September, as shown in the following Figure 6.

As part of the energy review in the SME, a preliminary analysis of the average consumption per hour, day, shift, and month of energy applications was carried out; and then the Pareto diagram was developed to establish the significant electrical energy uses considering mentioned, that gas is only used in oven 5.

3.2.2.4. Preliminary analysis of energy use in SMEs

In the analysis of the average consumption per day, per shift, and month, the percentile tool (Microsoft Excel conditional format) was used, which allows for describing the behavior of a variable, in this case, consumption, dividing the series of values into different numbers of percentage parts. Equal, in the percentile evaluation, three colors are distinguished that represent the following:

The results of the analysis of the average consumption day of the period between July and December 2019 show minimum consumption values in December, October, and also April; the latter, especially in the case of natural gas energy, values are presented as maximum mainly in November, additionally February for natural gas; and July and September for mixers (Table 3). Regarding the average consumption per shift of energy uses in

Figure 5: Consumption history. (a) Electric Power; (b) Natural Gas

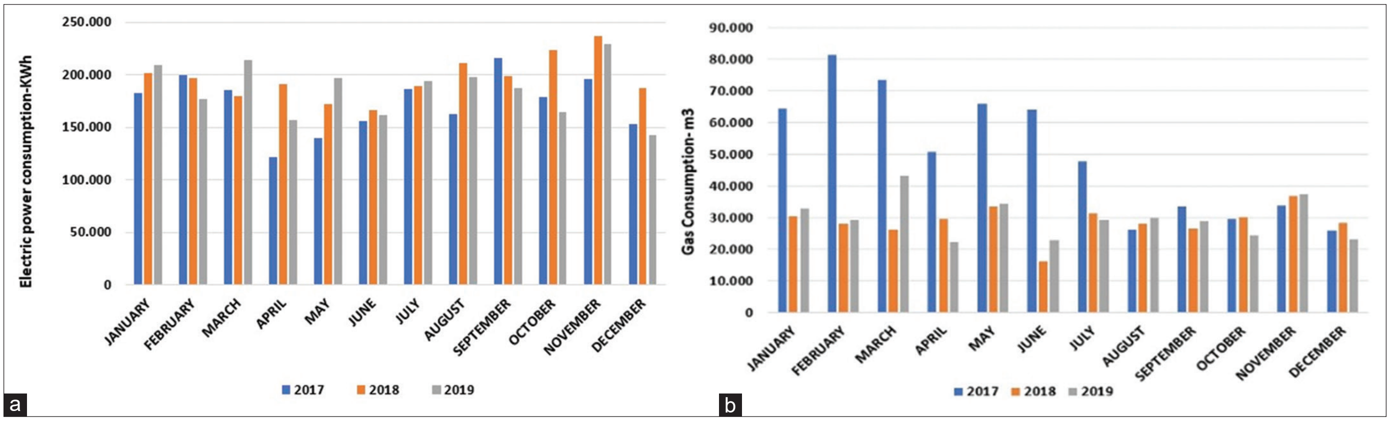
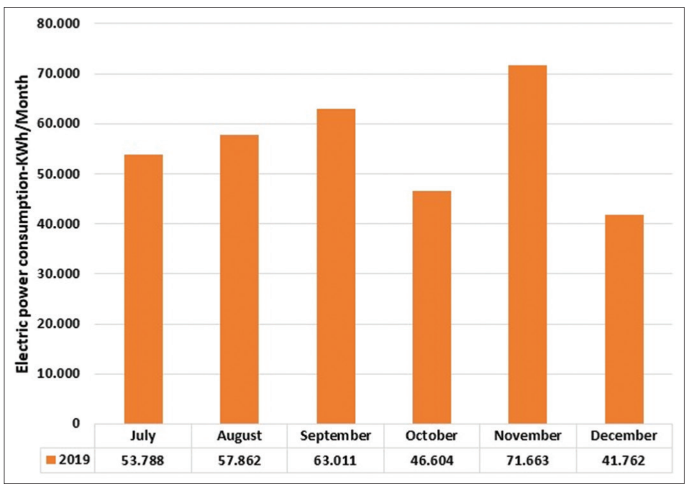


Figure 6: Historical consumption of electrical energy plaster and stucco area



2019, it can be seen that minimum consumption is reached on weekends, and mainly shift three exhibits low demand.

According to the profile of average gas consumption per hour in 2019 (Figure 7), the same pattern of behavior can be seen in the different months; given that, at 05:00, the oven is turned off; therefore the consumption is zero, there are decreases in demand at 1:00 p.m., 6:00 p.m. and 9:00 p.m., in addition to the above, it is observed that consumption is close in the time slots from 12:00 a.m. to 4:00 a.m.; 06:00 to 11:00; 3:00 p.m. to 5:00 p.m. and 7:00 p.m. to 8:00 p.m. Evaluating the average electricity consumption per hour in the plaster and stucco area, it is recognized several moments in which the energy consumption during the day is close and stable, except for hours 05:00, 13:00, 18:00 and 21:00, where the demand for energy decreases; Additionally, it is highlighted that in October, July, and December, there are minimum values of energy consumption.

Studying the profile of average consumption of electrical energy per hour of mill 5 in the period between July and December in the year 2019 (Figure 8), similar behaviors are exhibited in most of the months except for July and October, where consumption was lower than 80 KWh from 10:00 p.m. to 5:00 a.m. Additionally, it was found that the regular average consumption of the micronized equipment is lower than mills 5, 6, and 7, given that it is below 30 KWh except for July and October, where the demand reached up to 80KWh. On the other hand, according to the trend of the three mills, that mill 7 is the highest consumption. Finally, in the analysis of the average hourly consumption profile of the administrative circuit and other services, it is specified that the behavior of the office circuit was similar in all months, with a maximum demand of 6 KWh reached at 2:00 p.m. and 3:00 p.m. hours, consumption was stable at night and early morning and corresponded to 2KWh. While for compressors and single-phase, the behavior was heterogeneous in all months, especially from 05:00 to 17:00, energy consumption during night and early morning hours are very similar in all months; they are in the range of 12-14 KWh except for December when in the case of compressors, it was 10KWh and 8KWh in a single phase. It is important to highlight that the single-phase circuit presents a reduction in consumption due to the change in the company's distribution boards that were carried out in December, which had hot spots; in addition, photocells were installed in most of the circuits. Lighting guarantees the automatic switching on and off the luminaires.

3.2.3. Identification of significant energy uses-USE

It was identified, according to the Pareto of electricity consumption at a general level, that 80% of the total consumption of electrical energy that is part of 20% of the equipment or processes in the SME is concentrated in mill seven mills 5, mill 6, micronized and compressors (Figures 9); Regarding the area of plaster and stucco, said the share of electrical energy consumption is centralized in mill five and kiln 5 (Figure 10).

After recognizing the significant energy uses in SMEs as required by ISO 50001, we proceed to determine the relevant variables in the Plaster and Stucco area; the study focused on the mill five and kiln five equipment since they constitute a substantial consumption of electricity and gas; and represent considerable potential in improving energy performance.

