EARLY PRODUCTION FACILITY ENERGY EFFICIENCY ANALYSIS

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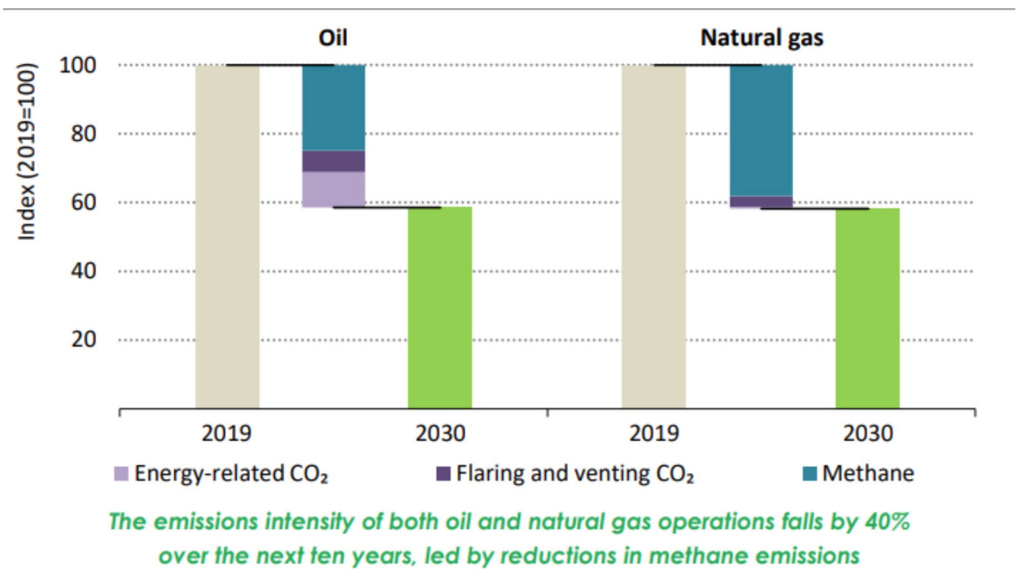
RESUMEN

El análisis presentado consiste en la identificación y cuantificación de usos energéticos significativos en la Early Production Facility (EPF) operada por Shell Argentina en Sierras Blancas, siguiendo la metodología descripta por la norma ISO 50.001 sobre Sistemas de Gestión Energética[1].
Dentro de la EPF, el límite definido para el análisis fueron los límites de las operaciones de la planta, y el alcance incluyó las instalaciones de procesamiento de petróleo, agua y gas, iluminación, flare, servicios y oficina de la planta. El período de análisis considerado fue desde mayo de 2020 hasta abril de 2021. Se realizaron un balance de gas combustible y un balance eléctrico para validar los inputs del análisis.
Se clasificaron los usos de energía, y el gas combustible resultó constituir más del 90% de la energía primaria de la instalación con solo 7 equipos representando más del 90% del consumo de gas. Se identificaron oportunidades de mejora para la operación y mantenimiento de las instalaciones existentes, y para el diseño de futuras plantas o renovaciones de las existentes. Se estiman ahorros potenciales de +10% en el consumo de combustible en comparación con la línea de base, en base a experiencias previas en instalaciones análogas[2].
Este análisis es replicable y escalable a instalaciones similares, por lo que se comparten los métodos y criterios utilizados, así como las principales oportunidades de mejora identificadas, con el objetivo de reducir las emisiones de gases de efecto invernadero de Alcance 1 a nivel de país de operaciones en el *upstream*.

INTRODUCTION

Energy efficiency plays an essential role in accelerating clean energy transitions and achieving global climate and sustainable development goals. Global improvements in energy efficiency have been declining since 2015. Energy efficiency along with methane emissions and flaring reduction, is expected to deliver more than 40% of the reduction in energy-related greenhouse gas (GHG) emissions over the next 20 years in the IEA's Sustainable Development Scenario (International Energy Agency, 2020)[3], which shows how to put the world on track to achieve international climate and energy goals in full.

Oil and gas extraction and processing, and the subsequent transport of oil and oil products to end-use consumers, were responsible for nearly 15% of global energy sector greenhouse gas (GHG) emissions in 2019, according to IEA (International Energy Agency, 2020). Above ground development and operational choices often determine the emissions intensity of production, and there are number of options available to reduce these emissions. Alternatives for this include the implementation of measures to limit methane emissions, the use of CCUS in refining, the use of renewable sources of power and heat in upstream operations, the implementation of measures to reduce flaring, and the acceleration of efforts to improve energy efficiency. In the Sustainable Development Scenario (SDS) developed by IEA (International Energy Agency, 2020), there are widespread and successful efforts to reduce the emissions intensity of oil and gas production, and sources with lower emissions intensities are increasingly preferred for



Note: Includes CO_2 and methane emissions from production, processing and transport, but excludes combustion emissions.

