ISSN: 0798-1015

REVISTA ESPACIOS

Vol. 41 (32) 2020 • Art. 22

Recibido/Received: 09/07/2020 • **Aprobado**/Approved: 08/08/2020 • **Publicado**/Published: 27/08/2020

Establishment of energy-production and environmental indicators in the physical refinery area of a Colombian food company

Establecimiento de indicadores de producción de energía y medio ambiente en el área de refinería física de una empresa de alimentos en Colombia

VANEGAS-CHAMORRO, Marley C.[1]
PEÑA-MARRIAGA, Miguel A.[2]
DURÁN-CONTRERAS, Michel P.[3]

Abstract
This paper shows the results of the application of the strategic decision stage for the implementation of an Integrated Energy Management System in the physical refinery area of a company in the food industry, 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.
key words: energy characterization, food industry, saving potential, energy performance indicator

Resumen
Este documento muestra los resultados de la aplicación de la etapa de decisión estratégica para la implementación de un Sistema Integrado de Gestión Energética en el área de refinería física de una empresa de la industria alimentaria, un productor de aceite y grasa vegetal ubicado en Colombia. Los principios para obtener gráficos de control e índices de consumo se muestran como un complemento a la implementación del método de producción equivalente para obtener las líneas base y objetivo en términos de consumo de gas natural y energía eléctrica para la elaboración de sus productos.
Palabras clave: caracterización energética, industria alimentaria, potencial de ahorro, indicador de desempeño energético

1. Introduction

As a priority of the 21st century, industries are trying to carry out productive processes 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 the U.S Energy Information Administration (E.I.A) criteria, the energy-intensive manufacturing industries, including

[1] Research professor. Universidad del Atlántico. Colombia. E-mail: marleyvanegas@mail.uniatlantico.edu.co
[2] Chemical engineer. Universidad del Atlántico. Colombia. E-mail: mandrespena@mail.uniatlantico.edu.co
[3] Chemical engineer. Universidad del Atlántico. Colombia. E-mail: mpduran@mail.uniatlantico.edu.co

food, rubber, paper, petroleum and petrochemicals spend 54% of the non-residential energy, therefore their carbon footprint impact have the 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 estimates 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 for companies from diverse areas of global economy in relation to rational and efficient energy use, thereby promoting the development of management strategies and operational improvement in order to obtain a cost reduction that at the same time reflects a decreased environmental impact (Campos Avella et al. (2011). From that, many researches have been developed focused on the develop of tools, models and manuals that allow to the industrial sector, in its different areas, to implement ISO standard requirements in the best way. Jovanovic et al. (2016) proposed a rigorous and maturate energy management 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, that allowed an energy planning and, based on this, savings of up to 17.7MWh/year in a metal-mechanic industry were projected. In 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 products on the same processing line. On the other hand, in the food area, Roy et al. (2009) highlighted the need to change, in general, the production, package, distribution and consumption processes in order to reduce environmental impact in this economic field. These modifications are aligned with improving strategies in the energy and production management.

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 economic area. Therefore, the aim of this work is to elaborate an energetic-productive diagnosis, to 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 the NTC ISO 50,001:2011 standard, in an edible oil company physical refiner section in Colombia. To produce the oil five stages are executed, which include a preprocessing of raw material, and depends if palm, soybeans or sunflowers are fed. Then a purification process is done under low pressure conditions to get crude oil. And then it is filtered, deodorized and finally stored to commercialize.

1.1. Theory

Worldwide, within the implemented and existents methodologies that deserve attention in the field of the food industry, the one that is used in Japan it has to be named, which is built on the base of indicators like: food self-sufficiency, food energy, primary calories consumption (Anishchenko, 2013). According to the Global Food Security Index from the Economist Intelligence Unit of Corteva Agriscience, the principles of affordability, availability and quality and safety must be followed, likewise it must be seen as a dynamic model of comparative quantitative and qualitative evaluation based on unique indicators that provide the food safety evaluation in different countries around the world. (Global Food Security Index, 2018).

The interest in the researches related to the food safety subject in general contributes to the emerge of new methods and models to evaluate the food affordability (Ushachev, 2014), so that in this labor the energy production and environmental element must be related too. In this particular case, the ideas of Bochna (2011) must be highlighted, who makes reference to the Colombian context and how this is related, for example, the friendly fuel production with the environment (biodiesel) with the generation of an edible product as the palm oil; this case is just one representation of the many that can be derived and developed in this aspect.

An article from Semana (2016) highlights how the concern about the search of clean energy in Colombia has benefited the industry, for instance the case of Brick makers in Caldas or the textile industry in Medellin that have disposed the use of new forms of energy in their productions and even the process of pumping potable water for the region of La Guajira. Taking into account such aspects, it is necessary to establish energy-production and environmental indicators in the physical refinery area of a Colombian food company, with the purpose of give evident examples of the implementation of methods of equivalent production and in that way obtain the baselines in the consumption for the elaboration of products; all this in order to obtain representative savings potentials in food production.