3.2.4. Relevant variables

The main variable that was determined in the different processes was production. Different techniques were used to assess whether the variable significantly affects energy consumption, such as energy consumption trend graphs and relevant variables against

Table 3: Average consumption day of energy use-year 2019

Mes	Average daily consumption-kwh/day																Consumption	Total Electric Energy Consumption
	Administrative and Other Services			Carbonate Area						Plaster and Stucco Area								
	Offices	Monophase	Compressor	Marmolina	Crusher 2	Crusher 1	Micronized	Mill 6	Mill 7	Mixer 3	Mixer 2	Mixer 4	Mixer 5	Mill 5	Oven 5	Oven 3	Natural Gas	
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,265	6,545
february	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,115	6,273
march	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,589	6,979
april	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	858	5,261
may	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,128	6,517
june	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	964	5,629
july	71	323	380	19	177	4	716	1,058	1,438	0	73	56	94	1,164	222	127	1,002	5,923
august	74	342	329	18	158	0	431	1,198	1,497	27	43	53	80	1,267	257	140	1,091	5,914
september	80	354	353	19	165	107	347	1,125	1,368	67	20	57	100	1,424	275	157	1,227	6,019
october	68	304	354	22	203	95	580	1,017	1,171	63	50	40	59	978	197	115	871	5,317
november	64	270	410	29	29	134	963	1,440	1,898	69	41	52	48	1,671	323	185	1,462	7,626
december	52	208	250	9	95	87	411	880	1,248	37	28	40	41	916	180	105	796	4,587
Average	59	258	346	19	138	71	492	1,120	1,436	53	43	50	70	1,237	242	138	1,114	5,055

High average consumption value
Percentile 50 is equivalent to the median average consumption
Low average consumption value.

time, simple scatter plots, coefficients of determination, and the P-value; this was applied later in validating energy baselines.

The validation of the production variable with monthly, daily, and shift energy consumption data is presented; The preceding was carried out through trend and dispersion graphs, in which it was possible to show a clear tendency to grow, for which it was concluded that the two variables production and consumption move together, in the same direction for most of the year analyzed time. In addition to the above, it was observed in the scatter graphs, especially with the production of packing silos, that the points seem scattered around the linear function shown as a trend line, indicating the presence of a relevant variable and the degree of linear association between the two variables is presented in each graph using R^2.

It is important to mention that in the SME, the production of plaster and stucco had initially been established as a relevant variable, and with this, the energy indicator had been set with which the monitoring and energy performance was quantified, but when performing the validation in the processes of oven five and mill 5, it showed great disparity when contrasting it with the consumption of natural gas and electricity respectively as shown in Figures 11, 12, 15 and 16, while when evaluating the production of packaging silo, a strong relationship was identified (Figures 13,14,17 and 18).

Another relevant variable potential that was analyzed was unproductive time. Considering that it is not measured nor monitored in SMEs, an energy audit was carried out following the guidelines of ISO 50002 in Mill 5 and Oven 5, as the case studies. The Figures 19 and 20, the planning of the audit and the measurement schedule are presented, respectively. Table 4 details the current transformers used to carry out the measurements with their respective calibration certificates.

Mill 5

In the Molino 5 process, where the grinding of natural gypsum is carried out, 12 induction motors participate, which corresponds to 16.3% of the total installed power and represents 21.42% of the total average consumption according to Pareto General, hence the importance of analysis in the identification and prioritization of opportunities for improvement.

The following six engines were analyzed:
Vibratory Hopper
Feeding Band
Hammer mill
Windlass
Windmill
Main Fan

Oven 5

The main function of oven 5 is the thermal transformation using a gaseous fuel; here, the calcination of natural gypsum is carried out, which is considered important as it is an online process.

This process is made up of 10 induction motors. Table 5 shows the inventory of motors for the two processes Mill 5 and Oven 5.

Figure 7: Hourly gas consumption profile

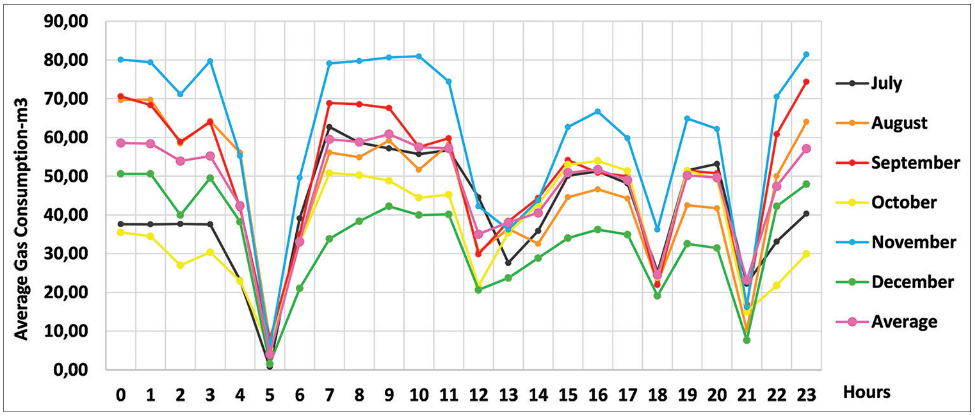
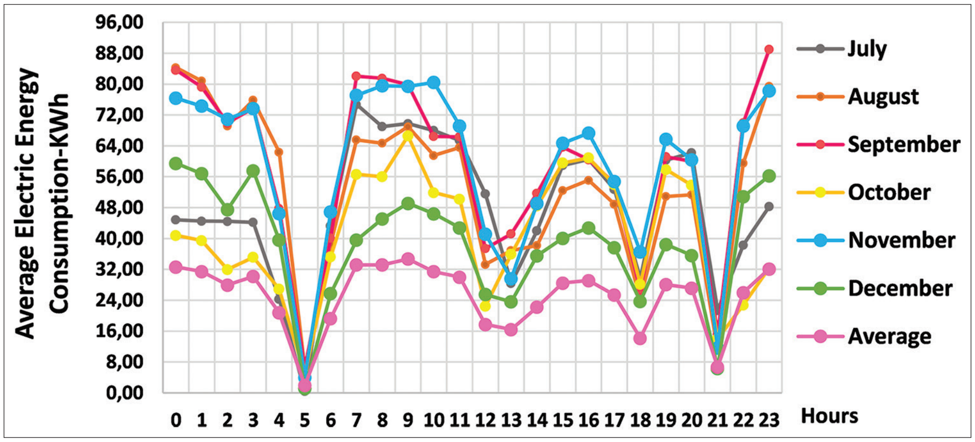


Figure 8: Hourly Mill 5 consumption profile



Quantifying the operating times of mill 5 in shifts and analyzing the feeding process made up of the Hopper, Band, and Hammer Mill, the unproductive time was estimated since it was possible to verify that the feeding band remains turned on without transporting raw material on repeated occasions. Thus, the savings by generating an automatic feeding control were quantified. The equipment ignition time was considered in the calculations. The following Table 6 shows the results.

Another diagnosis made in mill 5 was the analysis of productivity and load of the largest motors of the process and the motor that feeds said mill. The mill's feeding is carried out according to the pressure difference between the classifier; when the pressure difference is low, the feeder is turned on, and the raw material is loaded into the mill; the feeding process stops when the pressure difference exceeds the upper limit. Moreover, the mill feed has an on-off control; but it is not an ideal control for a process in which the feeding must be constant and guarantee maximum use; additionally, the main fan does not perceive notable changes to the moment of loading and unloading of the equipment, which suggests that more material could be transported using the same energy, estimating that the operating current in the load of the equipment should be 75 A; ideally, it should remain the same, without variations for make the most of the use of the equipment.

According to the recorded data of time (minute) in the measurements carried out, it was possible to calculate the percentage of load in which the mill operates, which is 13% (Table 7), a percentage that could be increased using a system of 4-20 mA power supply, that is to say, that the average produced amount of 1,526 ton/month is increased to 200.98 ton/month with an automatic feeding system.

Likewise, in Oven 5, it was observed for a week, and the unproductive time and savings that can be achieved per day were estimated, which is in the range of 90 KWh to 101 KWh, equivalent to COP 32.698 and 36.695, the Friday and Tuesday are the days of lowest and highest unproductive time, respectively. The results are shown in Table 8.

3.2.5. Improvement opportunities at SMEs

Table 9 summarizes the value of the investment and estimated annual savings of energy, economics, and CO_2 emissions that were not emitted in the plaster and stucco process by eliminating the unproductive times of mill five and oven 5.

