# Establishment of Energy-Production and Environmental Indicators in the Physical Refinery Area of a Colombian Food Company

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## Abstract

This paper presents the results of the application of the strategic decision stage for the implementation of an Integrated Energy Management System, based on the NTC ISO 50,001:2011 standard, in the physical refinery area of a company in the food area, a vegetable oil and grease producer located in Colombia. The principles for obtaining control charts and consumption indexes are shown as a complement to the implementation of the equivalent production method to obtain the base and target lines in terms of natural gas and electric energy consumption for the elaboration of its products from three different raw materials: palm, soybean and sunflower. Through the analysis of each of these graphs, some representative saving potentials were obtained of 30.7, 31.37 and 50.4% in electricity, for soybean, palm and sunflower, respectively, and 23.10, 22.7 and 45% in natural gas in the same order above. These savings are reflected also in the equivalent reduction of $CO_2$ emissions with an average of 670.43 $CO_{2Eq}$ annually, where 229.7 tons of $CO_2$ correspond to savings in the physical refinery area due to electrical energy saving consumption and 430.73 tons of $CO_2$ refer to the impact of reducing the consumption of natural gas.

***Keywords:*** *Energy characterization, food area, saving potential, energy performance indicator, $CO_2$ Emissions.*

## 1. Introduction

As a priority of the 21st century, industries are trying to carry out productive process in a socially responsible way. For this reason, an increasingly number of organizations around the world are applying sustainability principles including the reduction of their environmental impact (Mezinska and Strode 2015). According to U.S Energy Information Administration (E.I.A) criteria, the energy-intensive manufacturing industries, including food, rubber, paper, petroleum and petrochemicals spend 54% non-residential energy and should thus their carbon footprint impact have highest index (U.S. Energy Information Administration 2016). In accordance with the NTC ISO 14,067:2013 standard, carbon footprint is a sum of greenhouse gas emissions and removals in a product system, expressed as $CO_2$ equivalent. Colombian National Administrative Department of Statistics (DANE in Spanish) reports and estimate from 36,683 $CO_{2Eq}$ as polluting emissions from local manufactory (William et al. 2013), where 14.7% belongs to food processing industries (DANE 2017).

The implementation of the NTC ISO 50,001:2,011 standard about Energy Management Systems (EMS) has generated new challenges to companies from various fields of global economy in relation to rational and efficient energy use, thus promoting the development of management strategies and operational improvement in order to obtain a cost reduction which in turn reflect an environmental impact lessen (Campos Avella, Lora Figueroa, and Alvarez Garcés 2011). From that, many researches focused on develop tools, models and manuals have been developed that allow to the industrial sector, in its different areas, to implement ISO standard requirements in the best way. Jovanovic et al. (2016) proposed an energy management rigorous and maturate model according to this technical rule, which was industrially validated and related with management methods usually implemented in companies such as PDCA's cycle and CMMI model. Valencia et.al (2017) carried out an energy vs production correlation and operational performance indicators, which allowed an energy planning and, based on this, savings of up to 17.7MWh/year in a metal-mechanic industry were projected. On the same way, Cardenas et.al (2017) developed an equivalent production model to accomplish an energy diagnosis in an agroindustry, thus granted a correctly devise of different product on the same processing line. On the other hand, in the food area, Roy et al. (2009) highlighted the need to change overall in production, package, distribution and consumption processes in order to reduce environmental impact in this economic terrain. These modifications are aligned with improving strategies in the energy and production managements.

In Colombia, the food industries have reported the highest capital investment in projects to protect and preserve environmental with quantities around US$28,635M until 2015 (DANE 2015) showing their effort in the reduction of carbon footprint while optimizing their methodologies and renewing their technology, compared with other economy area. Thus, the goal of this work is to do an energetic-productive diagnosis, so as establish a linear adjustment to correlate energy consumption and production rates, and also calculate the energy saving potentials and reduction of $CO_2$ emissions, according to NTC ISO 50,001:2011 standard, in an edible oil company physical refiner section in Colombia. To produce the oil five stages are executed that include a preprocessing of raw material, which depends if palm, soybeans or sunflowers are fed. A purification process then is done under low pressure conditions to get crude oil. Then it is filtered, deodorized and finally stored to commercialize.