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 execute to achieve minimum energy consumption (Campos et al. 2008). For this study, two global activities were made in the target industry, starting with a *route diagnosis*, through which a charge register was executed to identify the productive energetic 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 of 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

Considering 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. Therefore, 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. Starting from this, the equivalence of soybean and sunflower oil with the palm oil as the quantity of product of a type production (soybean or sunflower) was calculated 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.

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

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.

$$E_C = mE_p + E_0 \tag{2}$$

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 knowing 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.

$$I_C = \frac{E_C}{E_p} \tag{3}$$

2.5. Energy saving and 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 the 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.

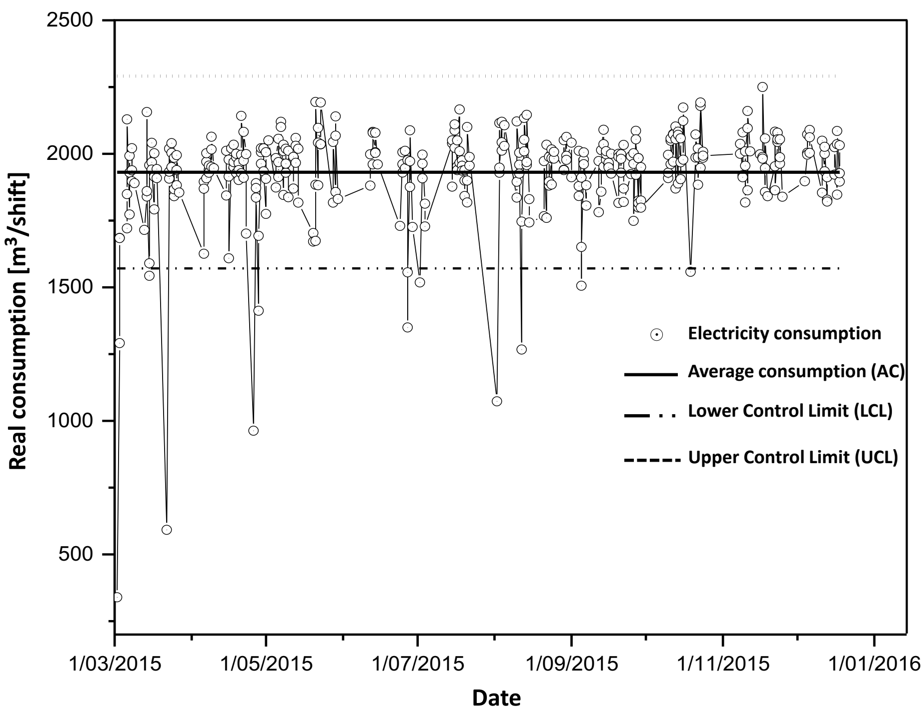
Finally, the main advantage of the study it's based on the reduction of atmospheric CO_2 emissions from the saving of gas and electricity consumption by energy management. The calculation of these potentials was based on the difference between actual consumption and expected consumption, which is based on the implementation of actions that can generate energy savings. For this, the Emission Factor (EF) was considered 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 chart

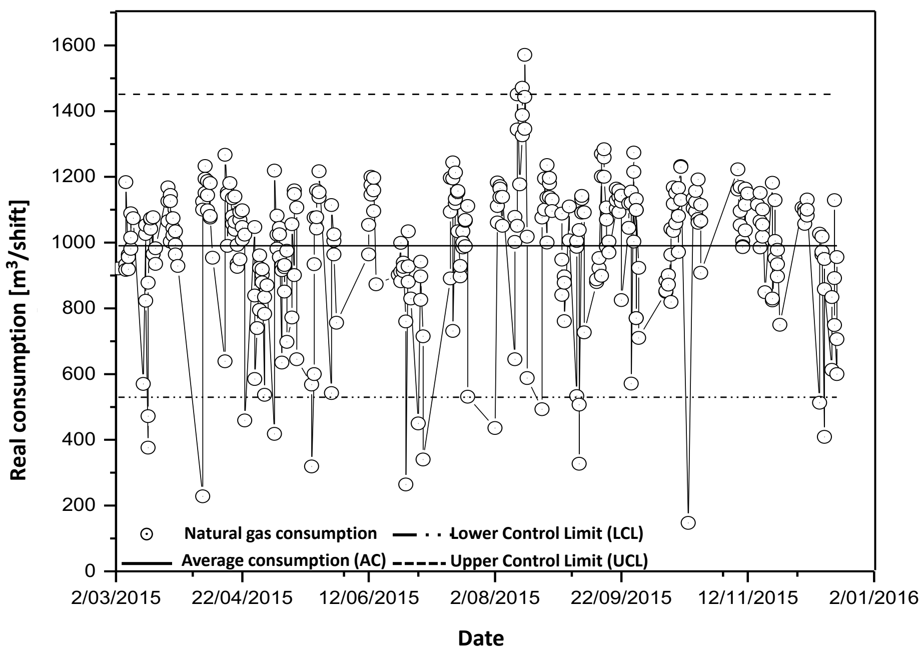
Figures 1 and 2 show the electrical energy consumption control chart for palm oil, where the upper and lower statistical limits and the calculated average line are clearly defined. Similarly, the graphics for electrical energy and natural gas in the physical refinery area were obtained for each of the 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.

