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A Methodology to Estimation of Savings Potential at Thermoelectric Plants in Colombia Based on ISO 50001 Standard

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ABSTRACT

The ISO 50001:2018 standard establishes a standardized set of concepts and practices for energy management of industrial assets and processes, providing criteria to establish policies, processes, procedures, and tasks related to energy management to meet established energy objectives. This article presents the application of these tools in thermal power generation systems in Colombia to analyze their energy performance, study possible saving potentials and propose strategies to improve their energy efficiency. As a result, a savings potential of 18568.4 GWh and 2008.7 GWh in 15 years was found for operation, maintenance, and production planning, respectively.

Keywords: Energy, Efficiency, Energy Management, ISO 50001, Thermoelectric Power Plants
JEL Classifications: L23, L94, L95, L98

1. INTRODUCTION

Energy is essential to maintain and improve the quality of life of people. Social changes and population growth after the industrial revolution required an increased demand for energy, supplied mainly by fossil sources such as coal and oil, which when burned generate polluting emissions, including CO_2 (Estrada, 2013). In 2015, the Paris Agreement set a long-term goal of keeping the global average temperature increase below 2°C and continuing efforts to limit it to 1.5°C above pre-industrial levels (Schleussner et al., 2016). Due to the direct relationship between global average temperature change and cumulative CO_2 emissions in the atmosphere (Damon et al., 2009), some countries, including Colombia, have committed, in terms of reducing their CO_2 emissions, to reach the Paris Agreement targets.

Colombia, in the latest update of its NDCs (Nationally Determined Contributions), committed to a 51% reduction in emissions compared to the 2030 projection in the baseline scenario (Min Ambiente y Desarrollo Sostenible, 2020). Specifically, the mitigation commitments of the energy mining sector of the country are presented in terms of Greenhouse Gas (GHG) emissions reduction potential, with about 1.21 Mt CO2eq for the energy efficiency strategic line and 4.74 Mt CO2eq for the electricity generation line (Resolución 40807_2018, 2018).

The country uses different primary energy sources such as water, natural gas, coal, biomass, oil derivatives, solar radiation, and wind in electricity generation plants. Figure 1 presents the approximate participation in the electricity matrix by type of plant for 2020, where more than 80% is supported by hydroelectric and thermoelectric plants (XM, 2022).

On the other hand, energy efficiency is a viable alternative to solve the energy supply problems of a country since it contributes to reducing energy losses on the generation side. In effect, this

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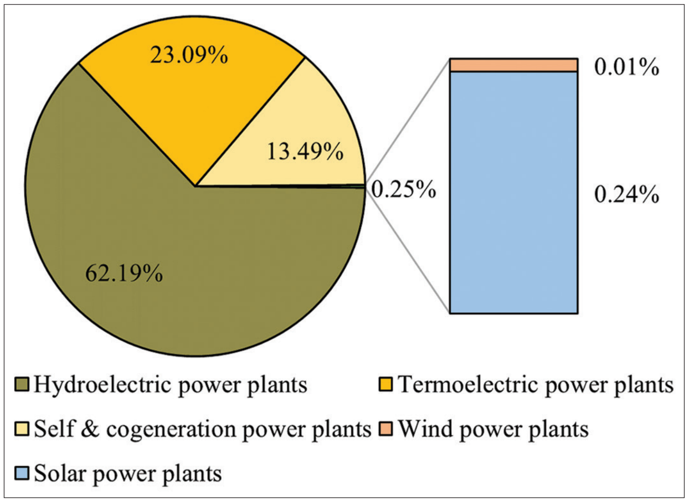
Figure 1: Electricity generation by type of generation plant in Colombia in 2020



reduces the need to invest in new generation sources and moderates the pressure on decision-making regarding energy planning and the selection of supply sources. Thus, energy efficiency makes it possible to perform the same productive activities or provide the same services with a reduction in the energy resources used (WEC, 2010). In Colombia, energy efficiency is defined by Law 1715 of 2014 as "the ratio between the energy harnessed and the total energy used in any process of the energy chain, which seeks to achieve maximized through good practices of technological reconversion or fuel substitution" (Congreso de la República de Colombia, 2014).

To generate energy efficiency policies and strategies, it is necessary to carry out energy management in a structured manner that allows monitoring of the processes and provides evaluation criteria to meet the established energy objectives, such as resource conservation, carbon footprint reduction, and cost savings. ISO 50001:2018 ("Energy management systems. Requirements and guidelines for use") requires an intensive energy assessment process to identify Significant Energy Uses (SEUs) and Energy Performance Indicators (EPIs) for achieving energy reduction targets. This standard establishes the requirements for creating, initiating, maintaining, and improving an energy management system (EMS), achieving continuous improvement in energy efficiency (Normas ISO, 2022).