Figure 1. Changes in the global average emissions intensity of oil and gas operations between 2019 and 2030 in the Sustainable Development Scenario. Source: IEA, 2020[3].

development. As a result, the global average emissions intensity of oil and gas production drops by around 40% between 2019 and 2030. Figure 1 shows the above-mentioned changes in the global average emissions intensity of oil and gas operations between 2019 and 2030 in the SDS. Along with measures to reduce methane emissions and flaring, energy efficiency plays an essential role in accelerating clean energy transitions and achieving global climate and sustainable development goals.

The analysis described in the current document is focused on the role of energy efficiency for energy transitions. It was developed in the frame of the Master on Sustainable Energy Development at ITBA and was based on the methodology proposed by the International Standard ISO 50.001 on Energy Management Systems (International Organization for Standardization, 2018). This standard specifies requirements for establishing, implementing, maintaining, and improving an energy management system, whose purpose is to enable an organization to follow a systematic approach in achieving continual improvement of energy performance, including energy efficiency, energy use and consumption.

The study was developed considering a specific scope and limit -defined based on standard requirements- and all energy uses within these were included. For each piece of equipment within the scope and limit, characteristic data were collected, such as nameplate capacity, load factor, performance, frequency of use, among others, to record an inventory of all energy consuming activities. Both a fuel gas and an electricity balance were also performed for a specified period to validate the inputs of the analysis. With recorded data, a critical review of the inventory was carried out to identify the most significant energy consumers. The standard ISO 50.001 does not impose criteria to define ‘significance’ threshold, therefore, the criteria followed to define significant energy uses were selecting those which involve substantial energy consumption related to the total energy consumption.

Regarding the above-mentioned energy uses, relevant variables were identified and analyzed. These variables are quantifiable factors that significantly impacts energy consumption and routinely change. To measure the activities carried out, the results obtained, and the resources used, energy performance indicators were defined. Stated indicators were established for facility level and specific equipment level, depending on the expected use for each one. With all the referred data from the specified period of analysis, energy baselines were determined, to be used as the quantitative references to assess future actual data and as the basis for comparison of energy performance. Finally, improvement opportunities were identified for the operation and maintenance of the existing facilities, and for the design of future plants or revamps of the existing one.

SCOPE, LIMIT AND PLANT DESCRIPTION

With the second largest shale gas reserves in the world[4], Vaca Muerta is an important part of Shell's global shale portfolio and growth potential. Shell currently has four operated and three non-operated unconventional blocks in Vaca Muerta. In December 2016, Shell commissioned its Early Production Facility which has the capacity to process up to 12,000 bopd from Sierras Blancas, Cruz de Lorena and Coiron Amargo Suroeste black oil blocks. These blocks are shown in Figure 2.