Figure 1
Control charts of physical refiner's
electricity consumption



Source: Source: Own assessment (2020)

Figure 2
Control charts of physical refiner's
natural gas consumption



Source: Source: Own assessment (2020)

Table 1 shows 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

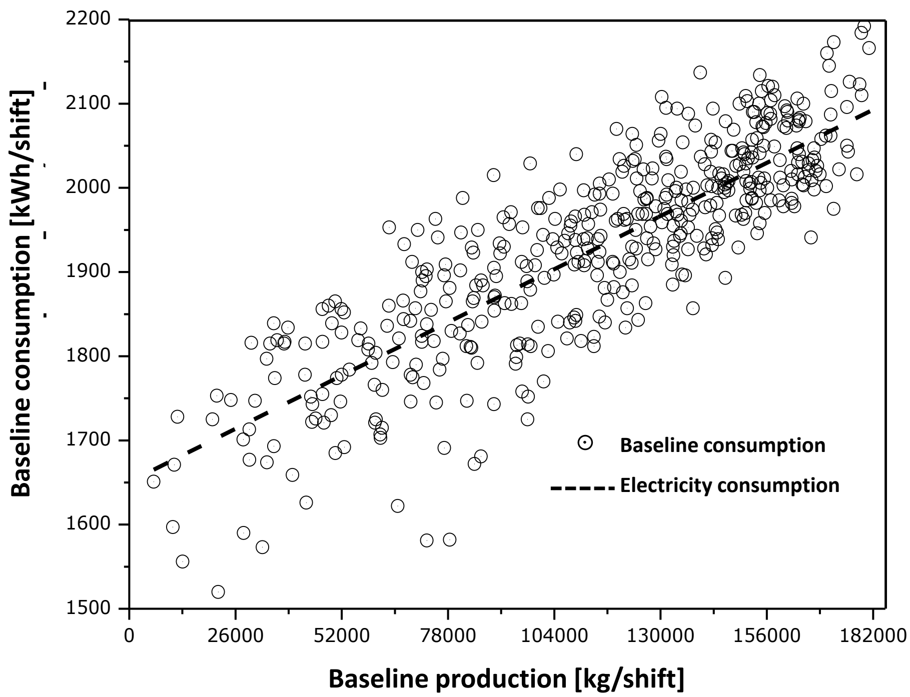
UCL: Upper control limit, LCI: Lower control limit, AC: Average consumption.
Source: Own assessment (2020)

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 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.

3.2. Baseline

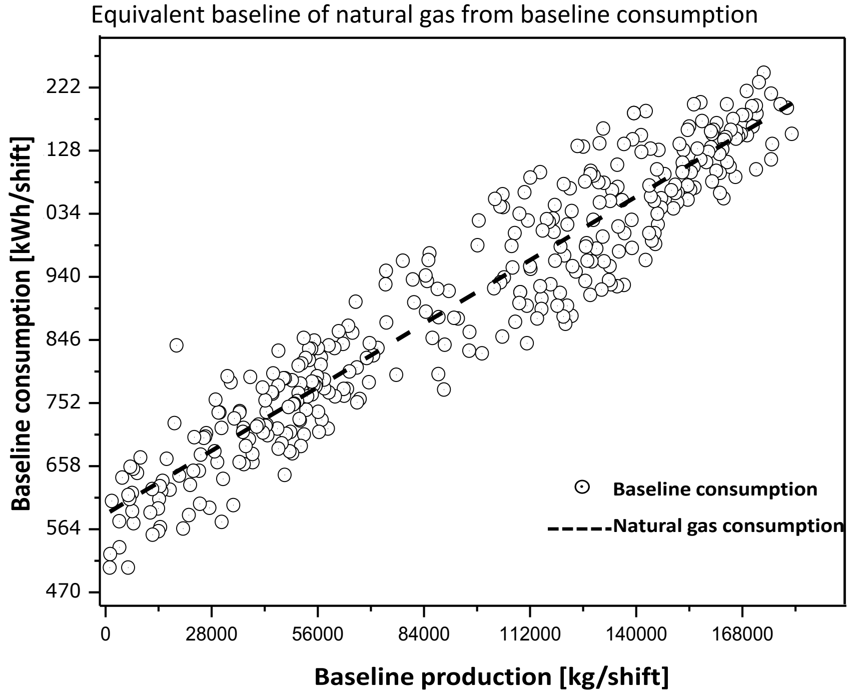
Figure 3 shows the resulting equivalent baseline for the treatment of data related to electrical energy consumption for the selected standard reference. It is observed that a correlation of 71.42%, and a minimum achievable consumption index of 0.0025 kWh/ kg were reached and 1645.9 kWh/shift is the value represented by the energy not associated with production. On the other hand, Figure 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^3NG/kg were reached and the energy consumed not associated with production resulted in 303.66 m^3NG/shift.