Different studies reflect the benefits of developing an energy management system in various fields of industry by allowing the determination of priority areas for energy reduction. G. Dall"O" et al. (Dall'O' et al., 2020) applied an ISO 50001-compliant energy assessment methodology, applied for the first time to an Italian public agency managing a social housing stock to reduce the heating load based on consumption control. The study highlighted the need for constant monitoring and data collection, essential for constructing the energy baseline. (Thollander and Ottosson, 2010) described and analyzed energy management practices in Swedish energy-intensive industries: pulp, paper, and foundry. The results show that about 40% of the mills and 25% of the foundries can be considered successful in energy management. Finally, Bonacina et al. (Bonacina et al., 2015) provided a state of the art of ISO 50001 certifications implemented in Italy, listing the certified organizations in the national territory to identify the advantages and difficulties encountered in implementing an EMS. The study identified that more than 35% of the companies that already have ISO 50001 certification have obtained benefits in terms of cumulative energy savings of more than 5% and that the main reason for implementing an EMS is related to the potential increase in business competitiveness in the market.

The above evidences the need and benefits of implementing an EMS in different industries. However, there are few bibliographic references on implementing an EMS based on ISO 50001 in the power generation sector. Therefore, the novelty of this work is to present the application of energy management tools in an Energy Planning process, following the methodology of ISO 50001:2018, to evaluate the potential for energy savings in the power generation sector in Colombia. Initially, the USEs in the electricity generation of the country were identified, being hydroelectric and thermoelectric plants with the highest energy consumption. This study analyzes thermoelectric plants due to the Greenhouse Gas (GHG) emissions they generate by burning fossil fuels.

2. METHODOLOGY

The study to determine the savings potential in thermoelectric plants was based on the ISO 50001 standard, which establishes the requirements that an EMS must have to continuously and systematically improve the energy performance of organizations (ISO Tools Excellence, 2022).

As mentioned by Kanneganti et al. (Kanneganti et al., 2017), the following components of the energy planning section of the standard were considered to address the objective of the article.
1. Energy review
2. Energy baseline
3. Identification of energy performance indicators
4. Energy objectives, goals, and action plans.

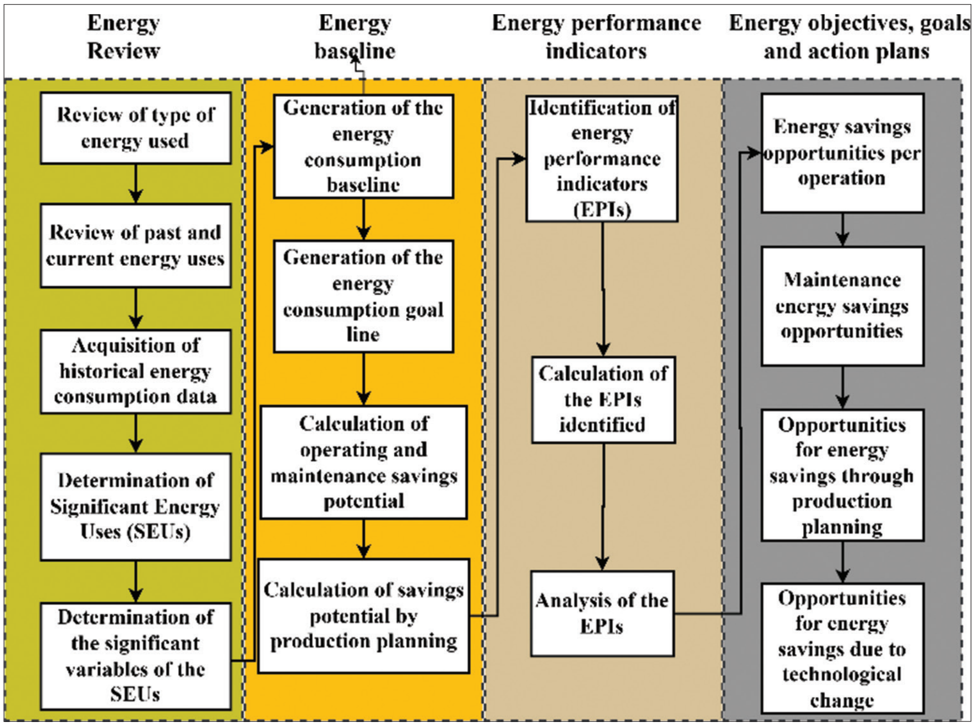
To estimate the savings potential in thermoelectric plants in Colombia and, at the same time, address the components of ISO 50001, the methodology used by Medina et al. (Medina et al., 2020) for energy planning, was used. Figure 2 shows the steps followed to achieve the objective of the article.

2.1. Energy Review

2.1.1. Review of type of energy used and past and present energy uses

The identification of the energy sources currently used in the Colombian electricity generation sector was carried out by reviewing the database presented by the Mining and Energy Planning Unit (UPME) in the Energy Balance of Colombia (BECO) (UPME, 2022). This database shows, among others, the "transformation centers" that include the different power generation plants and the types and quantity of fuels used in each one. In this database, there is historical information on fuel consumption since 1975. However, analyzing the information

Figure 2: Energy analysis methodology



there are inconsistencies in the information reported up to 2006, such as, for example, repeated data on consumption for several years, missing information, and abrupt changes in the amount of fuel consumed between years.