## 2. Methods

### *2.1 Strategic decision*

The strategic decision consolidates the beginning of three stages of the Integrated Energy Management System (IEMS) and includes the procedures and activities that a company must carry out to achieve a minimum energy consumption (Campos et al. 2008). For this study, two global activities were carried out in the target industry, starting with a *route diagnosis*, through which a charge register was carried out to identify the productive energy structure of the refinery area. Subsequently, an *energy characterization* was implemented through which the consumption of electricity and natural gas were analyzed as well as the production for each of three daily shifts during the period between February and December 2015. Based on the information collected, base and target lines were developed, so as energy performance indicators in order to identify opportunities for improvement in good practices, technology and therefore in $CO_2$ emission reductions.

### *2.2 Control charts*

The control charts allow monitoring the trend in consumption associated with energy during the period under study referred in this case to natural gas and electricity during 2015 in the physical refinery area for each of the oil references produced. Statistical control lines (SCL) were established, depending on the standard deviation of data, taking into account that within the limits, the presence of around 99% of the data in an acceptable range would be ensured. An average line was also drawn reporting the reference value of the global consumption associated with the energy determined.

### *2.3 Equivalent baselines*

Taking into account that production of refined oils in the company takes place from three different raw materials under the same process line and, for each of them there are different energy consumptions.

Hence, the equivalent production method was applied in order to carry out objective correlations of data and to eliminate the influence of consumption variability by reference variation produced.

To obtain the equivalent production, a standard reference is initially selected, which is chosen according to the reference with the largest quantities obtained in the process, in this case, palm oil was chosen. From this, the equivalence of soybean and sunflower oil to palm oil was calculated as the quantity of product of a production type (soybean or sunflower) that consumes the same amount of energy as the mass quantity of the reference production, i.e. kilograms of palm oil per shift.

The calculation expression for this method is shown in (1), where $E_P$ refers to the equivalent production, m is the slope of the baseline obtained by reference, P indicates the production, $E_0$ is the intercept of the resulting baseline by reference and the subscripts r and i refer to the standard reference and the remaining references, respectively.

$$E_P = \left[\frac{(m_i P_i + E_{0i}) - E_{0r}}{m_r}\right] \quad (1)$$

For this work, the energy baselines were constructed by plotting the energy consumption as a function of the equivalent kilograms per shift of products made in the refinery area, during the period of operation. The treatment of these data was based on the linear regression and filtering method by establishing limits based on theoretical consumption and standard deviation. The linear model describing this behaviour is shown in (2), where $E_C$ refers to the total equivalent energy consumption, m is the line's slope indicating the transformation consumption of the raw material of the process, $E_P$ is the equivalent quantity of transformed product and $E_0$ is the intercept of the line indicating the fixed energy consumption in the process.

$$\mathrm{E}_C = mE_P + E_0 \quad (2)$$

On the other hand, the target lines resulted from the correlation between the data below the equivalent baseline, that is, the best consumption achieved under real-operation conditions. These follow the general form expressed in (2) and allow to know the desired energy behavior.

### *2.4 Consumption index*

The consumption index is an energy performance indicator that provides information about the variation in energy consumption per unit of production as a function of the equivalent production rate, as shown in (3). Comparative graphs were plotted for each energy source between the theoretical and real data through which the critical point of production (minimum energy consumption per unit of production) and the production ranges with high and low energy efficiency can be identified.

$$I_C = \frac{E_C}{E_P} \quad (3)$$

### *2.5 Energy saving and emission reductions potential.*

Saving potentials can be calculated in terms of reducing operational variability or by production management. For the first case, a ratio was established on the basis of the difference between the amount of energy consumed per day shift not associated with production and the actual average consumption of each energy source in the study area.

On the other hand, for savings represented by production management, the product between the average production and the maximum and average production efficiencies were related with the average energy consumption.