3.2.5.1. Reactive energy excess analysis

The regulatory authority in Colombia, the Energy and Gas Regulation Commission (CREG), has adopted important measures to mitigate the effects of Reactive Energy in the National Interconnected System (SIN); it established in the CREG Resolution 097 in 2008 a cost for the transport of reactive energy produced by the demand that must not exceed fifty percent (50%) of the active energy delivered (kWh); this norm was modified by CREG Resolution 015 in 2018 and CREG Resolution 195 in

2020, and it dictates stricter measures for the penalty for reactive energy in Colombia; due to multiplying factor was defined and that must be applied after the thirteenth month of penalty. The cost of injecting capacitive reactive energy into the grid was also established. Therefore, the importance of carrying out an analysis to avoid the penalty increasing the energy costs.

Currently, the SME has a system of fixed capacitor banks that help to compensate for all the reactive energy generated in the production process, which comes from induction motors; however, the fixed capacitor banks can lead to problems of overcompensation.

As seen in Table 10, the SME does not present problems by excess inductive reactive energy; however, the injection of 370 kVA in total generated by fixed banks produced overcompensation in the grid. Table 11 calculates the value of the penalty.

Figure 9: Global electrical energy consumption

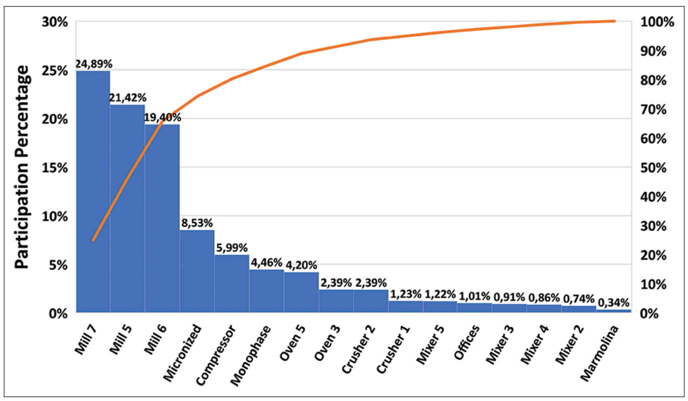


Figure 10: Electricity consumption Pareto of Plaster Pareto and stucco area

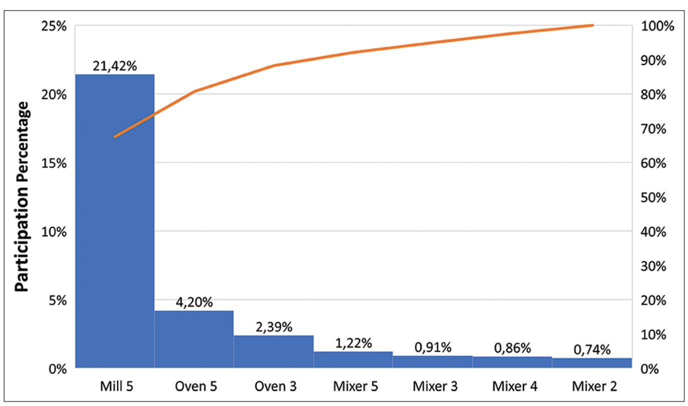
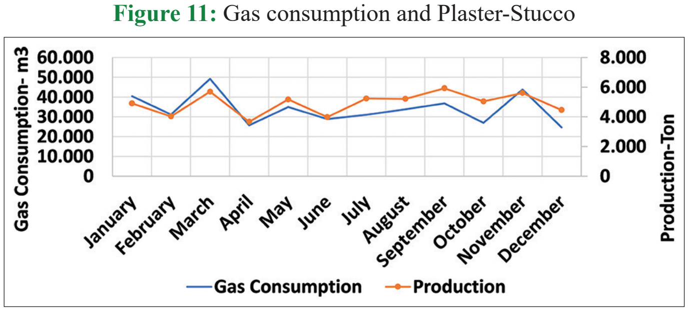


Figure 11: Gas consumption and Plaster-Stucco



If the company continues penalizing after the 13 month, the multiplying factor will be 2; in the 14 month, it will be three, and so it will continue until the end of the 2nd year (23 months), where the monthly payment must be 12 times the initial penalty.

3.2.5.2. Compressor analysis

The compressor analyzed was the AS30T; its brand of German origin is Kaiser; this equipment is composed of a dryer in-line, it has a motor of 30HP, and it generates compressed air for all the productive systems in the organization. The equipment that requires compressed air is butterfly and guillotine valves with pneumatic actuators, dust collectors, and pistons. The equipment does not