For this reason, it was used the information provided from 2006 to 2020 since these are the most consistent data.

2.1.2. Data collection of historical energy consumption

Energy consumption data by fuel type and power plant type were extracted from the BECO database from 2006 to 2020 and stored in a database. Next, to obtain the information on energy use associated with the power plants, fuel consumption, presented in its original units, was converted to energy units in GWh. Again, Equation 1 was used.

$$Ec_i = \sum_{j=1}^{n} CC_{uoj} * PC_{uoj} \tag{1}$$

Where EC_i is the energy consumed by type of plant i. CC_{uoj} is the Fuel Consumption in the original unit of fuel j of plant i (Unit referenced in the BECO), and PC_{uo} is the calorific value per original unit of fuel j used in plant i. This calorific value is established by UPME (UPME, 2016).

2.1.3. Determination of SEUs

Subsequently, a Sankey diagram and the Pareto principle were adopted to determine the USEs. The Sankey diagram observed the energy flows to and from the power plants. The Pareto principle (Knowlson et al., 2022) was used to observe where the 80% of the fuel consumption was accumulated, thus determining which power plants have significant energy use.

First, the energy consumption was plotted for each power plant, from highest to lowest. Second, the cumulative percentage share of each power plant was plotted using Equation 2.

$$P_{acum_n} = \sum_{i=1}^{n} \frac{CE_i}{CE_T} \tag{2}$$

Where P_{acumn} refers to the cumulative percentage of fuel consumption of power plant n. n refers to the position of the power plant, from highest to lowest, concerning energy consumption, where n=1 would be the power plant with the highest fuel consumption. CE_i Is the energy consumption of plant i, and CE_T is the total consumption of all power plants.

2.1.4. Determination of the significant variables of SEUs

The significant variable was determined by implementing the statistic called P-value with P=0.05 (Medina et al., 2020). This statistic tool reflects the significance of a model without a variable and can thus be used to know if it is significant within a process (Brereton, 2019). For example, this would imply that if the P-value of a set of data is less than an established limit, the model has no significance without that variable, being then a significant variable.

Additionally, to determine whether the amount of data is representative of the analysis, the *t-Student* distribution statistic is used. The value of the normal distribution is calculated using the *t-Student* table and compared with the value calculated by Microsoft Excel®. If the table value is less than that given by Excel, the amount of data is said to be representative of the model. For this, a confidence level of 95% was selected, and a degree of freedom of 14 was taken.

2.2. Energy Baseline

2.2.1. Elaboration of the energy consumption baseline

The energy baseline (E_b) is a fundamental element of an energy management system since, according to ISO 50001:2018, it is a quantitative reference against which changes in energy performance are compared.

However, neither the ISO 50001 nor ISO 50006 standard mentions how to calculate the baseline, leaving it to the free interpretation of the person performing the assessment. This indicator can be elaborated for the period of available information based on a simple linear regression (Medina et al., 2020), as presented in Equation 3.

$$E_b = mP + E_0 \quad (3)$$

Where E_b is the theoretical energy consumed, m is the ratio of change between energy consumption and production level, P is the production level, and E_0 is the energy not associated with the production of a process.

Additionally, two standard deviations of the data set were considered, thus having a 95.4% of data acceptance. Electricity consumption values above or below two standard deviations concerning the baseline were eliminated as outliers, thus having a data set with a behavior closer to reality.

2.2.2. Elaboration of energy consumption target line

To generate the energy consumption target line *Eg*, the starting point is the consumption baseline previously obtained. Then, a systemic cleaning process was carried out, eliminating the energy consumption data above the consumption of the base model, allowing the best operating points within the analyzed period to remain. Finally, with this new set of data, a new linear regression is generated, which has the same form as Equation 3.

2.2.3. Calculation of operating and maintenance savings potential

The energy savings potential for operation and maintenance was calculated about the baseline and target energy consumption. For example, Equation 4 below shows the calculation of the energy savings potential for operation and maintenance (Medina et al., 2020).

$$PS_{O\&m} = \sum_{i=1}^{n} E_{b_i} - E_{g_i} \quad (4)$$

Where E_{bi} refers to the expected energy according to the baseline given the production of period i, E_{gi} refers to the expected energy according to the target line given period i. $PS_{O\&m}$ is the potential energy savings from operation and maintenance in the analyzed period.

2.2.4. Calculation of savings potential by production planning

Calculating the savings potential by production planning is obtained through Equation 5. This potential is related to keeping production close to critical value (Medina et al., 2020). The latter is the production where higher production values do not influence energy consumption, but, on the contrary, lower productions affect it notoriously.

$$PS_{pp} = \left(IC_{average} - IC_{critical}\right) P_{average} \quad (5)$$

Where $IC_{average}$ is the average of the consumption indexes of all the data, $IC_{critical}$ is the consumption index of the critical production, $P_{average}$ is the average of the productions within the analysis period, and PS_{pp} is the savings potential by production planning. The consumption index is the ratio between the energy consumed and the production associated with such consumption for period i, which is represented in Equation 6.

$$IC_i = \frac{EE_i}{P_i} \quad (6)$$

Where EE_i is the electrical energy consumption of period i, P_i is the area's production in period i, and IC_i is the consumption index of period i. Finally, the critical production is determined by equating the derivative of the theoretical consumption rate to production to zero. The theoretical consumption rate is the division of the baseline consumption to the production unit. The procedure for this calculation is described in Equation 7 and Equation 8.

$$\frac{d}{dP}\left(\frac{mP + E_0}{P}\right) = 0 \quad (7)$$

$$-\frac{E_0}{P^2} = 0 \quad (8)$$

The critical production is found graphically where the curve approaches an asymptote, meaning that from this point on, there is no significant change in energy consumption at higher productions.