Finally, the main benefit of the study lies on the reduction of atmospheric $CO_2$ emissions from the saving of gas and electricity consumption by energy management. The calculation of these potentials was based on the difference between actual consumption and expected consumption, which is based on the implementation of actions that can generate energy savings. For this, the Emission Factor (EF) was taken into account, which refers to the amount of $CO_2$ released per unit of fuel consumed for gas. In terms of electricity, it indicates the amount of $CO_2$ emitted per unit of electrical energy needed for production. This factor is determined by the Energy Mining Planning Unit (UPME in spanish) of Colombia, according to the composition or participation of the different sources in generation (hydroelectric, thermoelectric, renewable, etc.). The values used for the calculations in this analysis were 0.401 kg of $CO_2$/ kWh for electrical energy and 1,985 kg of $CO_2/m^3$, according to Colombian Resolution 0843 of 2016 (UPME , 2016).

## 3. Results

### *3.1 Control charts*

Fig. 1 & 2 shows the electrical energy consumption control chart for palm oil, where the upper and lower statistical limits and the calculated average line are clearly defined. Similarly, the graphs for electrical energy and natural gas in the physical refinery area were obtained for each of the oils produced. Results are shown on. With those graphics, atypical consumption and trend along time are identified. In electrical energy, a low variability is shown (almost all data are within in limits), registering 10 shifts with unusual consumptions and even though these data were excluded from the study, the company did study the causes of the anomaly. Concerning to natural gas, more variability was observed with 18 shifts off-limits and higher quantity of consumptions near or over the limits.

Table 1 shows a closeness between the limit values and the average consumptions to palm, soybean and sunflower in electrical energy data but not to natural gas information. From this, a previous conclusion is obtained referred to variability on this energetic.

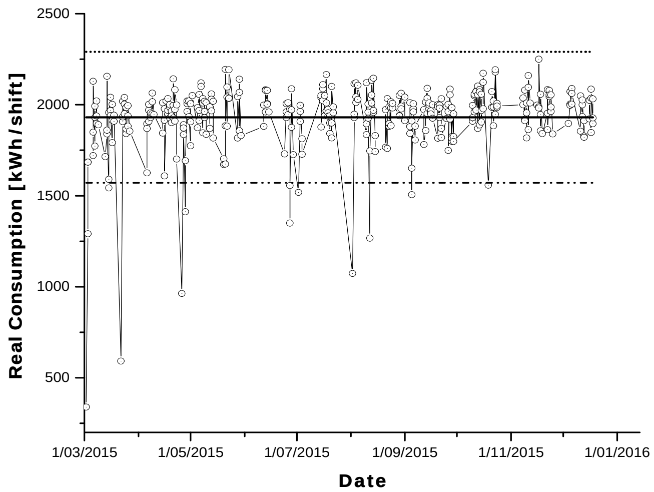


**Fig. 1.** Control charts of physical refiner's electricity consumption (⊙). UCL(····) AC(━) and LCL (- - -)

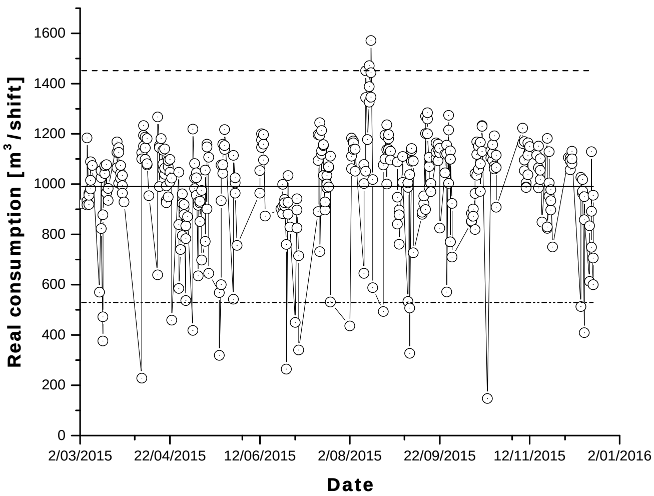


**Fig. 2.** Control charts of physical refiner's natural gas consumption (⊙). UCL(····) AC(━) and LCL (- - -)

With those graphics, atypical consumption and trend along time are identified. In electrical energy, a low variability is shown (almost all data are within in limits), registering 10 shifts with unusual consumptions and even though these data was excluded from the study, the company did study the causes of the anomaly. Concerning to natural gas, more variability was observed with 18 shifts off-limits and higher quantity of consumptions near or over the limits.