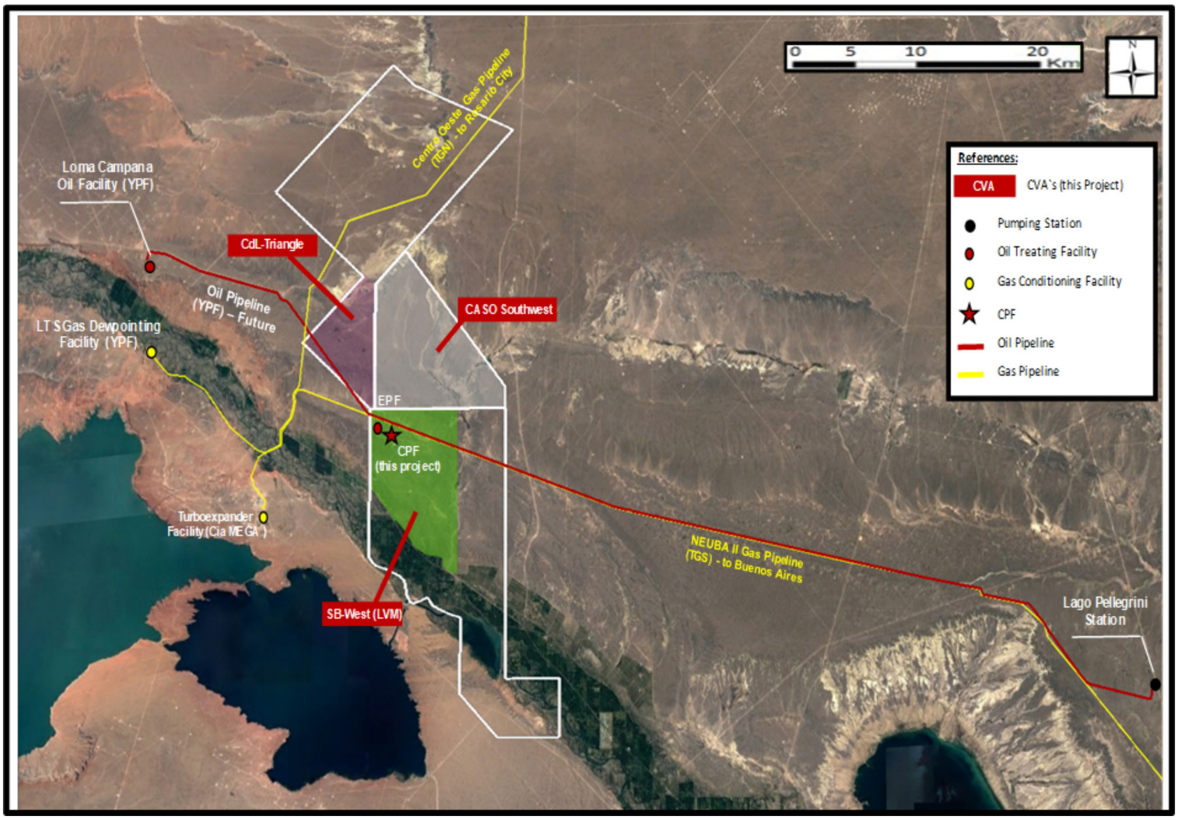


Figure 2. Map of the three Vaca Muerta blocks that produce hydrocarbons to the EPF and CPF.

Following a successful shale exploration and production pilot, the decision to move into the development phase of those three blocks in the Neuquen province was announced in 2018.

As of April 2022, the production system for these blocks includes 72 production wells, 17 producing well pad facilities, a field gathering system, two water disposal wells, water distribution networks and two processing facilities, the Early Production Facility (EPF) and the Central Processing Facility (CPF). All oil and gas processing necessary to meet downstream gas pipeline and oil sales specifications is done at both facilities.

The total oil capacity of the process facilities, EPF and CPF, is 42 kbopd (EPF:12 kbopd and CPF:30 kbopd). The multi-phase flow from the well pads arrives to a centralized manifold where production can be aligned to the EPF or the CPF.

The analysis described on the present work is focused on the Early Production Facility (EPF), located in the Sierras Blancas block. The limit of the analysis is from the inlet separators to the oil and gas delivery to 3rd parties and water disposal. The facilities upstream of the inlet separators (well pads, gathering lines) are not part of the scope of this analysis.

The period of analysis considered is from May 2020 to April 2021 (Figure 3), which were the months with more stable production. During the analyzed period, the plant operated in average at 88% of its installed capacity. This data was used to calculate the fuel gas and electric consumptions.