2.3. Identification and Calculation of Energy Performance Indicators (EPIs)

Based on what is mentioned in ISO 50006, EPIs can range from energy values to ratios between measured values. Therefore, for this study, the following indicators will be analyzed: (i) cumulative energy performance; (ii) one hundred base index; (iii) production, time, and energy (p-t-e) indicator. The description of these indicators is shown in Table 1.

These indicators are appropriate since they are quantitative, measurable, comparable, and reflect changes in energy consumption. In addition, they make it possible to analyze energy performance in terms of the relevant variables that affect the evaluated system (Fichera et al., 2020).

2.4. Energy Objectives, Goals, and Action Plans

A bibliographic review of national documents was carried out, especially documents created by the Colombian government, to observe what possible actions, objectives, goals, and plans the government has regarding the improvement in the performance of these power plants. This information is compiled and presented in this last section to have a condensed national vision regarding improving energy efficiency in thermal power plants.

3. RESULTS AND ANALYSIS

The information gathered by XM and UPME for the period from 2006 to 2020 was used. The following are the results obtained.

3.1. Energy Review

3.1.1. Determination of SEUs

Figure 3 shows the Sankey diagram of the energy flow of the national electricity matrix. It shows the power plants, their primary energy consumption, and the electricity generation delivered to the National Interconnected System (NIS) in 2020.

Hydroelectric plants have the highest primary energy consumption (71.89%), characterized by being fully hydroelectric. Thermoelectric plants (26.69%) have the second-highest consumption of primary energy. These are characterized by the use of mainly natural gas and coal.

It is possible to observe that most of the consumption of primary energy sources for electricity generation in the country comes from renewable sources. Additionally, the diagram shows that the energy transformation process in hydroelectric power plants has lower energy losses than in thermoelectric power plants.

Figure 4 shows the Pareto diagram of power plant energy consumption. 80% of primary energy consumption is contained in hydroelectric and thermoelectric power plants. Therefore, these plants are defined as the SEUs of the national electricity generation process and where there is the most significant potential for energy savings.

Thermoelectric power plants were selected as the object of study in this analysis since, in addition to being an SEU, they directly influence GHG emissions due to the burning of fossil fuels. In addition, energy savings in the consumption of their primary sources would imply a reduction in operating costs and a decrease in emissions.

3.1.2. Determination of the significant variables of the SEUs

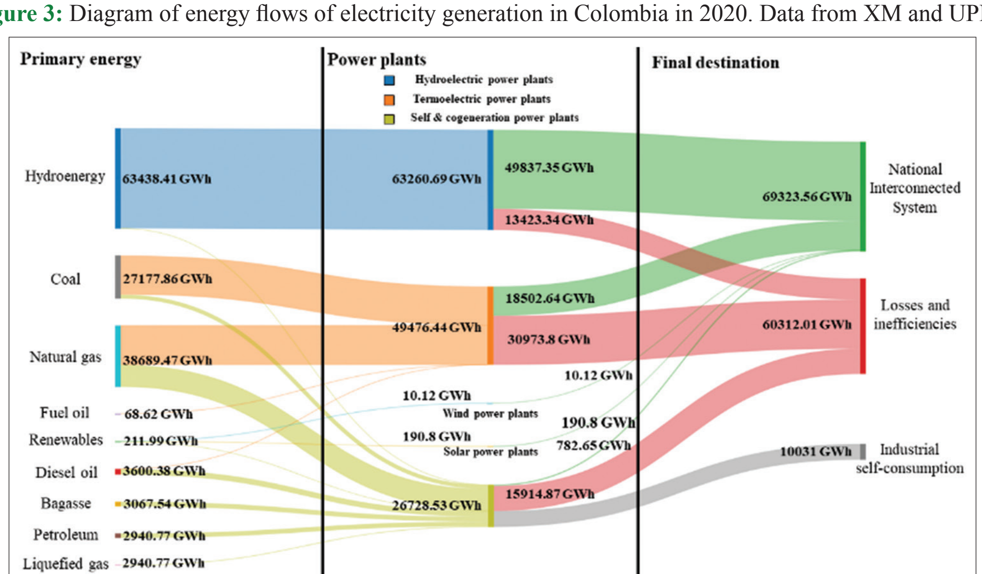
Table 2 presents the result of the statistical analysis of the fuel consumption model and electric generation. It was obtained that the P-value of the model for the variable "electric generation" was 2.51* 10^{-10}, which is lower than the established limit of 5%. This means the fuel consumption model has no significance without the variable, therefor being a significant variable within the process.