Figure 12: Linear regression Gas versus Plaster

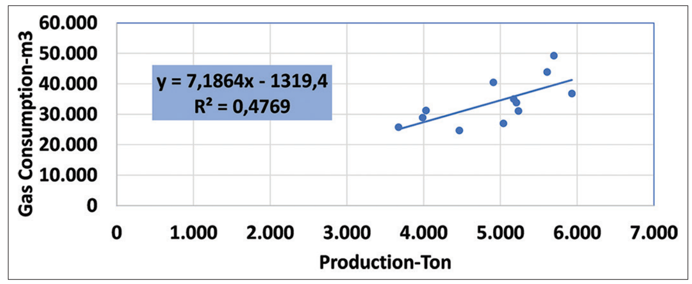


Figure 13: Oven 5 Consumption and Silo

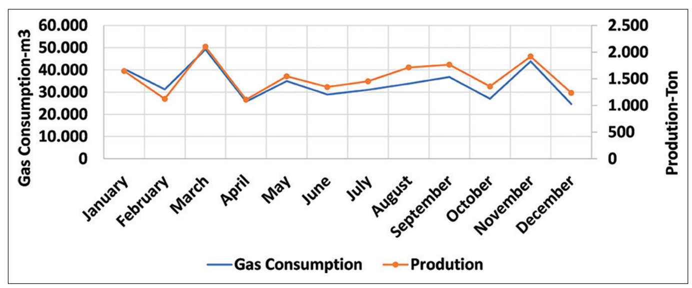


Figure 14: Linear regression Gas versus Silo

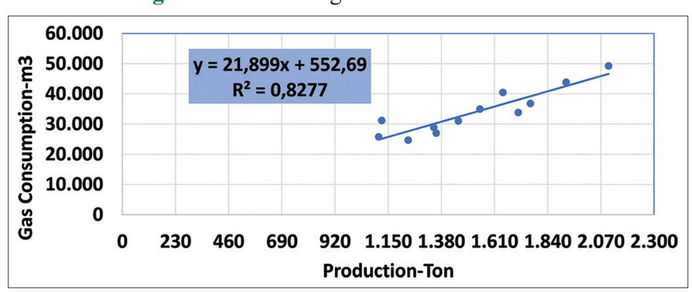


Figure 15: Mill 5 Consumption and production

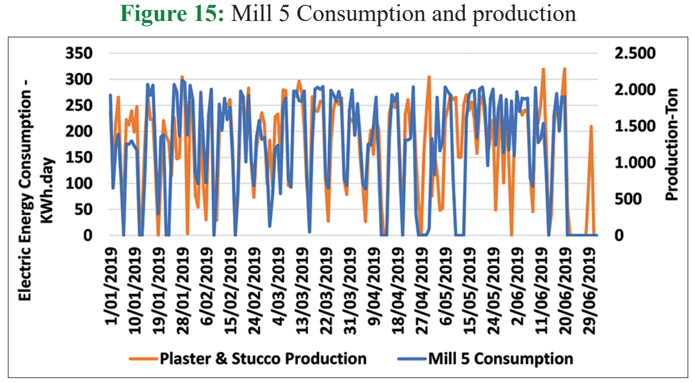


Figure 16: Linear regression Mill 5 versus Plaster

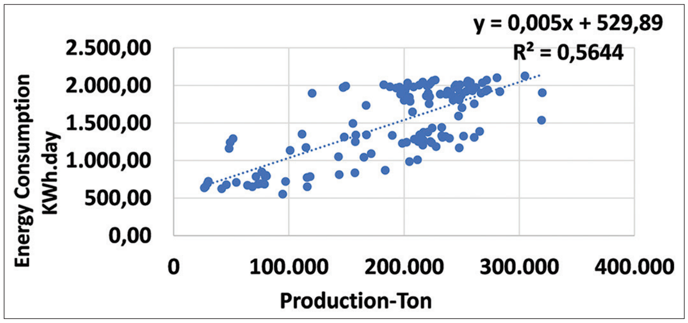


Figure 17: Mill 5 consumption and silo

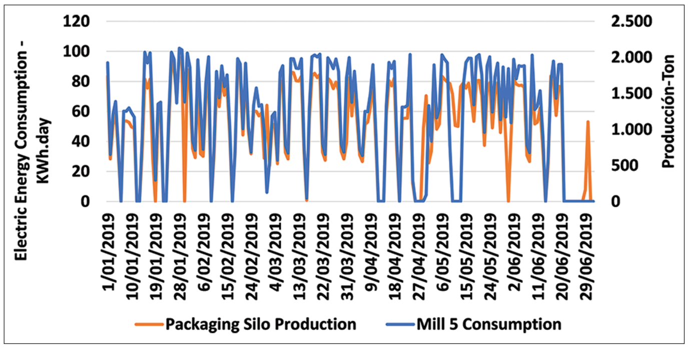
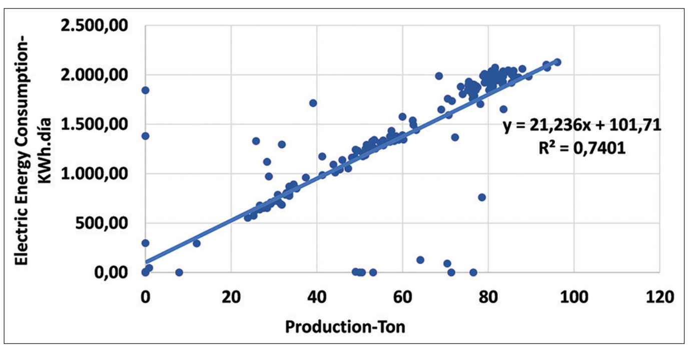


Figure 18: Linear regression mill 5 versus Silo



use a variable speed drive to adjust the electrical frequency and regulate the speed of the motor according to the demand required in the process. Therefore, it has generated energy losses and increased costs even for maintenance. In the following Figure 21 seen that the equipment remains turned on most of the time, and the power consumed is constant. According to the analysis of the use and consumption of energy carried out previously, the daily and monthly average consumption was determined as 326 kWh/day and 9,600 kWh/month.

The maximum demand for the equipment is 140 cfm, and the minimum is 20 cfm. However, it usually remains in low demand, which suggests that the equipment mostly supplies compressed air leaks; since the minimum demand must be ten cfm, it represents a measure to optimize and an opportunity to save energy.

In the Kaiser modeling software was made the evaluation and calculation of the savings potential for changing the compressor to one of 18.5 kW motor, which is 20% less than the size of the current equipment and with a variable speed drive, ensures that the motor only generates the energy necessary to energize the compressor. The results showed that supplying the same demand required 73.652 kWh/year, which is 30.75% less than the current equipment, and considering the present demand, the reduction would be of 39.177 kWh/year, it generates a saving of \$14.691.405/year. Additionally, if the leaks are eliminated in the compressed air system, and the constant load is reduced by 30c.f.m at ten c.f.m, it is possible to achieve a 20% more energy reduction to 26.377 KWh/year, estimating a saving of \$9.553.522/year, for a total saving of \$24.244.927/year and 10.882 kilogram of CO_2 emissions that were not emitted.

3.2.6. Current energy performance

The current energy performance of USEs can be determined through energy performance indicators and baselines. The energy baselines were established monthly and daily for shifts and analyzed in two equipment. The 06% energy consumption and production data were filtered to adjust the energy baseline. Likewise, the energy baseline was validated through the significance test or probability p-value, the analysis of residues, and distribution. The results showed that the linear regression model predicts the behavior of consumption with production due to the high degree of relationship that exists between the two variables, and that could be measured through the coefficient of determination-R^2, which in the two cases was above 0.80 (Figures 21 and 22). Additionally, when the significance of the model was evaluated through the F statistic, it establishes acceptance if $P < 0.05$; all were below that value; in the diagnosis of residuals, it is evident that these are independent, and the homoscedasticity was accomplished, because the residuals do not follow a trend, according to the graphs of probability observed the distribution is normal due to the points that follow a linear trend.

According to the energy baselines, the energy not associated with production represents 7.5% of average consumption for mill 5 in shift 1 and 3.6% in 2 and 3 shifts. In the case of oven 5, it constitutes 7.2%, 1.6%, and 2.3 in shifts 1,2 and 3, respectively. The energy not associated with production corresponds to the base energy of equipment operation, operating bad practices, and time outs because the production feed flow is not constant. Moreover, the consumption index formed by the quotient between energy and production (22.47 KWh/Ton in and 21.3 m3/Ton in oven 5) was lower in the first shift.

The performance indicators were established for the energy baselines that were previously defined. The three indicators evaluated were: specific consumption, Energy Efficiency, and Trend or Cumulative Sums-CUSUM.

3.2.6.1. Energy performance indicators of Oven 5-natural gas

According to the specific consumption index of 2019, only 30% of days operated were below the optimal levels of operation where less energy is required per unit produced (Figure 23), while that monthly occurred in 50% of the months. The monthly specific consumption indicator is 22 KWh/Ton; this value was exceeded in February, January, and, at a minimum dimension, March, and

Figure 19: Audit planning in the Mill 5 and Oven 5 processes

ENERGY AUDIT PLANNING							FPP-020 Version 0.0 2020
Scope: Gypsum & Mix Processing Area límits: Calcination y Natural Gypsum Grinding Objective(s): Calculate unproductive time; analyze flue gases and energy efficiency of the Oven. Responsible Personnel: Assistant and Maintenance operator Auditor: Jenny Lorena Valverde							
Date (day-month-year)	objective	Time to make the evaluation (hour)	Process(es)/ Team(s)/ system(s)	Activity(s) to be developed in the audit	Calibration equipment and certificates	Others Which? (for example, the need for additional measurement).	Evaluation o audit criteria-Observation
7/01/2020-08/01/2020	Study unproductive time	24	Mill 5	1- Assignment roles and responsibilities to the person participating in the audit. 2-Do opening meeting 3- Characterize equipment and operating conditions 4- Analyze the productive time of the feeding process of mill 5, which is made up of the Hopper, Belt, and Hammer Mill, to identify how long the equipment remains on without producing. 5-Analyze the behavior of the largest motors in the process and the motor that feeds mill 5 to evaluate the on-off control implemented in the mill feed in terms of productivity. 6-Analyze results 7-Generate opportunities for improvement. 8-Dissemination of results	Network Analyzer -(see the calibration certification number in table 22)	The two processes include electricity tariff, production, and electric energy consumption data.	Phase 1: Actual Operation Time and Cost vs. Ideal Operation Time and Cost. Phase 2: % grinding sub-operation and productive time.
2/03/2020-05/03/2020	Study unproductive time	120	Oven 5				Phase 1
Produced by: Auditor					Reviewed and approved by: Audit Leader-Maintenance Assistant		