Table 1 shows a closeness between the limit values and the average consumptions to palm, soybean and sunflower in electrical energy data but not to natural gas information. From this, a previous conclusion is obtained referred to variability on this energetic.

**Table 1.** Results of statistical control limits

| | Electrical energy | | | Natural gas | | |
|---|---|---|---|---|---|---|
| | **UCL [kWh/shift]** | **LCI [kWh/shift]** | **AC [kWh/shift]** | **UCL [kWh/shift]** | **LCI [kWh/shift]** | **AC [kWh/shift]** |
| **Palm** | 2,291 | 1,571 | 1,931 | 1,451 | 530 | 991 |
| **Soybean** | 2,333 | 1,432 | 1,882 | 1,071 | 181 | 626 |
| **Sunflower** | 2,477 | 1,080 | 1,779 | 935 | 104 | 519 |

*UCL: Upper control limit, LCI: Lower control limit, AC: Average consumption.*

### *3.2 Baseline*

Fig. 3 show the resulting equivalent baseline for the treatment of data related to electrical energy consumption for the selected standard reference. It is observed that a correlation of 71.42%, and a minimum achievable consumption index of 0.0025 kWh/ kg were reached and 1645.9 kWh/shift is the value represented by the energy not associated with production.

On the other hand, Fig.4 shows the equivalent line obtained for natural gas, in which a correlation of 93.08% and a minimum achievable consumption index of 0.003 $m^3$NG/kg were reached and the energy consumed not associated with production resulted in 303.66 $m^3$NG/shift.