On the other hand, the value obtained from the t-student distribution using the software was 17.21, while the value obtained by the table was 2.145. That means the number of samples is representative of the model.

Table 1: Energy performance indicators

Indicator	Sub-indicator	Equation	Function	Source
Base 100 index (Ib100)	Base 100 index (Ib100) of baseline	$I_b = 100\left(\frac{E_{LB}}{E_r}\right)$	It used to observe energy compliance concerning the baseline	(Medina et al., 2020)
	Base 100 index (Ib100) of target line	$I_M = 100\left(\frac{E_M}{E_r}\right)$	It used to observe energy compliance concerning the target line	
Cumulative energy performance	N.A	$Sum_i = Sum_{i-1} + (E_{ri} - E_{model_i})$	It is used to observe the accumulated energy performance of the actual energy consumed and expected by the model	(Medina et al., 2020)
p-t-e	N.A.	N.A.	It is used to observe the behavior of production and energy consumption at a given time	(Medina et al., 2020)

Figure 3: Diagram of energy flows of electricity generation in Colombia in 2020. Data from XM and UPME



3.2. Energy Consumption Baseline

3.2.1. Generation of the energy consumption baseline

Figure 5 shows the energy consumption baseline with its respective upper and lower limits defined by the standard deviation. This graph shows the energy consumption model related to the level of electricity generation, with its respective slope and intercept.

Additionally, no data outside the confidence interval of 95.4%, established by the two standard deviations, is observed. Therefore, no data is eliminated since no data is considered atypical according to the established considerations.

3.2.2. Generation of energy consumption target line

Once the energy consumption baseline has been obtained, and the systemic elimination process of the points above the baseline energy consumption model has been carried out, the energy consumption target line is obtained, as shown in Figure 6.

Concerning the baseline, there was a decrease of 44.68% (2015.4 GWh) in energy not associated with production in the target line. This component of the model is associated with: (i) energy consumption of the equipment necessary to operate the processes. (ii) Unfavorable operating and maintenance conditions. The reduction in energy not associated with the production of the target line represents the capacity to reduce the fixed consumption of the equipment necessary in the processes of the thermoelectric plants. It also represents the capacity to have an electricity generation process with less variability and more profitable operation and maintenance conditions.

The latter can be appreciated the by increased sample determination coefficient R^2. This coefficient represents the accurate data adjustment. For example, the R^2 of the baseline is 0.9579, and that of the target line is 0.9908. This increase represents the possibility to have a process with less operational variability and, therefore, better energy performance based on the best operating points of the data set.

The baseline had an increase in the slope, from 2.3331 $\frac{GWh_c}{GWh_p}$ to 2.3888 $\frac{GWh_c}{GWh_p}$ in the target line. This component of the models is associated with the efficiency of the technologies implemented in the processes. This increase represents a potential for technological replacement of the equipment involved in the thermoelectric plants, which could increase their efficiency.

The differences between the baseline values and those resulting from the target line could be related to environmental conditions, equipment efficiency, equipment maintenance, required operating conditions, and the state and costs of the energy vectors (Pelser et al., 2018).

3.2.3. Energy saving potentials

Once the baseline and target energy consumption lines have been obtained, the potential energy savings from operation and maintenance are calculated based on Equation 4. For example, Table 3 shows a savings potential for proper operation and maintenance of 3.34% (18568.4 GWh over 15 years or 1237.89 GWh per year). That means that, based on historical behavior, there exists the capacity to maintain the energy transformation

Table 2: Results of statistical analysis

Variable	t-student		P-value
	Calculated	statistical table	
Electric generation	17.21	2.145	2.51E-10

Table 3: Saving potentials

Level	Saving potential
Operation and maintenance	3.34
Production planning	5.42

Figure 4: Pareto diagram by power generation plant. Year 2020.