Figure 3
Equivalent baseline of electricity consumption from baseline consumption



Source: Source: Own assessment (2020)

Figure 4
Equivalent baseline of natural gas from baseline consumption



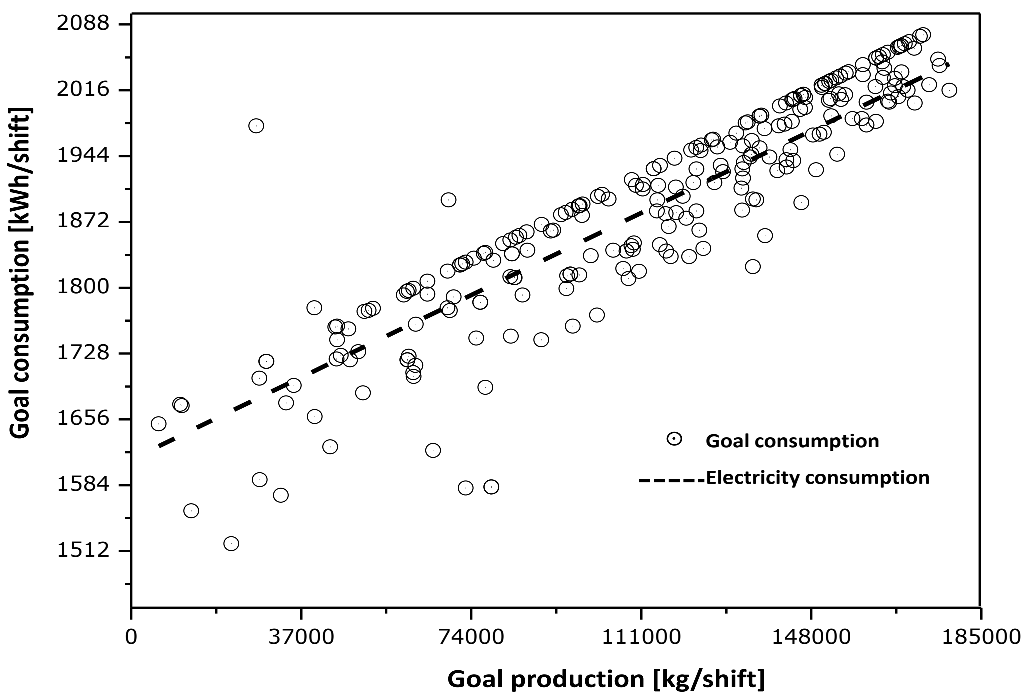
Source: Own assessment (2020)

3.3. Target line

The resulting equivalent target line for electrical energy is shown on Figure 5. This 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, Figure 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^3GN/kg and finally the energy consumed not associated with production was 303.66 m^3GN/day. Table 2 summarizes the final equations for the energy-equivalent baselines and targets and the correlation coefficients for each of them.

Figure 5
Goal equivalent baseline of electricity consumption from goal consumption



Source: Source: Own assessment (2020)