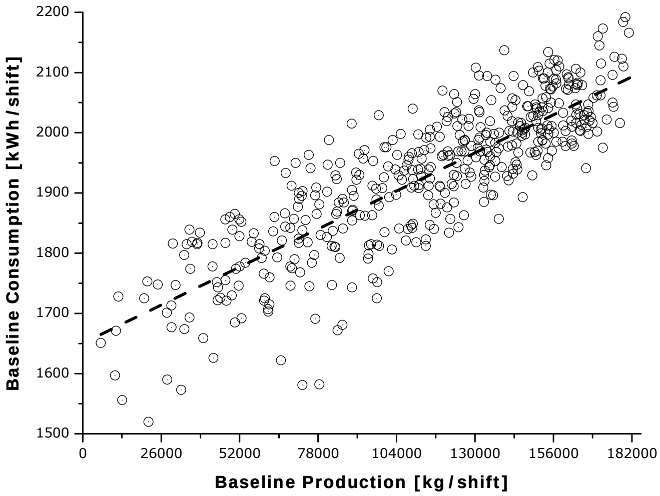


**Fig. 3.** Equivalent baseline of electricity consumption (▬ ▬) from baseline consumption (⊙)

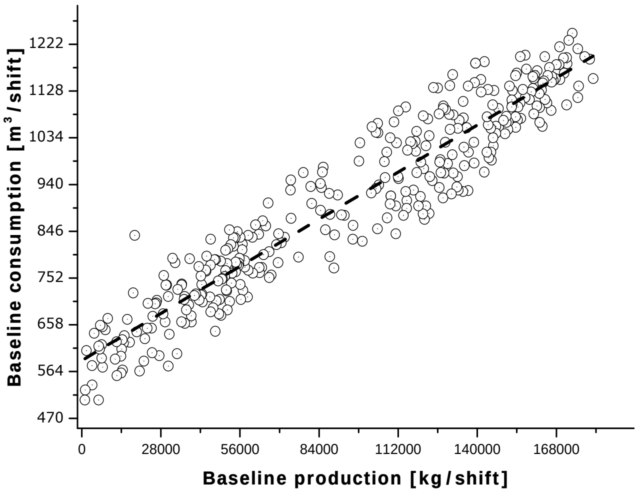


**Fig. 4.** Equivalent baseline of natural gas (▬ ▬) from baseline consumption (⊙)

### *3.3 Target line*

The resulting equivalent target line for electrical energy is shown on Fig. 5. Which shows that a higher correlation of 89.62% was reached with respect to the base line, also a constant minimum achievable consumption index according to the one previously obtained of 0.0025 kWh/ kg and 1,643.7 kWh/shift is a slightly lower value that represents the energy not associated with production.

In the case of natural gas, Fig. 6 shows the equivalent line obtained, which presents that a representative high correlation of 97.3% was reached, as a minimum achievable consumption index of 257.2 $m^3$GN/kg and finally the energy consumed not associated with production was 303.66 $m^3$GN/day.

Table 2 summarizes the final equations for the energy-equivalent baselines and targets and the correlation coefficients for each of them.

**Table 2.** Summary of base and target lines by energetic

| Electrical Energy | | Natural Gas | |
|---|---|---|---|
| **Baseline** | **Target line** | **Baseline** | **Target line** |
| [kWh/shift] | | [m³/shift] | |
| $E_C = 0.0025E_P + 1645.9$<br>$r^2 = 71.42\%$ | $E_C = 0.0025E_P + 1589.3$<br>$r^2 = 89.2\%$ | $E_{eq} = 0.003\ E_P + 303.66$<br>$r^2 = 93.08\%$ | $E_{eq} = 0.003\ E_P + 257.2$<br>$r^2 = 97.3\%$ |

### *3.4 Consumption index*

The consumption indexes for electrical energy and natural gas, obtained from the calculations made, are shown on Fig. & Fig**.** , respectively. The behavior of data on Fig. 3 & 4 exhibits a high density of energetic-productive information around the linear adjustments proposed. Based on this and high values of correlation obtained, it is possible to conclude reliability in expense-benefits performance and the model suggested. In conformity with this, consumption indexes illustrated in the Fig. 7 & 8 show the typical operation range and the tendency to produce in the level of minimum expenditure for unity produced besides how assertive is the equation for both lower and higher consumptions.