Figure 20: Measurement schedule

MEASUREMENT SCHEDULE																					FPP-016 Version 0.0 2020
EQUIPMENT	DATA EQUIPMENTS					DATE MEASUREMENTS												VARIABLE(S) TO BE MEASURED	EQUIPMENTS USED IN THE MEASUREMENT (BRAND AND SERIAL NUMBER OF THE EQUIPMENT)	THE EQUIPMENTS ARE CALIBRATED	RESPONSIBLE PERSONNEL OF MEASUREMENT
	CURRENT			PLATE DATA		7/01/2020 MILL 5						8/01/2020 MILL 5									
	L1	L2	L3	HP	Kw	1 SHIFT		2 SHIFT		3 SHIFT		1 SHIFT		2 SHIFT		3 SHIFT					
Vibratory Hopper				15		10-11-12	6:00-14:00	10-11-12	14:00 - 22:00	10-11-12	22:00-6:00							Power and actual operating time	Network Analyzer CIRCUTOR CVM-C9	Yes (check table 21.)	Maintenance Operator
Feeding Band					3	13-14-15	6:00-14:00	13-14-15	14:00 - 22:00	13-14-15	22:00-6:00							Power and actual operating time	Network Analyzer CIRCUTOR CVM-C8	Yes (check table 21.)	Maintenance Operator
hammer mill				50		1-2-3	6:00-14:00	1-2-3	14:00 - 22:00	1-2-3	22:00-6:00							Power and actual operating time	Network Analyzer CIRCUTOR CVM-C4	Yes (check table 21.)	Maintenance Operator
windlass					3							7-8-9	6:00-14:00	7-8-9	14:00 - 22:00	7-8-9	22:00-6:00	Power and actual operating time	Network Analyzer CIRCUTOR CVM-C7	Yes (check table 21.)	Maintenance Operator
Windmill	59	62	65	75								1-2-3	6:00-14:00	1-2-3	14:00 - 22:00	1-2-3	22:00-6:00	Power and actual operating time	Network Analyzer CIRCUTOR CVM-C5	Yes (check table 21.)	Maintenance Operator
Main Fan	84	81	83	20	15							4-5-6	6:00-14:00	4-5-6	14:00 - 22:00	4-5-6	22:00-6:00	Power and actual operating time	Network Analyzer CIRCUTOR CVM-C9	Yes (check table 21.)	Maintenance Operator
						20/01/2020 OVEN 5															
burner turbine				3	2	7-8-9	6:00-14:00	7-8-9	14:00 - 22:00	7-8-9	22:00-6:00							Power and actual operating time	Network Analyzer CIRCUTOR CVM-C8	Yes (check table 21.)	Maintenance Operator
Oven	17	17	17	25	19	10-11-12	6:00-14:00	10-11-12	14:00 - 22:00	10-11-12	22:00-6:00							Power and actual operating time	Network Analyzer CIRCUTOR CVM-C7	Yes (check table 21.)	Maintenance Operator
Main Fan	17	17	16	20	15	13-14-15	6:00-14:00	13-14-15	14:00 - 22:00	13-14-15	22:00-6:00							Power and actual operating time	Network Analyzer CIRCUTOR CVM-C9	Yes (check table 21.)	Maintenance Operator

Table 4: List of calibration certificates current transformers portable network analyzers Open core current transformer calibration certificates for portable network analyzers

# TC	Calibration certificate	Serial number	Transformation relationship	# Tc	Calibration certificate	Serial number	Transformation relationship
TC1	ABT00000022994	8.1552E+13	200 A/5 A	TC6	ABT00000022999	8.1426E+12	200 A/5 A
TC2	ABT00000022995	8.1552E+13	200 A/5 A	TC7	ABT00000023024	8.16211E+12	50 A/5 A
TC3	ABT00000022996	8.1552E+13	200 A/5 A	TC8	ABT00000023112	8.16211E+12	50 A/5 A
TC4	ABT00000022997	3382001	200 A/5 A	TC9	ABT00000023113	8.16211E+12	50 A/5 A

April. The analysis by shift revealed that one shift, with 42%, is the highest percentage, while shifts two and three had 27% and 31% days of inefficiency. Also, the critical production value where the variation of the consumption index is minimal corresponds to a production level greater than 60 Tons per day.

According to the base 100 energy efficiency indicator, the process remained energy inefficient in the first 5 months and November 2019. The analysis of the behavior of daily energy performance (Figure 24) reveals that the days of greatest inefficiency were August 10 and 19, when the production was low by 15 Tons and 4 Tons, respectively; in addition to this, only 4 days were worked at maximum efficiency. Regarding the analysis by shift, it is evident that shift 1 is where the operation was most inefficient, with a percentage of 61%, while the other shifts were 48% of the days.

Table 5: Inventory of motors for the two processes Mill 5 and Oven 5

Process	Location	Type	Hp	Kw	Brand	Frame	Sf	Type sk	No	Sort	Ip	V		A		Cos fi	Rpm	Ie	Efficiency
Mill 5	Vibratory Hopper	Engine	15	11.19	Siemens		1.15		1LE0141-ICB86-4AA4-7		55	220	440	39.5	19.7		1760	IE2	91.00%
	Feeding Belt	Gearmotor	3.42	2.55	Nord		1.15	7731X	201807395-600 23592972		55	220	440	9	5.2		1730		81.40%
	Hammer mill	Engine	50	37.3	Siemens		1.15				55	220	440	128	64		1770	IE1	92.40%
	Windlass	Gearmotor	4.02	3	Nord			SK42	201068094-800		55	220	440				1685		
	Windmill	Engine	75	55.95	Siemens		1.15				55	220	440				1770	IE1	93%
	Main Fan	Engine	125	93.25	Weg	160	1.15		330-73		55	220	440	52	26		1765	IE1	90.20%
	whezzer	Gearmotor	28.6	21.3	Nord			180WX/4			55	220	440	60	35		1760		
	Cyclone Valve	Gearmotor	3.02	2.25	Nord		1.15	100W/4	201807935-600-2359272		55	220	440	9	5.2		1770		
	Conveyor Belt 1	Gearmotor	3.02	2.25								220	440						
	Conveyor Belt 2	Gearmotor	3.02	2.25								220	440						
	Auxiliary Fan		7.5	5.595								220	440						
	Dust Collector Valve	Gearmotor	2.95	2.2	Assi			MS90H2-4	1003107433		55	220	440	8.56	4.27		1650		81.40%
Oven 5	Dosing valve	Gearmotor	3.02	2.25	Nord			100H/4	201864114- 500 2449 7306		55	220	440	9	5.35		1730		
	Burner turbine	Engine	3	2.238	Weg	90S	1.15		140UT2015 1030033553		55	220	440	8.36	4.18			IE1	
	Oven	Gearmotor	24.8	18.5	Nord			180WX/4	201068094/15001744 8701		55	220	440	61.6	30.8		1760		
	Bucket Elevator	Gearmotor	4.62	3.45	Nord			100LA/4	35510000 18560732		55	220	440	11	6.73		1700		
	Dust Collector Valve	Gearmotor	0.74	0.55	Sew		1.15	R37DRS71M4	580264184701 000000		55	220	440	2.6	1.31		1700		
	Main Fan	Engine	20	14.92	Weg	160	1.15		05MAR151027546476		55	220	440	52	26		1765	IE1	90.20%
	Worm Screw 1	Gearmotor	3.42	2.55	Nord			100H/4	350100001 9510090		55	220	440	9	5.35		1730		
	Worm Screw 2	Gearmotor	3.42	2.55	Nord			100H/4	201807395-60023592903		55	220	440	9	5.35		1730		
	Worm Screw 3	Gearmotor	3.42	2.55	Nord			100H/4			55	220	440	9	5.35		1730		
	Cyclone Valve	Gearmotor	2.32	1.73	Nord			90H/4	311510000 20464424		55	220	440	6.15	3.55		1375		