Table 2
Summary of base and target lines by energetic

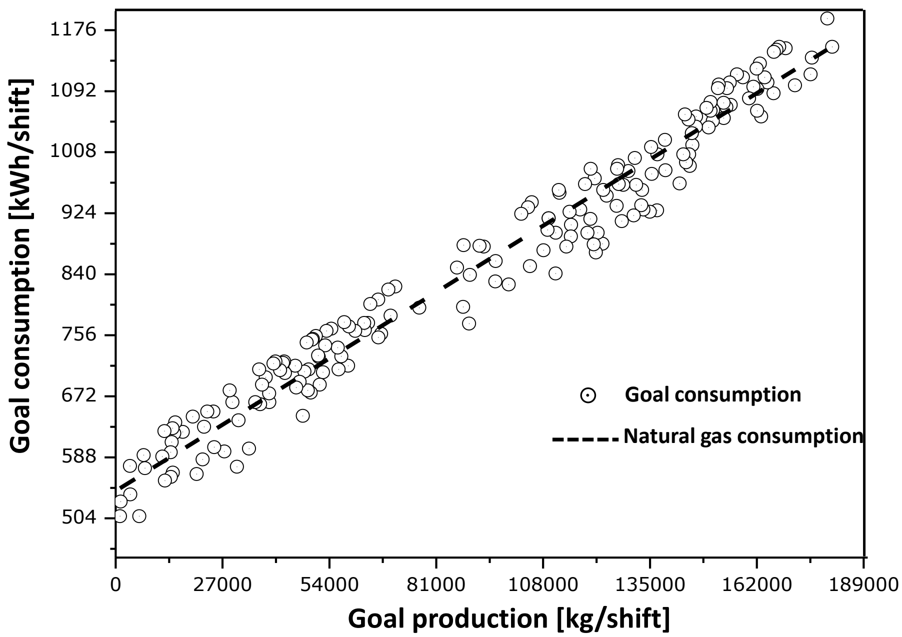
Electrical Energy		Natural Gas	
Baseline	**Target line**	**Baseline**	**Target line**
[kWh/shift]		**[m^3/shift]**	
$EC = 0.0025E_P + 1645.9$ r^2= 71.42%	$EC = 0.0025E_P + 1589.3$ r^2=89.2%	$Eeq = 0.003\ E_P + 303.66$ r^2= 93.08%	$Eeq = 0.003\ E_P + 257.2$ r^2=97.3%

Source: Own assessment (2020)

3.4. Consumption index

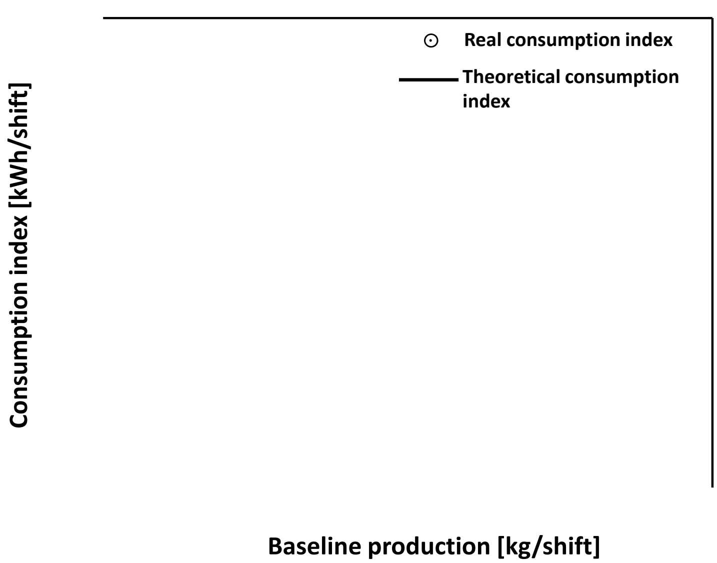
The consumption indexes for electrical energy and natural gas, obtained from the calculations made, are shown on Figures 6 and 7, respectively. The behavior of data on Figures 3 and 4 exhibits a high density of energetic-productive information around the linear adjustments proposed. Based on this and 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 Figures 7 and 8 shows 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.

Figure 6
Goal equivalent baseline of natural gas
consumption from goal consumption



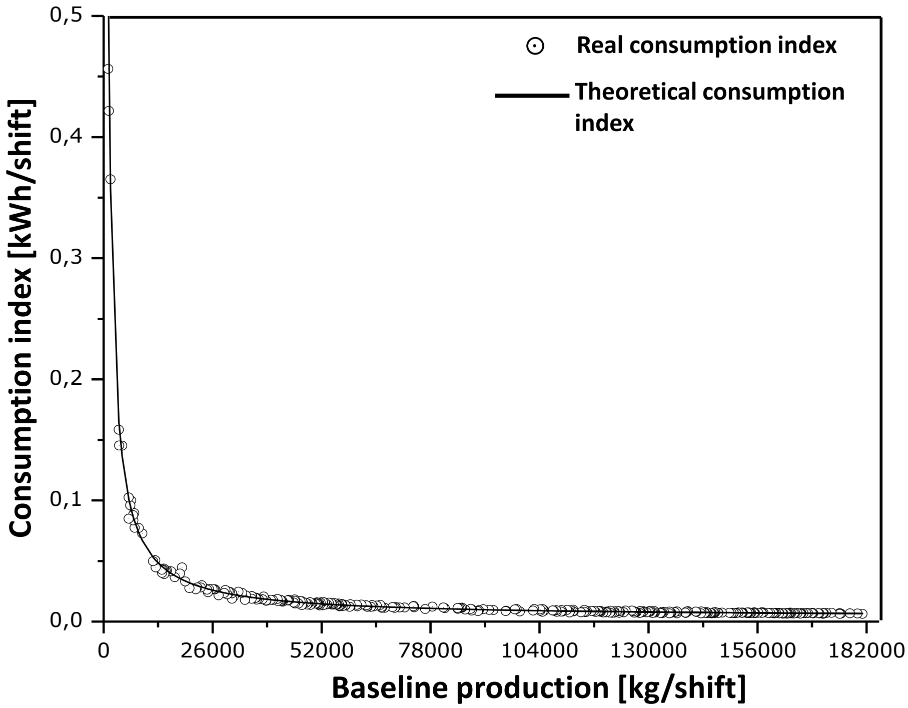
Source: Source: Own assessment (2020)