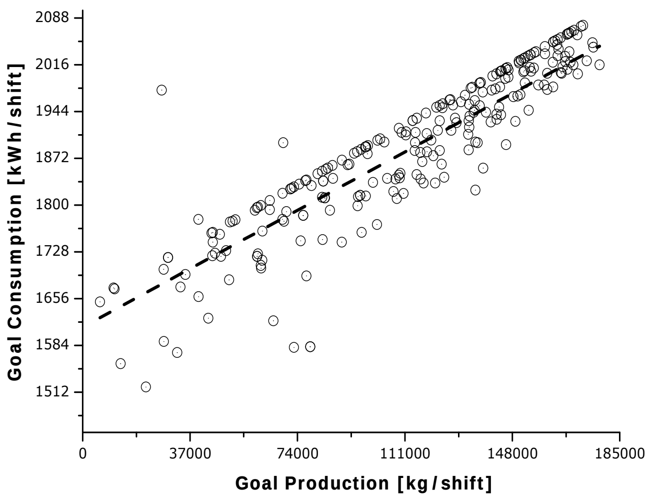


**Fig. 5.** Goal equivalent baseline of electricity consumption (▬ ▬) from goal consumption (⊙)

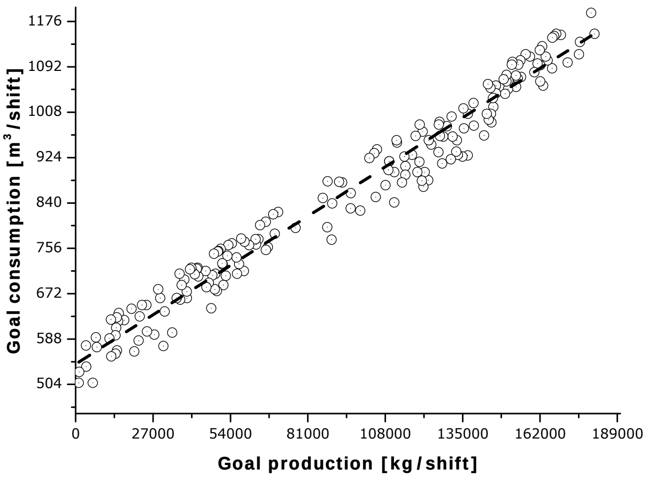


**Fig. 6.** Goal equivalent baseline of natural gas consumption (▬ ▬) from goal consumption (⊙)

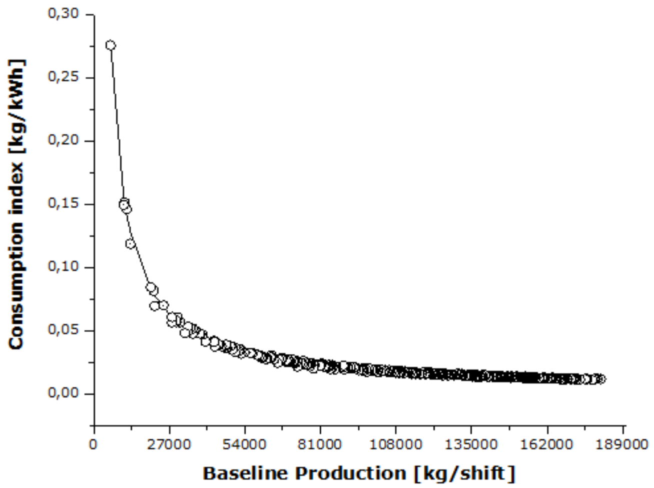


**Fig. 7.** Electricity theoretical (—) and real (⊙) consumption indexes.

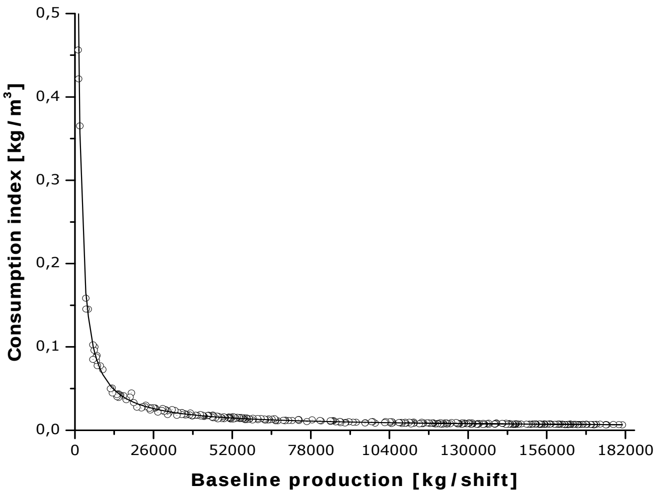


**Fig. 8.** Gas natural theoretical (—) and real (⊙) consumption indexes.

From these models, the company can associate in a better way the energy and production management in order to operate with the highest productions rates as long as possible, spending the least and polluting less. With respect to Fig. 5 & 6, the expected performance in which the process must operate are presented. This is because of the fact that this behavior has been gotten with real data, consequently these results become feasible and should become in the operation target. Besides that, the target lines have a better correlation and low-dispersion around the linear adjustment and thus ensure a closer alignment between the models and process performance. It is important to highlight that this target can be achieved without capital investment and only with an improvement of manufacture practices.

### *3.5 Energy saving and emition reductions potentials*

The annual potential of energy savings and reduction of emissions of $CO_2$ by promote better operational practices and maintenance actions are shown on Fig. 9 & 10, both to electrical energy and natural gas. This information is illustrated also for improvements in production management on Fig. 11 & 12.