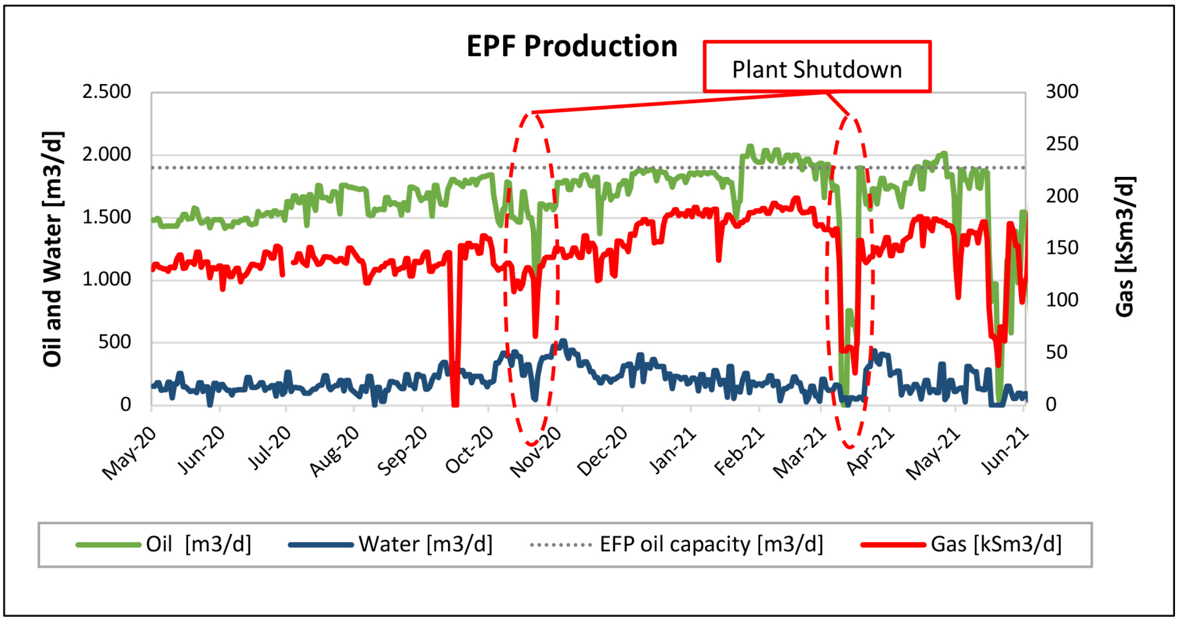


Figure 3. EPF oil, gas and water production at sales or injection point from May 2020 to April 2021. EPF nameplate capacity: Oil: 12.000 bopd (1.900 m^3/d) | Gas: 7.2 MMSCFD (204 kSm^3/d) | Water 2000 bwpd (320 m^3/d).

At the EPF, as it can be seen in Figure 4, the production of the well pads is received in 3-phase inlet separators (V-1110/20), were gas, oil and water are separated by gravity.

Oil is then treated, stored, metered and sent to a third-party oil pipeline through pumps (P-1280A/B/C). The treatment includes one preheater (E-1210A/B), one heater treater (V-1220) and one electrostatic coalescer (V-1290, currently out of service).

Gas from inlet separators (V-1110/20) is compressed using compressors (X-2000/3000), dehydrated in a teg contactor (T-1320), and metered, prior to entering the gas export pipeline. The gas export pipeline transports compressed dehydrated gas to a nearby (<1km) pipeline owned and operated by TGS.

The remaining hydrocarbons in water are separated at the skimmer tank (TK-1610). Then, water is filtered (F-1630A/B, F-1640A/B, F-1650A/B), and stored in a tank (TK-1660) prior to final disposal in a nearby water disposal well using injection pumps (P-1670A/B/C).

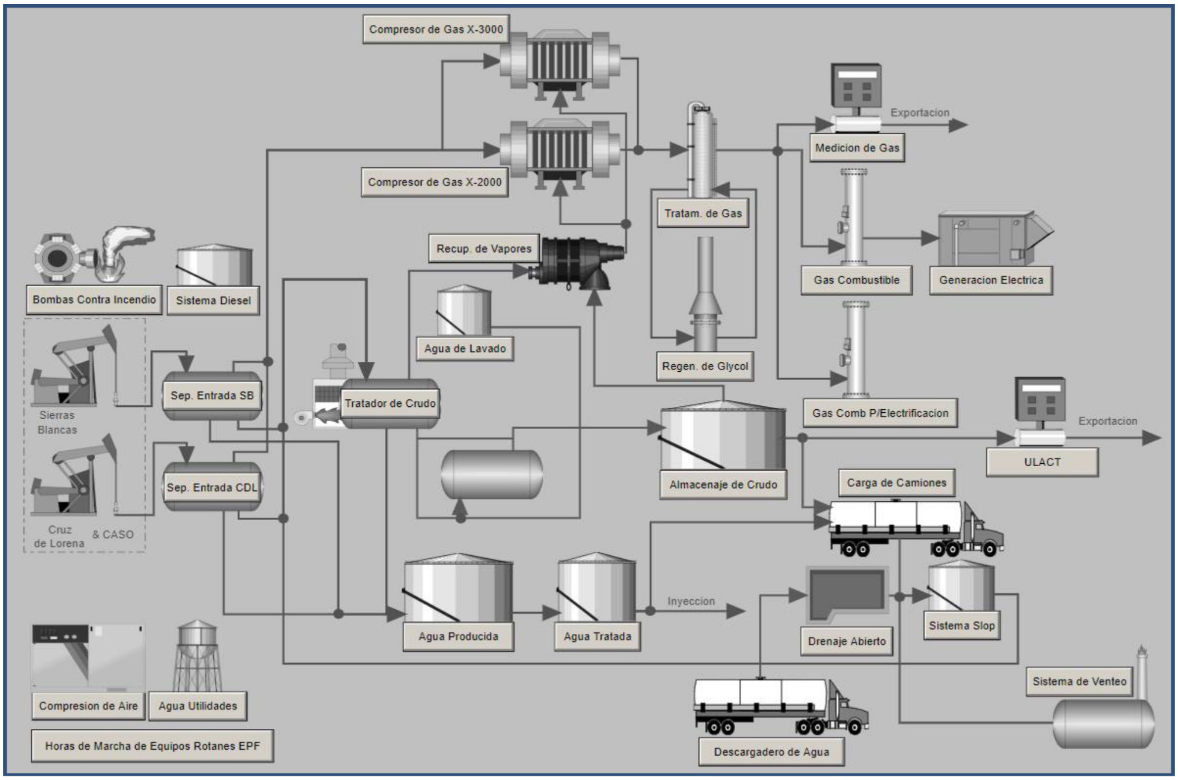


Figure 4. Simplified diagram of the Early Processing Facility (EPF).