Table 6: Operating Time, Unproductive Time, and Estimated Savings of Mill 5

Equipment/ USE	Time/Cost	Hammer mill			Feeder Belt			Vibratory Hopper		
		Shift 1	Shift 2	Shift 3	Shift 1	Shift 2	Shift 3	Shift 1	Shift 2	Shift 3
Mill 5	Actual Operating Time (hour)	4.30	4.52	5.25	1.45	0.97	5.67	0.65	0.73	0.85
	Expected Operating Time (hour)	0.72	0.81	0.94	0.72	0.81	0.94	0.65	0.73	0.85
	Unproductive Time (hour)	3.59	3.71	4.32	0.74	0.16	4.73	0.00	0.00	0.00
	Actual Operation Cost ($ COP)	$ 32,224	$ 30,700	$ 38,864	$ 1,384	$ 1,014	$ 5,882	$ 1,089	$ 1,089	$ 1,089
	Expected Operation Cost ($ COP)	$ 5,358	$ 5,483	$ 6,922	$ 682	$ 846	$ 971	$ 1,089	$ 1,089	$ 1,089
	Saving/Shift ($ COP)	$ 26,866	$ 25,217	$ 31,942	$ 702	$ 168	$ 4,911	$ 0	$ 0	$ 0
	Total saving. day($ COP)			$ 89,806						
	Expected saving. Month ($ COP)			$ 2,245,144						
	Expected saving. Years ($ COP)			$ 26,941,732						

Table 7: % Load grinding operation, Operating and Unproductive Time of Mill 5

Equipment	% Load grinding operation				Operating Time (Minute)			Unproductive Time (Minute)			% Operability		
	Shift 1	Shift 2	Shift 3	Average	Shift 1	Shift 2	Shift 3	Shift 1	Shift 2	Shift 3	Shift 1	Shift 2	Shift 3
Mill 5	10	15	14	13	410	410	410	314	386	385	76.6%	94.1%	93.9%

Table 8: Operating and unproductive time, expected saving of Oven 5

Equipment/ USE	Time/Cost	Monday	Tuesday	Wednesday	Thursday	Friday
		3/2/2020	3/3/2020	3/4/2020	3/5/2020	3/6/2020
Oven 5	Operating time (minutes)	1440	1440	1440	1440	1440
	Turned on time (minutes)	1440	1415	1440	1440	1440
	Time without Process (minutes)	350	349	330	323	319
	Potencia consumida (KWh/día)	405.46	410.00	404.64	412.48	406.75
	Saving in KWh	98.50	101.10	92.70	92.50	90.10
	Operating Cost-included unproductive time ($ COP)	$ 147,132	$ 148,779	$ 146,834	$ 149,679	$ 147,600
	Operating Cost-without including unproductive time ($ COP)	$ 111,370	$ 112,084	$ 113,185	$ 116,105	$ 114,902
	Expected saving ($ COP)	$ 35,762	$ 36,695	$ 33,649	$ 33,574	$ 32,698
	Expected saving-weekly ($ COP)			$ 172,378		
	Expected saving-Month ($ COP)			$ 689,512		
	Expected saving-Year ($ COP)			$ 8,274,144		

Table 9: Summary of expected saving for unproductive time

Process	Improvement opportunities	Type of opportunity	Saving-year				Estimated investment	IRR (Month)
			KWh/year	m^3/year	Kg CO_2/year	Saving $ COP/year		
Mill 5	Elimination of unproductive time, automating the start-up of the hammer mill and the feeding belt in the gypsum grinding process	Low investment	74,244		12,325	$ 27,247,548	$ 7,000,000	3.1
Oven 5	Elimination of unproductive time considering the 30 minutes that the equipment requires to reach the required temperature in the process.	Low investment	22,801		3,785	$ 8,367,967	$ 3,500,000	5.0
						$ 35,615,515 $ 25,115,515	$ 10,500,000	3.5

Table 10: Data of active, reactive, and capacitive energy month

Power \ month	January	February	March	April	May	June	July	August	September	October	November	December
Active-kwh	207,226	174,850	216,022	159,804	201,316	170,512	193,888	198,791	185,472	175,929	243,181	155,252
Capacitive-kvar	24,576	24,385	37,380	57,960	53,711	52,976	66,606	45,357	33,769	55,524	32,976	66,990
Reactive-kvar	55,811	41,572	48,736	46,464	57,525	46,007	35,962	44,925	51,792	46,834	52,134	32,114

In the case of the cumulative sums indicator, the gas consumption trend observed in 2019 corresponds to the following two periods:

i. Ascending from January to May and from October to November indicates that it was inefficient in this period.

ii. Descending from May to October and November to December, this period was energy efficient, generating savings.

Additionally, when monitored for shifts, the same previous behavior of variability between efficiency and inefficiency was

Table 11: Penalty value for presenting capacitive reactive energy

Power \ month	January	February	March	April	May	June	July	August	September	October	November	December
Capacitiva-kvar	24,576	24,385	37,380	57,960	53,711	52,976	66,606	45,357	33,769	55,524	32,976	66,990
$/Distribucion	103	103	102	99.49	101.46	99.43	98.55	101.73	103.59	101.91	99.46	108.45
$ Penalidad	2,535,955	2,522,653	3,827,690	5,766,415	5,449,488	5,267,381	6,563,987	4,614,193	3,498,143	5,658,445	3,279,835	7,265,070

Table 12: Presents the magnitude of the savings and energy and economic losses, and the CO_2 emissions that were not emitted in 2019 in each shift

Total	Shift 1		Shift 2		Shift 3	
	Savings -m³	Over Consumption -m³	Savings -m³	Over Consumption -m³	Savings -m³	Over Consumption -m³
	-13,930	16,769	-5,004	17,932	-5,004	17,932
Over Consumption Net-m³	2,839		12,928		12,928	
Economic Over Consumption Net-$	5,536,206		25,209,746		25,209,746	
Environmental Over Consumption Net-KgCO_2	6,220		28,323		28,323	

Table 13: Presents the magnitude of the savings and energy and economic losses, and the CO_2 emissions that were not emitted in 2019 in each shift

Total	Shift 1		Shift 2		Shift 3	
	Savings -m³	Over Consumption -m³	Savings -m³	Over Consumption -m³	Savings -m³	Over Consumption -m³
	-1,038	24,736	-2	23,199	0	24,704
Over Consumption Net-KWh	23,698		23,197		24,704	
Economic Over Consumption Net-$	8,697,102		8,513,178		9,066,358	
Environmental Over Consumption Net-KgCO_2	3,934		3,851		4,101	

Figure 21: Compressor circuit hourly consumption matrix

Date\ Hour		kWh																										
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	Shift 1	Shift 2	Shift 3	Day
1/07/2019	Monday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	17	18	0	0	22	128	41
2/07/2019	Tuesday	18	17	19	19	18	19	19	19	19	19	19	19	19	19	19	19	20	18	20	21	20	19	19	18	152	154	152	452
3/07/2019	Wednesday	19	19	19	19	19	19	19	19	17	17	19	18	19	19	19	19	19	18	19	20	19	19	19	19	147	150	149	450
4/07/2019	Thursday	19	19	18	19	19	18	19	19	19	19	19	19	20	20	21	20	19	19	19	21	20	18	18	19	154	156	145	458
5/07/2019	Friday	18	17	18	18	18	19	20	19	20	19	20	19	20	20	20	20	20	19	20	21	19	18	18	18	156	156	142	456
6/07/2019	Saturday	18	17	17	18	17	19	20	19	20	20	19	19	19	21	12	0	0	0	0	0	0	0	0	17	157	12	17	292
7/07/2019	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	17	17	0	0	22	121	39
8/07/2019	Monday	17	17	17	18	17	18	19	20	19	19	19	19	20	19	19	19	19	19	19	17	19	18	18	18	153	148	142	441
9/07/2019	Tuesday	17	18	17	18	18	19	19	19	19	19	19	19	20	19	19	20	20	19	19	20	19	19	19	17	155	155	148	452
10/07/2019	Wednesday	19	19	19	19	19	19	19	20	19	19	20	19	19	19	19	19	20	19	20	20	20	19	19	19	154	155	152	460
11/07/2019	Thursday	19	19	18	19	18	19	19	20	20	19	19	19	19	19	19	19	19	18	19	20	19	18	19	20	153	151	150	456
12/07/2019	Friday	18	18	18	19	18	20	19	19	20	19	20	19	19	20	19	19	19	19	19	20	19	19	19	19	155	153	148	456
13/07/2019	Saturday	18	19	19	19	19	18	18	17	17	18	18	17	18	18	9	0	0	0	0	0	0	0	0	18	141	9	18	279
14/07/2019	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	17	17	17	17	17	17	18	18	0	0	133	124	150
15/07/2019	Monday	18	18	18	18	17	18	18	17	18	18	18	19	19	18	18	19	18	17	18	20	19	18	19	18	145	147	149	434
16/07/2019	Tuesday	19	18	18	18	19	20	20	19	19	19	19	19	19	19	19	19	20	18	19	20	19	19	19	18	152	153	149	454
17/07/2019	Wednesday	19	18	18	20	18	18	18	18	19	19	18	18	19	18	19	19	19	17	19	20	18	19	19	19	147	150	148	445
18/07/2019	Thursday	19	18	18	18	19	19	19	18	19	18	18	18	19	18	18	18	19	18	18	19	18	18	19	19	147	147	148	442
19/07/2019	Friday	19	18	18	18	19	19	19	18	19	19	18	18	19	18	18	18	18	18	17	19	17	4	0	18	146	130	18	403
20/07/2019	Saturday	0	0	0	0	0	0	0	0	6	17	17	17	16	16	16	16	6	0	0	0	0	0	0	0	89	38	34	128