These figures clearly represent the high improve potential on the company in spite of the strong correlation between energy consumptions and production rates. In general, the wide optimization range that company can get is marked, creating the necessity of reprogram operation rates. On the other hand, when raw material is sunflower, higher index are reached notwithstanding the low frequency in which it is fed, showing then disturbed on planning and lack of knowledge while operating it. For such situations, keep records of energetic performance indicators with on-line management is suggested in order to generate synergy between operators, promoting them to identify and take control from critical variables with major impact on the perform and raise actions plans aimed to the continuous improvement.

In addition, it is important to emphasize the difference between $CO_{2Eq}$ according to what energy consumption is reduced. The saving percentage depends on the ratio between total energy saving and average consumption when this raw material is in process, being different for each one as in Table 1 was shown. Although the ratio of natural gas improvement potentials between palm and sunflower is almost 1:2, the reduction in emissions is practically the same, showing that the impact of improving by one percentage point when operating the palm generates both a greater environmental and operational impact. It is also important to note that natural gas savings are higher than electrical energy and with more effect in the $CO_{2Eq}$ emitted too.

- **For improvement in operational practices and maintenance strategies.**

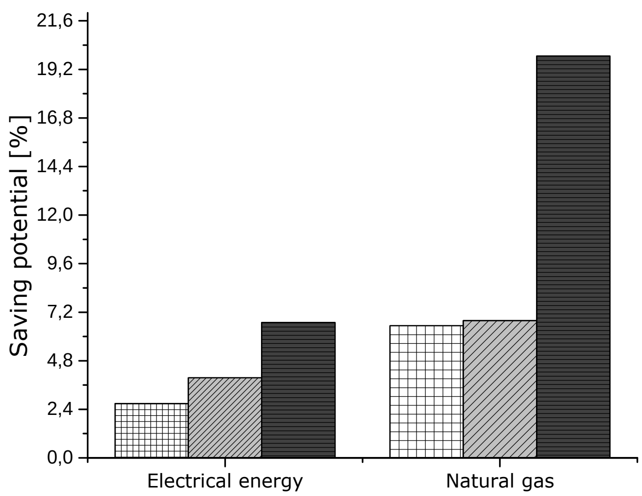


**Fig. 9.** Saving potentials in energetics sources for improve in operational practices and maintenance.

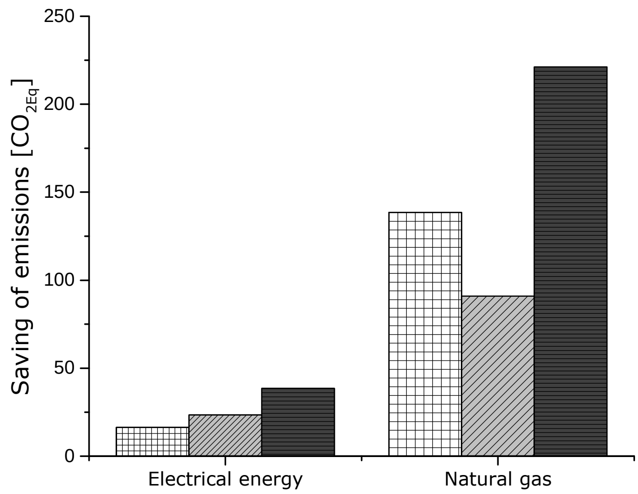


**Fig. 10.** Saving of emissions for improve in operational practices and maintenance.

Palm (▦), Soybeans (▨) and Sunflower (■)

It should be noted that it is necessary to present the savings potentials individually and not equivalently in order to demonstrate the individual behavior of each raw material. The equivalent behavior allows a global monitoring of the process and to detail the level of standardization of the same one, being more practical and easy to unify a model, nevertheless, it is pertinent as a starting point towards the options of improvement to detail in each product and to determine deficiencies at the time of producing under each one of these, congruent this to the significant differences obtained in the percentages of improvement for palm, soybean and sunflower.