FUEL GAS BALANCE

The objective of the fuel gas balance is to determine the fuel gas consumption of each piece of equipment of the plant.

The EPF has a fuel gas skid, where produced gas is conditioned for later distribution. The equipment of the plant does not have individual fuel gas flow meters, there is only a general meter at the fuel gas skid outlet before distribution. For this reason, to determine the fuel gas consumption corresponding to each piece of equipment, different approaches had to be followed for each one.

The methods followed to estimate the fuel gas consumption for each piece of equipment are described below:

- For the compressors, heater treater and the glycol regenerator, a fuel gas balance of the plant developed by an engineering services company was consulted. An average of winter and summer scenarios was used.
- In the case of gas generators, the consumption was estimated by considering the difference

between the electrical power required to operate the plant and the power provided by the diesel generators. The diesel generator fuel consumption was estimated using the electrical power produced by this generator during the analyzed period.

- The purge gas consumption was determined with the data sheet and the value of the local flowmeters in the field.
- The consumption of the flare pilots was obtained from the engineering data sheet.
- Finally, the blanketing gas consumption was estimated with the plant supervisor assistance and the engineering documents of the plant original design.

The fuel gas balance was considered acceptable when the aggregate of all estimations for each individual consumption was equal +/- 1% to the fuel gas skid measurement. The final output of the balance can be seen in Table 1.

Variable	Fuel Gas Consumption Estimation [Nm^3/yr]	Total Fuel Gas Metered [Nm^3/yr]	% Consumption/Metered
Fuel gas	3.150.000	3.138.000	100.3%

Table 1. Fuel gas balance comparing the total fuel gas metered vs the individual consumption estimates of fuel gas consuming equipment.

During the period of analysis, the plant consumed mainly fuel gas and some diesel for its operation. The gas was used for both electricity generation and the different processing units of the plant.

The EPF was designed to supply electricity from three gas generators. However, in the period under analysis, specifically from Aug-20 to mid-Apr-21, there were operative issues due to hydrates formation in the gas power generation system. Therefore, a diesel generator provided the additional electric power required for the operation of the plant. A summary of the total fuel gas and diesel consumption can be seen in Figure 5.

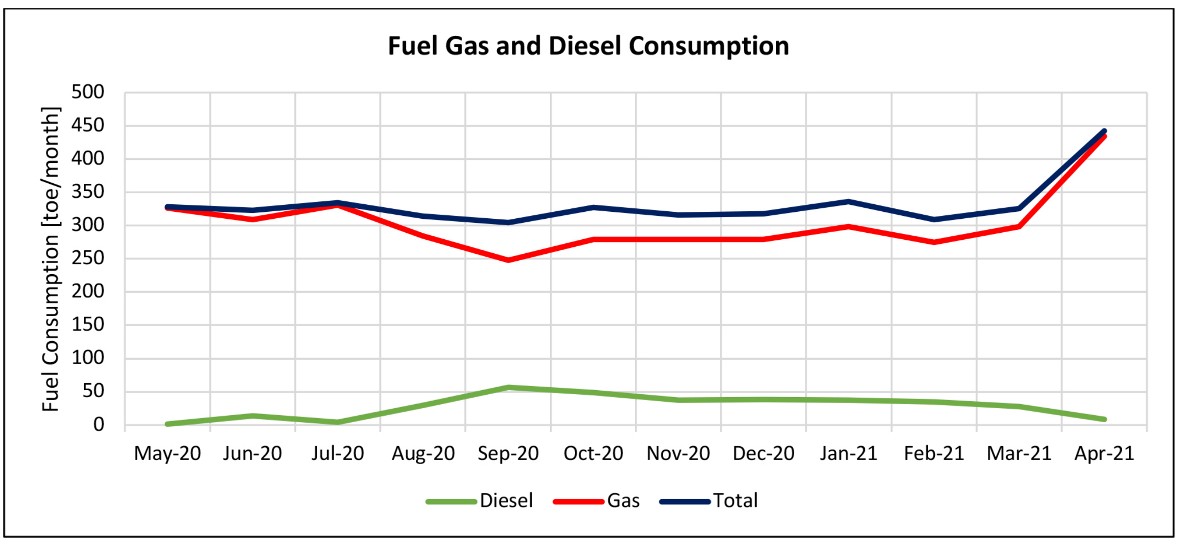


Figure 5. Fuel gas and diesel consumption evolution during the period of analysis.