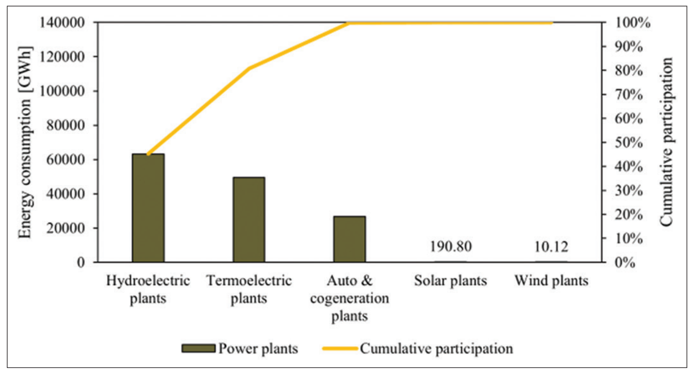


Figure 5: Energy baseline control chart

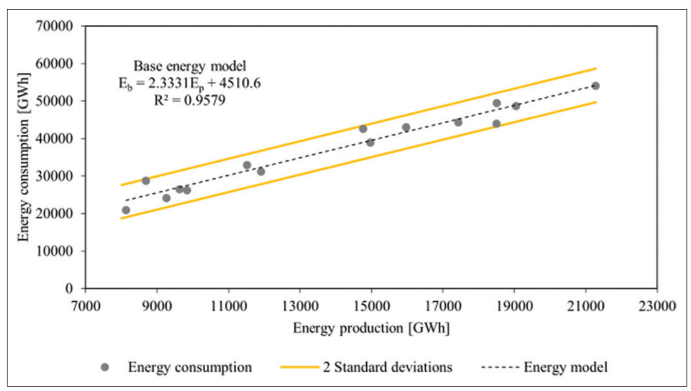
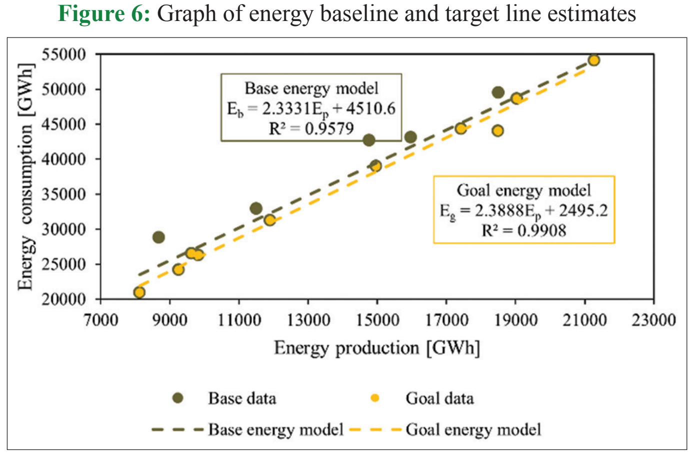


Figure 6: Graph of energy baseline and target line estimates



process under operation and maintenance conditions that allow to have lower fuel consumption without reducing electricity production. For this, it would be necessary to carry out a rigorous follow-up of operational and maintenance parameters to know what actions and strategies allow the right conditions to improve energy performance.

On the other hand, Figure 7 shows graphically the behavior of the change in the slope of the theoretical consumption index, a procedure presented in Equation 8. In this figure, the critical value of electric power production can be estimated by observing where the change in the slope does not have a considerable variation. It is then obtained that the critical value of the electric energy production is around 19000.00 GWh. That means that, around this value, the energy consumption, and the production of one unit of electrical energy are close, implying better process efficiency. However, producing below this value would cause the ratio between energy consumption and electricity generated to increase, implying that per unit of energy generated, a more significant amount of energy consumed would be required.

Knowing the value of the critical production, the value of the critical consumption index is 2.56 $\frac{GWh_c}{GWh_p}$. In addition, from the historical data of fuel consumption and electricity generation, the average consumption index and average production for the analyzed period can be obtained, which are 2.69 $\frac{GWh_c}{GWh_p}$ and 13958.83 GWh, respectively. Based on Equation 5, it is obtained that the potential energy savings from production planning are of 5.42% (2008.66 GWh per year or 30129.87 GWh over 15 years) for the time analyzed, as shown in Table 3. This implies that this energy saving can be achieved by keeping production close to the critical value.

3.3. Energy Performance Indicators

This section will calculate and analyze the energy performance indicators defined in Table 1.

3.3.1. Base 100 index

Figure 8 shows the trend of the base 100 index, both for the baseline and the energy consumption target line. Respect the baseline, it can be observed that, in general, the values were above 100, except for the years 2010, 2017, 2018, 2019, and 2020. That means that, in most of the years, actual energy consumption was lower than expected by the energy baseline. However, in the years when the value is below 100, there is a baseline noncompliance. Since the actual consumption was higher than expected with the baseline, resulting in low energy performance. The latter may be due to improper operation and maintenance, weather phenomena, and improper production planning.

The base 100 index of the target line shows that in general, with exception of values for 2007, 2008, and 2016, there are values below 100. That means efforts must be increased to improve energy performance in operation and maintenance to achieve the savings potential related to the periods of lower electricity consumption in the historical data.

In 2006, 2009, and from 2011 to 2015, there was a good energy performance related to the energy consumption baseline. However, the energy goal still needs to be met according to the indicator, showing that conditions can be improved despite having favorable operating and maintenance conditions to reduce electricity consumption further.

On the other hand, in the years in which energy performance was not met for both the baseline and the target line, it is necessary to observe the conditions that caused this behavior to take measures and propose strategies to improve the situation.