observed in shifts 2 and 3. In contrast, in shift 1, the prominent trend was the ascent of energy inefficient (Figure 25). The Table 12 presents the magnitude of the savings and energy and economic losses, and the CO_2 emissions that were not emitted in 2019 in each shift.

3.2.6.2. Energy performance indicators Mill 5

According to the monthly specific consumption index, in the second semester of 2019, the months where the indicator exceeded the expected value, and the operation optimal levels were above corresponded to July, November, and December; Figure 26 highlights the days with the highest consumption index. Additionally, 34% of the day's operated present indicators below the standard limit; the analysis by shift revealed that shift 1, with 63% is the highest percentage of inefficient operation days according to production levels, in the case of shift three and shift one corresponded to 55% and 52% days.

The energy efficiency indicator-Base 100 (Figure 27); established that in the period from August to October, the process was operated

Figure 22: Energy baselines shifts of mill 5

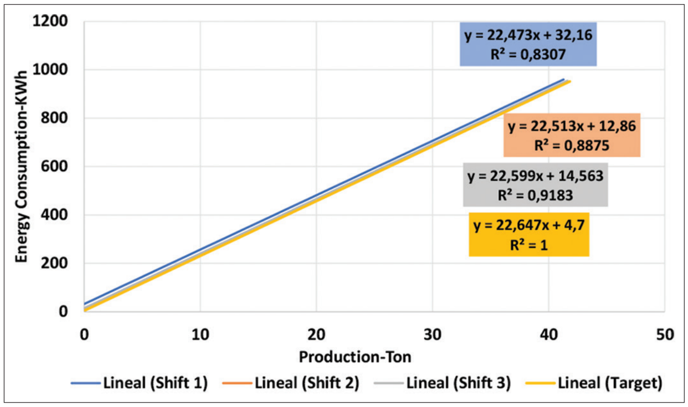


Figure 23: Gas baselines shifts of Oven 5

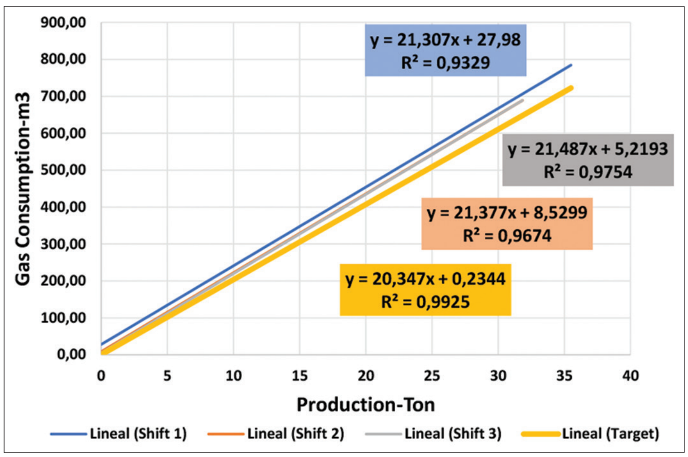
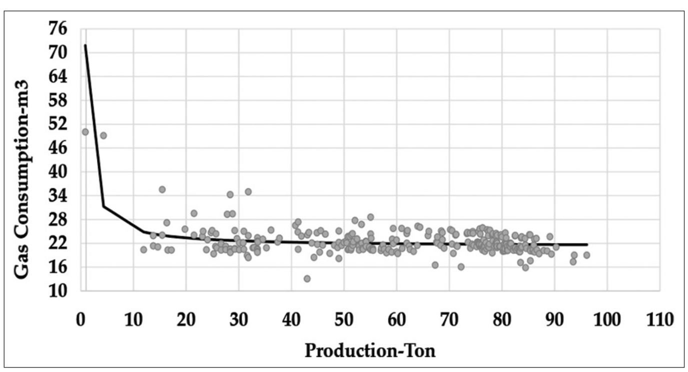


Figure 24: Specific consumption indicator Day/Gas



energy efficiently; the analysis per day showed that 63% of the day's evaluated present values below the standard limit where the actual energy consumption exceeds the calculated energy base, and in the evaluation per shift the percentage of energy inefficiency during the semester corresponded to 86% in shift one; 79% shift two and 81% shift three.

Through the indicator of cumulative sums, the gas consumption trend registered in 2019 corresponded to the following periods:

i. Descending from July to October.
ii. Ascending from October to December.

Regarding the shifting trend, higher overconsumption was observed in shift 1 (Figure 28)

4. CONCLUDING DISCUSSION

This study contribute to further development of theoretical knowledge about the contribution of ISO 50002 in energy management based on ISO 50001 by providing guidelines and relevant information for data collection, monitoring, measurement, analysis of: use and consumption of energy; and energy efficiency, as well as in the identification of opportunities to improve energy performance, it play an important role in energy review requirements, energy baselines, energy indicators, energy performance evaluation and auditing, all this was validated through on-site application in an SME of Non-Metallic Minerals sector, where in it was identified all energy currents in the installation, the energy significant uses centralized in the equipment: mill 7, mill 5, mill 6, micronized, compressors and oven 5; Consumption was evaluated, additionally the potential saving in 1 year of COP 140.763.805 and 150.104.000 $KgCO_2$ not emitted was estimated, and measures to improve energy efficiency were determined in a cost-effective manner by eliminating unproductive times in the gypsum grinding and calcining processes, correcting fugitives of compressed air, reducing energy losses due to operational variability, and automating the starter of the hammer mill and the feeding belt in the gypsum grinding process.

The project evidenced that applying energy management in SMEs not only in non-metallic minerals but also in another type of sector is a fundamental element in competitiveness and the decarbonization horizons; it is key to carry out energy audits to establish criteria or actions that improve or avoid significant deviation of energy performance, although most SMEs lack measurements and these could represent a considerable initial investment; Once an appropriate measurement plan is implemented and the improvement actions identified in the audit materialize, this value can be returned in the short or medium time, although it will depend on how the study is tackled and the barriers that the organization presents regarding financial limitations, the lack of staff skills and the lack of commitment from management that prevent the effective implementation of Energy Efficiency measures. The savings and benefits estimated compensate for the budget assigned to carry out the energy audit, which is near COP 15,000,000 for 1-2 months, and the potential savings calculated in 1 year would be COP 140.763.805.