Figure 7
Electricity theoretical and real consumption indexes



Source: Source: Own assessment (2020)

Figure 8
Gas natural theoretical and real consumption indexes



Source: Source: Own assessment (2020)

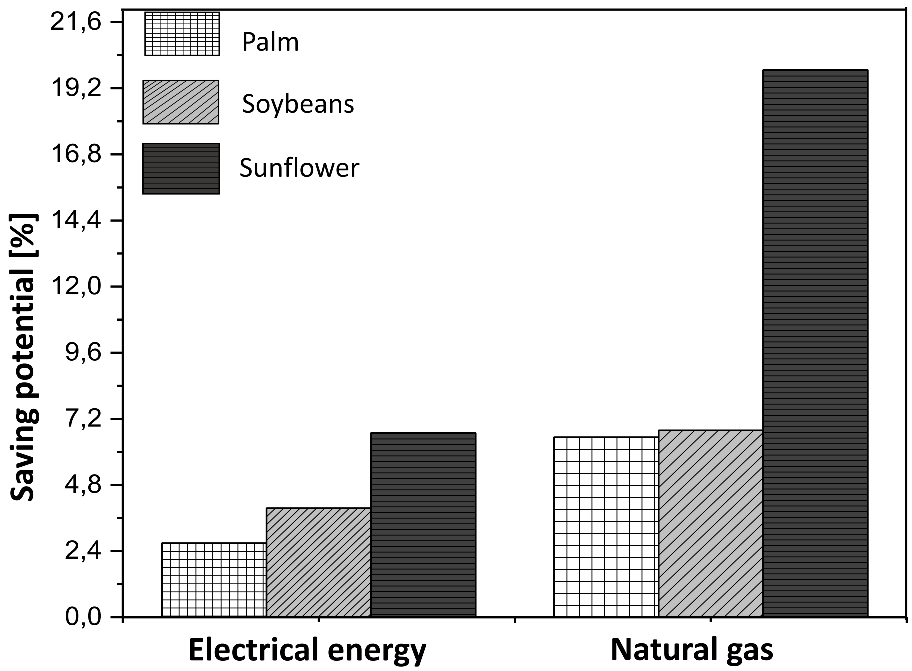
From these models, the company can associate in a better way the energy and production management in order to operate with the highest productions rates as long as possible, spending the least and polluting less. With respect to Figures 5 and 6, the expected performances in which the process must operate 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 potentials emission reductions

The annual potential of energy savings and reduction of emissions of CO2 by promoting better operational practices and maintenance actions are shown on Figures 9 and 10, both to electrical energy and natural gas. This information is illustrated also for improvements in production management on Figures 11 and 12.

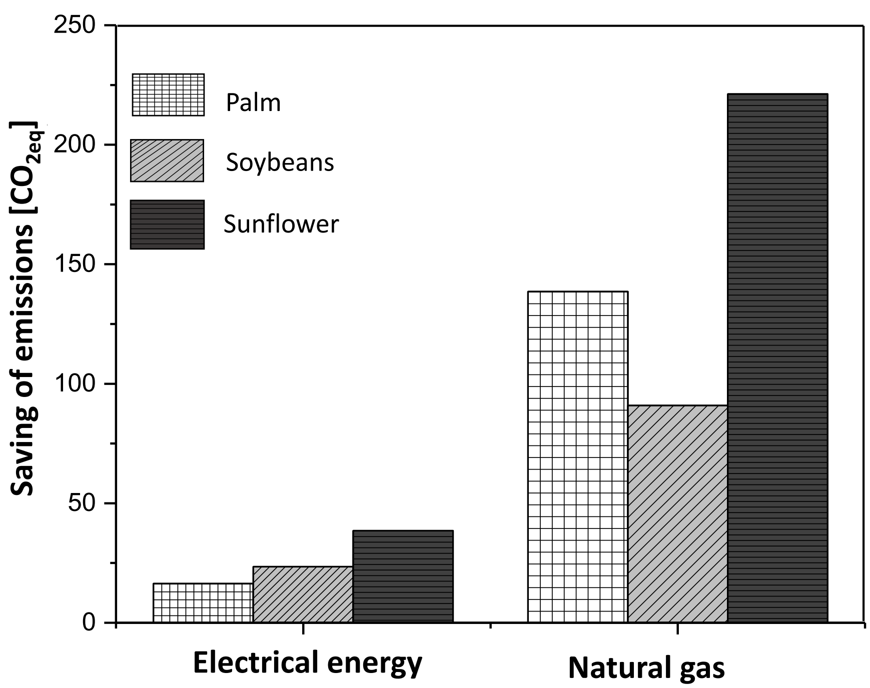
These figures clearly represent the high improve potential on the company in spite of the strong correlation between energy consumptions and production rates. In general, the wide optimization range that the company can get is marked, creating the necessity of reprogram operation rates. On the other hand, when raw material is sunflower, higher index are reached in spite of the low frequency in which it is fed, showing then disturbed on planning and lack of knowledge while operating it. For such situations, keeping the 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.