The total diesel volumes were estimated from the electricity generation produced during the analysis period by the diesel generator. The power generated by the diesel generator was obtained from the plant PI Vision system. For the diesel volumes estimation, the heating value of the fuel and an efficiency of 40% for the generator were used.

It can be observed in Figure 5 that fuel gas consumption had an increase of 46% respect to the prior month. This change can be partially explained due to the fact that less diesel was consumed that month. Nonetheless, such a considerable increase could be potentially explained due to an increase in the plant processed fluids, which is not the case, as it can be seen in Figure 3. Since this variation could not be easily explained with the available data, it was decided to exclude this data point from part of the analysis which will be shown in the following sections.

Table 2 below shows the summary of the fuel consumption per piece of equipment.

Source	Equipment	Consumption per year	
		[toe/year]	%
Fuel Gas	Compressors	1,760	48%
	Gas generators	741	20%
	Heater treater	585	16%
	Purge gas	206	6%
	Blanketing gas	172	5%
	Glycol regenerator	124	4%
	Flare pilot	51	1%
Total Fuel Gas		3,640	100%
Diesel	Diesel generator	337	100%

Table 2. Fuel consumption per fuel and per equipment item.

Figure 6 shows graphically the relative contribution of each fuel gas consuming system in the plant. As can be noticed on Table 2, the compressors, gas generators and the oil heater treater represent nearly 90% of the total fuel gas consumption. As a preliminary conclusion, it could be stated that including online flowmeters in these pieces of equipment is essential to measure individual fuel gas consumption in real time.

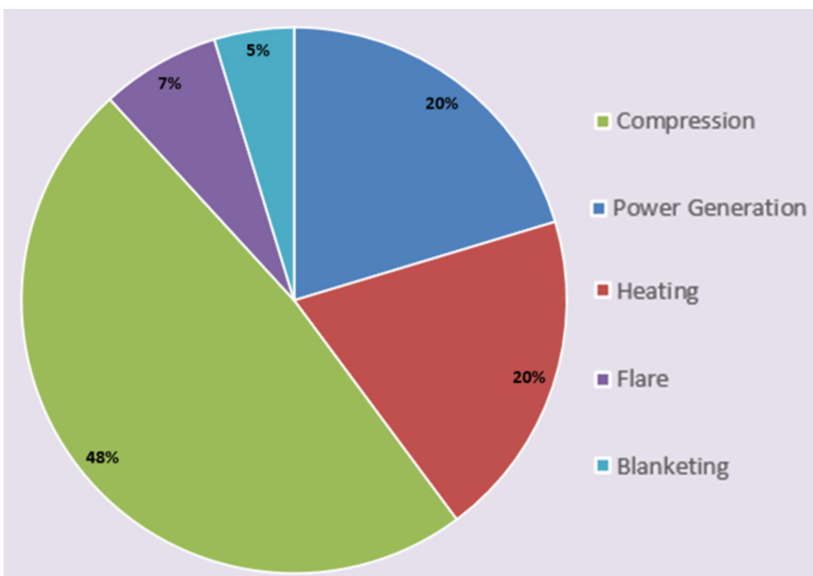


Figure 6. Relative contribution of each fuel gas consuming system.

ELECTRIC BALANCE

The electrical balance analysis considers the supply and demand of electric power and energy in the electric power system of the EPF. This analysis includes all electrical equipment within the limits of this study.

First, the consumption of the electric motors was estimated according to the technical data of each equipment and operational variables, such as frequency of use and load factor. Electric motors were grouped into 24 groups, including pumping, tracing, vapor recovery unit (VRU), cooling and other equipment. The electrical consumption of these equipment is about 3,500,000 kWh/year, which represents 77% of all EPF power consumption.

The consumption of other electrical equipment including lighting, office and instrumentation and control equipment was also estimated in a similar way. The following considerations were taken:

- A 50% use of lighting equipment: 12 hours a day, averaging 10 hours for summer days and 14 hours for winter days.
- The electrical consumption of the office was included in the lighting category.
- 24 hours of use and 365 days a year were considered for instrumentation and control equipment.

Finally, the electricity consumption of 17 lighting equipment, instrumentation, consumption associated with the office and utilities was obtained. These equipment represent a consumption of approximately 1,000,000 kWh/year, corresponding to 23% of the electricity consumption of the EPF.