3.3.2. Cumulative energy performance

Figure 9 shows the trend of the cumulative energy performance (CUSUM). As mentioned in Table 1, it allows observing the trend

Figure 8: Base 100 index

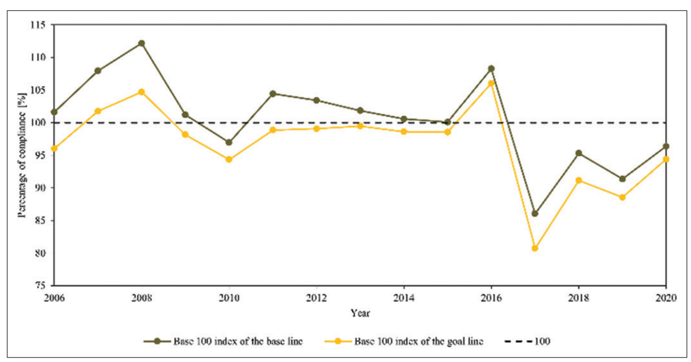


Figure 7: Cumulative sum of the derivative of the consumption index

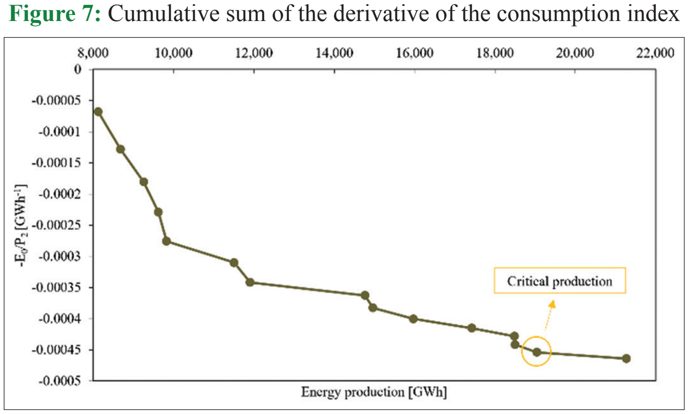
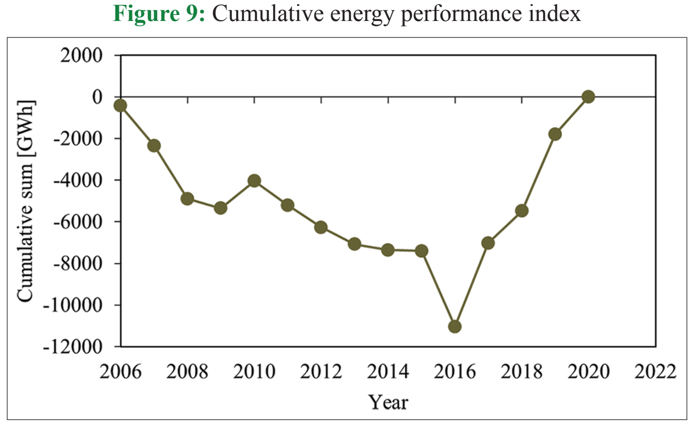


Figure 9: Cumulative energy performance index

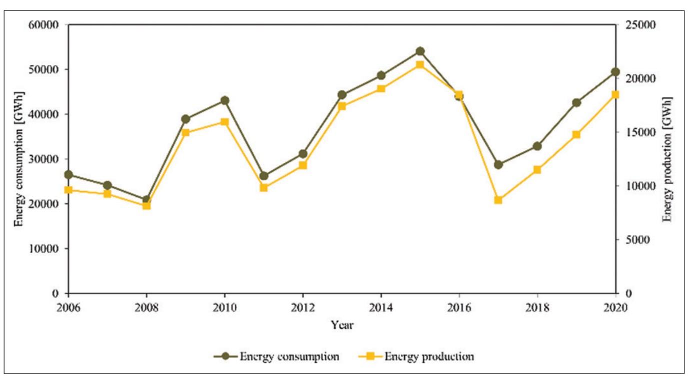


of the cumulative difference between actual consumption and the consumption expected by the energy model. It can be observed that from 2006 to 2016, there was a general decreasing trend in cumulative energy performance, except for 2010. That means that, for the period, the energy consumption in each year was lower than expected by the energy consumption model, resulting in such trend, representing a period of good energy performance. On the other hand, in 2010, there was a punctual increase caused by higher energy consumption concerning the energy consumption model, resulting in a period of poor performance. Likewise, in 2016 there was a sharp drop in the indicator, which is caused by the operation close to the critical electricity production of thermoelectric plants, where there is also a lower energy consumption than expected by the model (3635.45 GWh less).

This production at critical levels is due to the drought period caused by the El Niño phenomenon between 2014 and 2016. This phenomenon caused the water reserves of the hydroelectric plants to gradually decrease, as well as the flows of the rivers that feed the run-of-the-river power plants, with the water shortage being more pronounced in 2016 (UNGRD, 2016). This caused a greater part of the electricity demand to fall on thermal power plants, forcing them to work at higher capacity, close to critical production.

On the other hand, from 2017 to 2020, there was an increase in the indicator's value, meaning that there was a period in which energy performance was low. Higher than theoretically expected. In addition, this decrease in energy performance is linked to the return to the regular operation of the hydroelectric power plants, which meant that it was not necessary to rely mainly on electricity

Figure 10: Energy and Production versus time



production from thermal power plants. This caused the thermal power plants not to operate above critical values, which is why the energy performance decreased.

3.3.3. Production-time-energy

Figure 10 plots the production and energy consumption of the thermal plants over the defined time to analyze the behavior of the variables and observe anomalies.