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



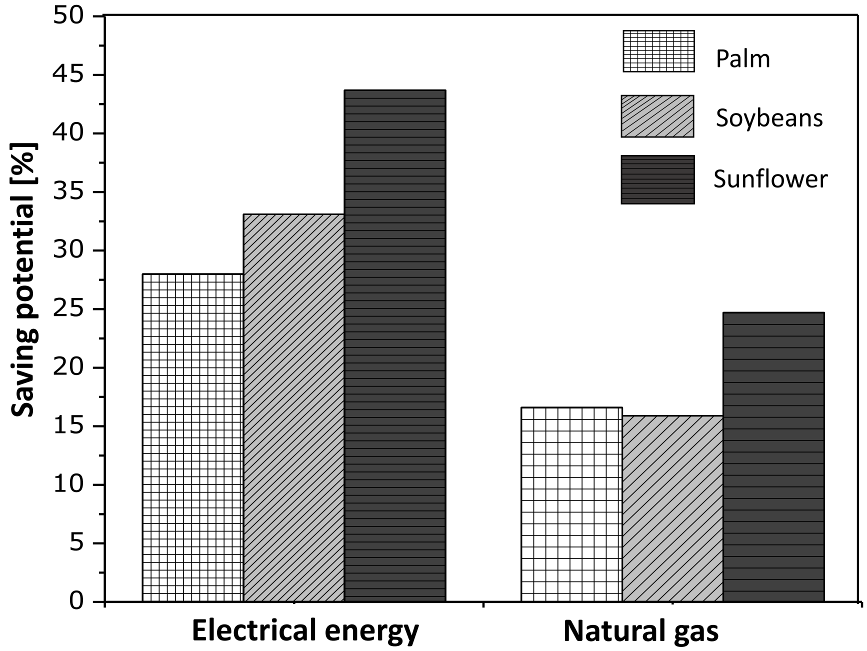
Source: Source: Own assessment (2020)

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



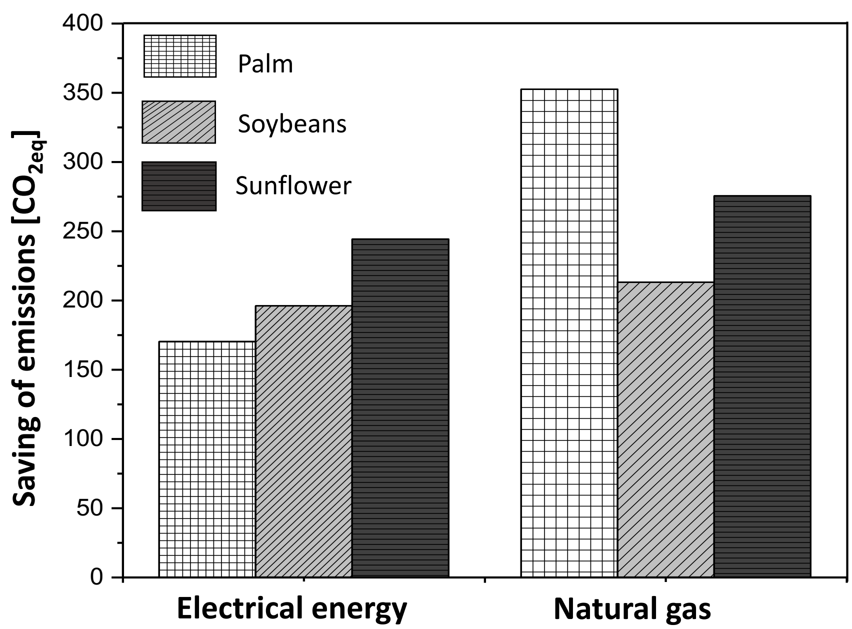
Source: Own assessment (2020)

Figure 11
Saving potentials for
production management.