Figure 7 shows the electrical energy consumption of the EPF in the period under analysis.

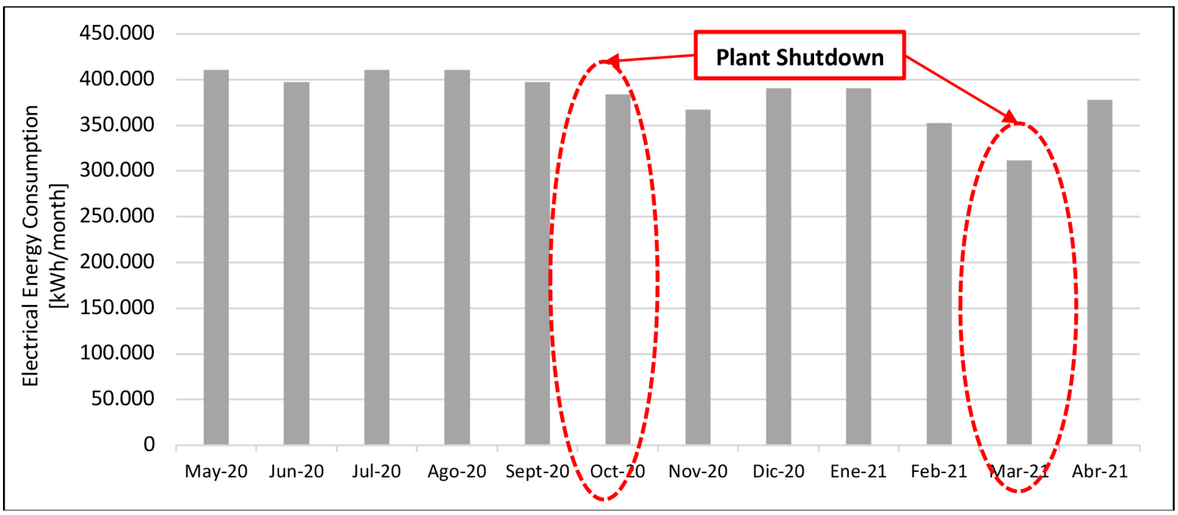


Figure 7. Electrical energy consumption at the EPF.

Regarding the electrical generation, the electrical system is not supplied by the electrical grid. As mentioned before, the power demand is supplied by three gas generators, as primary power supply, and one diesel generator, used as a back up option in case of contingencies. However, during the analysis period, there were operational issues in the gas power generation system, which forced a higher use of the diesel generator. The electrical power of the diesel generator was collected using measured data from PI vision system. Fuel gas consumption for power generation was partially measured during the analyzed period. Finally, it was adjusted taking into account the difference between the electricity produced by the diesel generator and the electricity demand of the plant.

Electricity generation was calculated considering fuel consumption, its respective calorific power (Table 3) and the efficiencies of each electric generator. All diesel consumption is intended for electrical generation and the efficiency of this generator is around 40%. The volume of gas intended for electric generation was computed from the electrical power that the gas generators had to supply, considering a generation efficiency of 35% and the calorific power of the fuel gas used.

Fuel	Unit	Calorific Value
Fuel gas	Nm^3	11,555 kcal/Nm^3
Diesel	kg	10,200 kcal/kg

Table 3. Calorific values of fuels used at the EPF.

Figure 8 shows the generation of electrical energy according to the fuel used.