It is not worth measuring and monitoring everything, especially if starting, since monitoring the prevailing aspects and making decisions about them is more appropriate.

Although Colombia currently has a legal framework to access the tax benefits of income tax discount, income deduction, and VAT exclusion for efficient energy management projects in the transport, service, and industrial sectors applied to electric motors, thermal insulation, for improvements in combustion, and the design and implementation of Energy Management Systems-EMS, for SMEs

Figure 25: Base 100 Indicator. Day/Gas

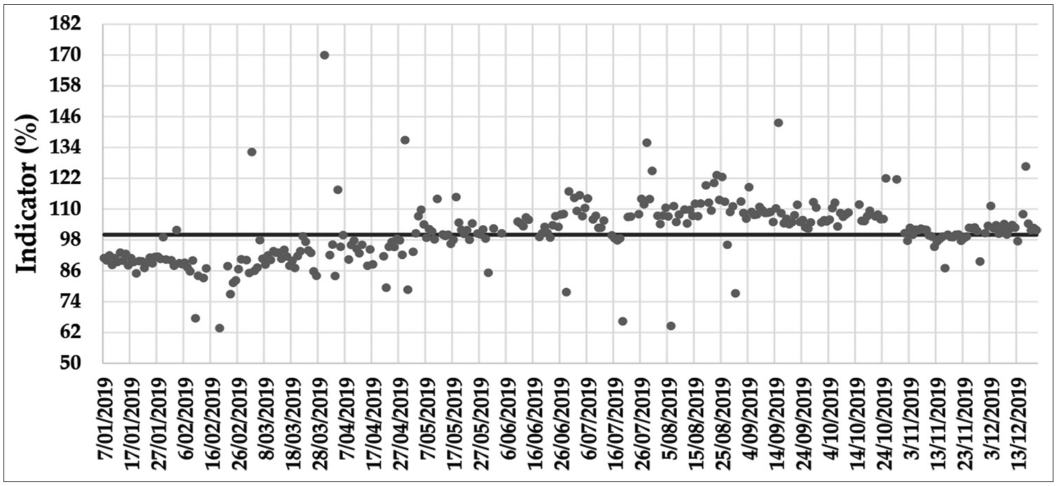


Figure 26: Cumulative sums indicator/Shift Gas

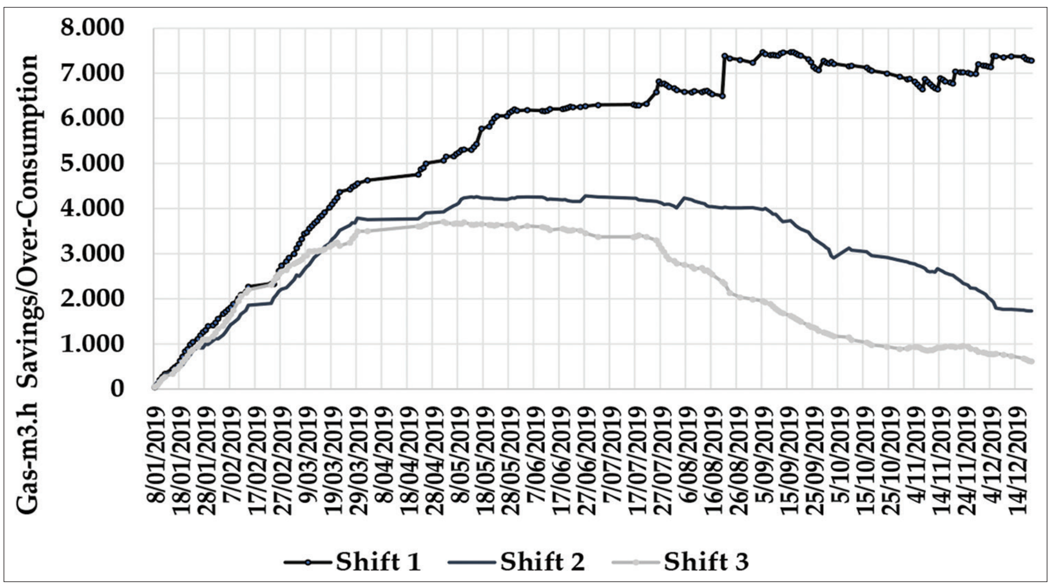


Figure 27: Specific consumption indicator. Day/Mill 5

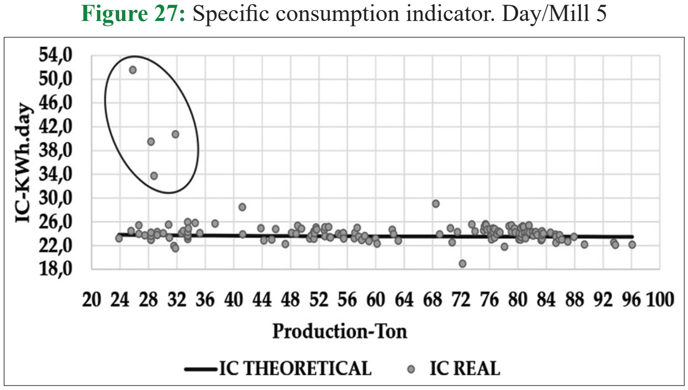
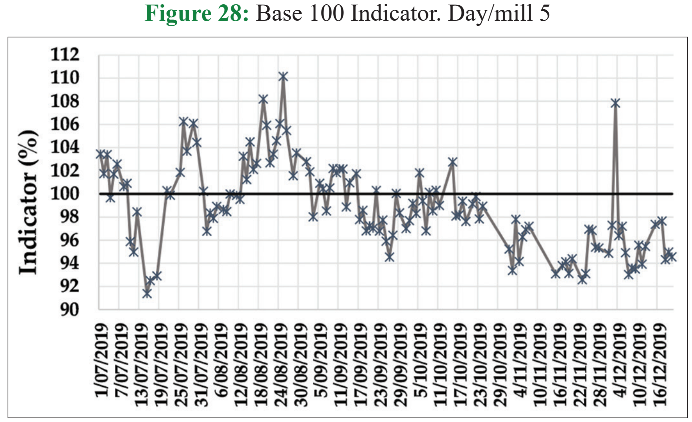


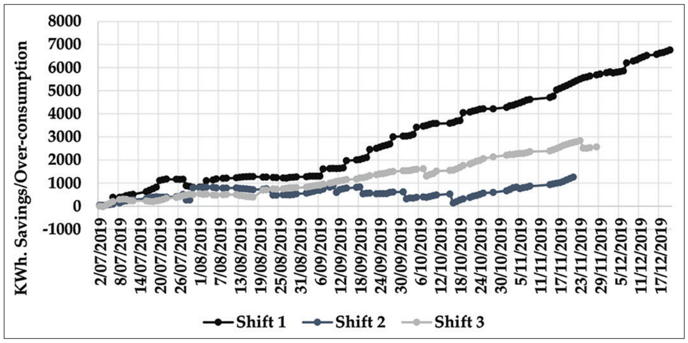
Figure 28: Base 100 Indicator. Day/mill 5



that do not even have a measurement system, it is still a challenge to apply these advantages, and therefore it would be convenient to think about economic incentives. Considering the realization of preliminary energy audits in SMEs, allowing them to obtain easy access to the financing of these preliminary studies to make investments more attractive considering that most SMEs lack measurements, and these could be a significant initial investment.

In addition to our research, we found authors such as (Kalantzis and Revoltella, 2019) who, when evaluating the role of energy audits in improving energy efficiency in SMEs, deduced that the impact of energy audits is positive and statistically significant in the investment decisions of energy efficiency measures in companies, additionally providing recommendations and helping to overcome

Figure 29: Cumulative sums indicator/Shift mill 5



the information gap that is one of the main barriers to investments in energy efficiency.

(Schleich and Fleiter, 2019) They found that the German energy audit program accelerated the adoption of energy efficiency measures in small businesses.

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