Source: Own assessment (2020)

Figure 12
Saving of emissions for
production management



Source: Source: Own assessment (2020)

In addition, it is important to emphasize the difference between CO2Eq 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 CO2Eq emitted too.

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.

3.6. For improvement in production planning

This study represents a starting point for the implementation of an energy management system under the guidelines of the NTC ISO 50,001 standard, presenting 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 were validated, subject to equations E_{eq}= 0.0025P_{eq} + 1,645.9 [kWh/shift] for electrical energy, E_{eq}= 0.003P_{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}= 0.0025P_{eq} + 1,589.3 [kWh/shift] and E_{eq}=0.003P_{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} per year, 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.

Bibliographic references

Anishchenko, A.N. (2013) Assessment of food security of the region. *Problems of the development of the territory*, *4*(66), 30-39.

Bochno, E. (2011) Estado del Arte y Novedades de la Bioenergía en el Colombia. Organización de las naciones unidas para la alimentación y la agricultura.

Campos Avella, J.C.; Lora Figueroa, E.; Alvarez Garcés, K. (2011). *Manual de Gestión Energética Para La Industria Del Petróleo Y Gas.* 1st ed.

Campos Avella, J.C., Lora Figueroa, E., Meriño, L., Tovar, I., Navarro, A., Quispe, E. C., Vidal, J.R., Castrillón, Y., Castrillón, R., Prias, O. (2008) Guía para la implementación de sistemas de gestión integral de la energía. UPME, COLCIENCIAS.

DANE (2015) Encuesta Ambiental Industrial Resultados Consolidados. 33. Retrieved from: http://www.dane.gov.co/files/investigaciones/boletines/EAI/2013/pre_EAI_2013p.pdf

DANE (2017) Boletín Técnico Encuesta Anual Manufacturera Boletín Técnico. Retrieved from: https://www.dane.gov.co/files/investigaciones/boletines/eam/boletin_eam_2016.pdf

Global Food Security Index (2018). *Rankings and trends.* https://foodsecurityindex.eiu.com/Downloads

Jovanović, B.; Filipović, J. (2016) ISO 50001 Standard-Based Energy Management Maturity Model - Proposal and Validation in Industry. *Journal of Cleaner Production.* 112(27)44–55.

Mezinska, I.; Strode, S. (2015) Emerging Horizons of Environmental Management in Food Sector Companies. *Procedia - Social and Behavioral Sciences.* 213,527–32. Retrieved from: http://linkinghub.elsevier.com/retrieve/pii/S1877042815058000

Revista Semana (201) Los casos de éxito de la energía limpia en Colombia. Recuperado de: https://sostenibilidad.semana.com/medio-ambiente/articulo/energias-alternativas-en-colombia/35965

Roy, P. et al. (2009) A Review of Life Cycle Assessment (LCA) on Some Food Products. *Journal of Food Engineering.* 90(1),1–10.

UPME (2016) Resolución 0843. Retrieved from: http://servicios.minminas.gov.co/compilacionnormativa/docs/resolucion_upme_0843_2016.html

Ushachev, I. (2014). Prospects for the development of agribusiness in Russia in the context of global and regional integration *Agribusiness: Economics, Management. 1*, 3-15.

U.S. Energy Information Administration (2016) International Energy Outlook 2016; With Projections to 2040. Retrieved from: https://www.eia.gov/outlooks/ieo/pdf/0484(2016).pdf%0Ahttps://www.eia.gov/outlooks/ieo/pdf/industrial.pdf

Valencia, G. E.; Cárdenas.; Ramos, E.S.; Morales, A.; Campos, J.C. (2017) Energy Saving in Industrial Process Based on the Equivalent Production Method to Calculate Energy Performance Indicators. *Chemical Engineering Transactions*. 57,709–14.

Valencia, G.E.; Ramos, E.S.; Meriño, L. (2017) Energy Planning for Gas Consumption Reduction in a Hot Dip Galvanizing Plant. *Chemical Engineering Transactions*. 57,697–702.

William, I.; Vargas Monge, D.; Bolaños Barrantes, M. (2013) Boletín Técnico: Cuenta Ambiental y Económica de Energía Y de Emisiones Al Aire, Flujos Físicos 2013 – 2014. (49),1–23. Retrieved from: https://www.dane.gov.co/files/investigaciones/pib/ambientales/cuentas_ambientales/cuenta_ambiental_economica_energia_emisiones/BL_Energia_emisiones_2013def_2014_provisional.pdf