It observes a close relationship between energy consumption and electricity production. For example, in 2010, which is known to be a year of poor energy performance, the increase in the growth rate of energy consumption was higher than that of electricity production, resulting in a drop in plant performance. On the other hand, 2016 is known to have been a year of good energy performance. It observed that there was a higher drop in the growth rate of energy consumption than that of production, causing less energy to be consumed to produce one unit of electric power.

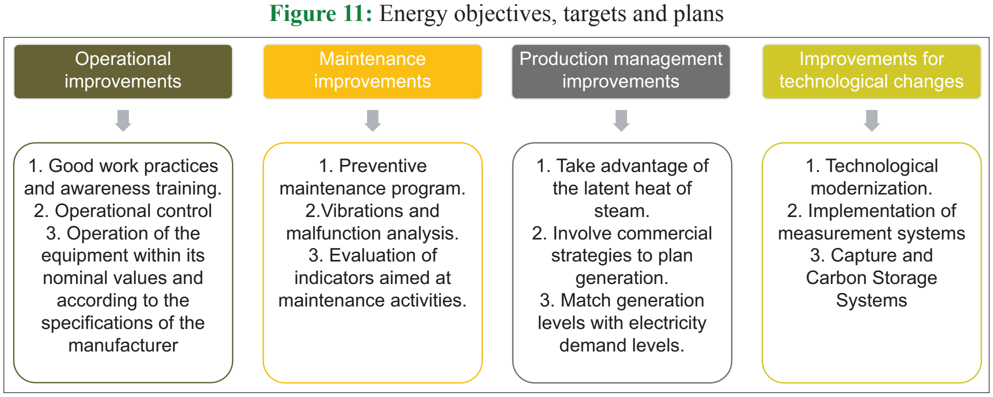
In the period from 2017 to 2020, there was a more significant variation in the energy consumption growth rate than in electricity production, which is reflected in the poor energy performance of the period.

3.4. Energy Objectives, Goals and Action Plans

Colombia, through the document National Energy Plan 2020-2050 (PEN 2020-2050) designed by the Mining and Energy Planning Unit (UPME), defined the long-term goals and objectives for the energy sector and identified the possible ways to achieve them through 4 possible scenarios. Among the scenarios for electricity generation, they considered the increase in the installed capacity of Non-Conventional Renewable Energy Sources (NCRES), the installation of new technologies such as geothermal and nuclear, the exit from operation of inefficient thermoelectric plants or those at the end of their life cycle, the progressive development between scenarios of distributed resources according to the area available for their installation, and the increase in the energy efficiency of generation plants (Min Minas y energía and UPME, 2019).

Figure 11 presents a series of recommendations from the energy analysis of thermoelectric power plants for electricity generation in Colombia and the literature review made by the authors (Blanco and Peña, 2011).

Figure 11: Energy objectives, targets and plans



4. CONCLUSIONS

In this study, an analysis of the energy savings potential of thermoelectric plants in Colombia was carried out based on the Energy Planning section of ISO 50001:2018, and energy performance indicators were analyzed in the defined period. In addition, savings opportunities were proposed based on the goals set out in the PEN 2020-2050 and through the literature review.

Regarding the baseline energy consumption, it is possible to save about 1237.89 GWh of fuel consumption per year (a reduction of 3.34%) through proper operation and maintenance of the thermoelectric power plants, in relation with prior periods of good operation.

The value of the critical production of the thermoelectric power plants was calculated at approximately 21272 GWh. From this value, there is evidence of a decrease in the energy consumption growth rate as the rate of electricity production increases. The increased ratio of electrical energy generated to the energy consumed increases energy performance, which is why it is recommended to operate close to this production value.

Likewise, by operating thermoelectric plants close to the critical production, a potential savings of 2008. 7 GWh of fuel consumption per year (a reduction of 5.42%) is obtained by the planning of the production of electrical energy.

Between the years 2006 and 2009 and 2011 to 2016, good energy performance was evidenced according to the cumulative energy performance index and the baseline 100 base index. However, it could also be seen that phenomena such as La Niña and El Niño phenomena affect the energy performance of Colombian electricity generation. The latter was especially noticeable in 2016 when thermal power plants were operating close to the nominal capacity to supply electricity demand due to the decreased hydroelectric generation caused by the reduction in reservoir levels due to the El Niño phenomenon. In the period from 2017 to 2020, there was a low energy performance of thermal power plants due to the recovery of reservoir levels and river flows. They were allowing a higher electricity generation from water resources causing thermal power plants to decrease their electricity production, moving them away from their critical production and affecting their performance.

There was a predominance of electricity generation based on hydroelectric and thermoelectric plants, which caused the country's electricity matrix to be inelastic to exogenous variables and affected the energy security of the country. Therefore, the government must generate policies that allow the correct development and implementation of new technologies to take advantage of the energy resources available in Colombia, thus addressing the issue of ensuring the supply of electricity and the decarbonization of electricity generation.

Finally, it should be noted the importance of the studying the climate phenomena such as La Niña and El Niño phenomena, to predict the availability of the electric generation resources and properly plan strategies to address the electric energy demands in draught periods.

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