- **For improvement in production planning**

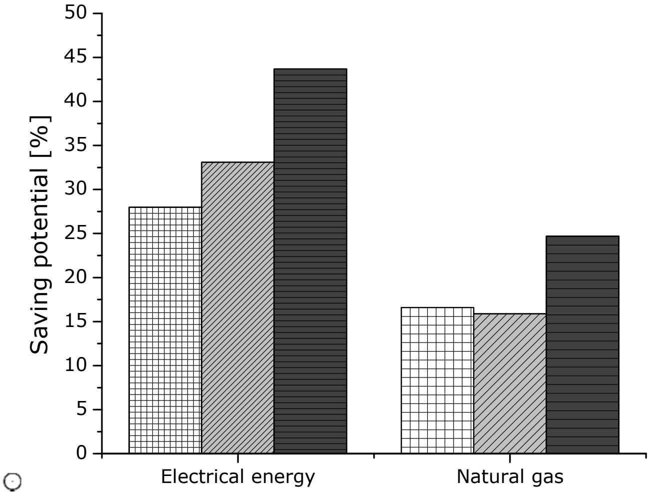


**Fig. 11.** Saving potentials for production management.

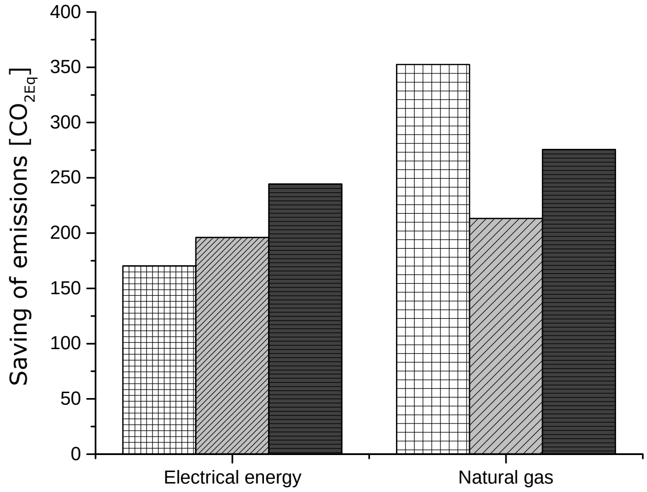


**Fig. 12.** Saving of emissions for production management.

Palm (), Soybeans () and Sunflower ()

This study represents a starting point for the implementation of an energy management system under the guidelines of the NTC ISO 50,001 standard, raising the need to establish new energy performance indicators at all stages of the process and to set up an operational control system for energy efficiency in the major energy-consuming areas and at the company level, which will allow the establishment and standardization of these processes in the long term within the company.

## 4. Conclusions

- Energy-productive models was validated, subject to equations $E_{eq}$= 0.0025$P_{eq}$ + 1,645.9 [kWh/shift] for electrical energy, $E_{eq}$= 0.003$P_{eq}$ + 303.66 [$m^3$/shift] for natural gas, with correlation coefficients of 71.2% and 93.08%, respectively, which show a high correspondence between the energy services invested and the final product obtained in the physical refinery area.

- Projection of target models, which allow estimating an ideal long-term behavior for both electrical energy and natural gas subject to models $E_{eq}$= 0.0025$P_{eq}$ + 1,589.3 [kWh/shift] and $E_{eq}$=0.003$P_{eq}$+257.2[$m^3$/shift], respectively, for operational improvement actions, without incurring in investment project in technological renovation.

- By energy management and production planning, savings can be obtained in the physical refinery area of 30.7, 31.37 and 50.4% in electricity, for soybean, palm and sunflower, respectively, and 23.10, 22.7 and 45% in natural gas in the same order above.

- As far as environmental impact is concerned, it is possible to reduce an average of 670.43 $CO_{2Eq}$ annually, where 229.7 tons of $CO_2$ correspond to savings in the physical refinery area due to electrical energy saving consumption and 430.73 tons of $CO_2$ refer to the impact of reducing the consumption of natural gas.

- The impact of saving natural gas in palm processing will be more significant than any other reduction.

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