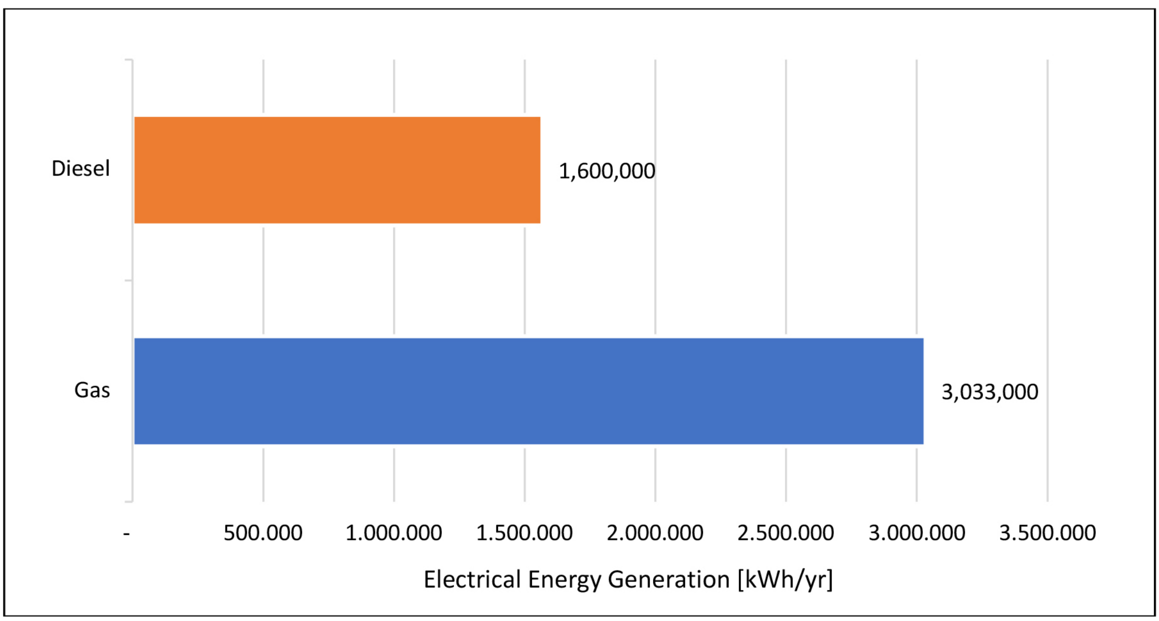


Figure 8. Relative contribution of each power generating system at the EPF.

The electricity balance was considered acceptable when the aggregate of all the estimations for the individual consumptions was equal +/- 1% to total power provided by the fuel gas and diesel generators. The final output of the balance can be seen in Table 4.

Variable	Electrical Energy Consumption [MWh/yr]	Electrical Energy Generation [MWh/yr]	% Consumption/Generation
Electricity	4.583	4.601	99.6%

Table 4. Power balance comparing electricity generation vs consumption.

Figure 9 shows the relative contribution of each power consuming system in the plant. As can be seen, the pumps and heat tracing systems are the most important power consumers in the facility, accounting for 56% of the total power consumption.

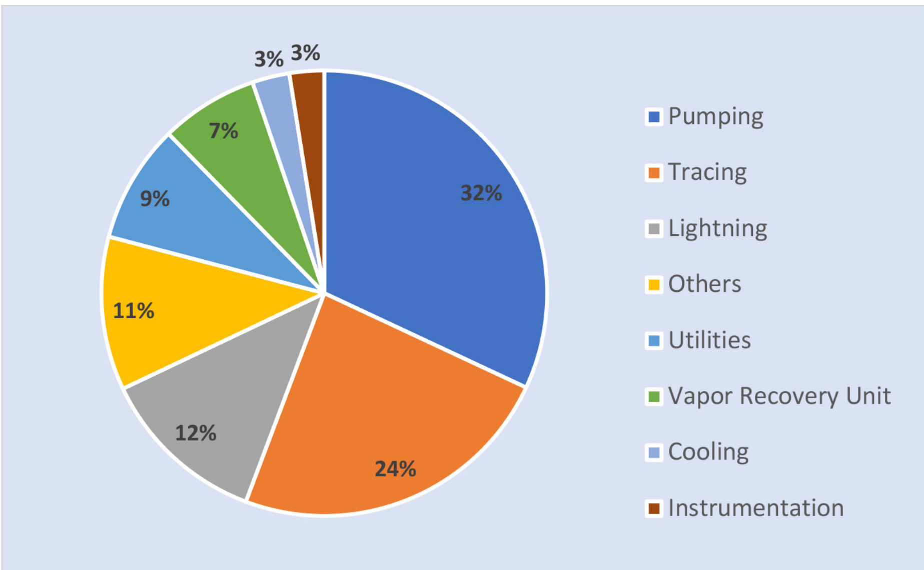


Figure 9. Relative contribution of each power consuming system. Tracing includes fuel gas heaters.

SIGNIFICANT ENERGY USES

The total energy consumption of the plant was measured and compared against the energy usage of the installed equipment. Fuel gas and diesel were identified as the primary energy sources of the plant; however, fuel gas represents more than 90% of the primary energy source of the facility and only 7 pieces of equipment represent more than 86% of the fuel consumption, as can be seen on the Figure 10. The list of the high fuel consuming equipment includes two gas compressors, three gas generators, an oil heater treater, a diesel generator, and the gas release to the flare system.

The fuel gas consumed in the different processes is gas produced by the wells whose production is treated in the EPF. In other words, there is no purchase of natural gas from third parties. The cost of the fuel gas consumed was calculated based on the product's sale price, i.e., it is assumed as an unsold product. On the other hand, the cost of diesel consumed was calculated based on its market price.

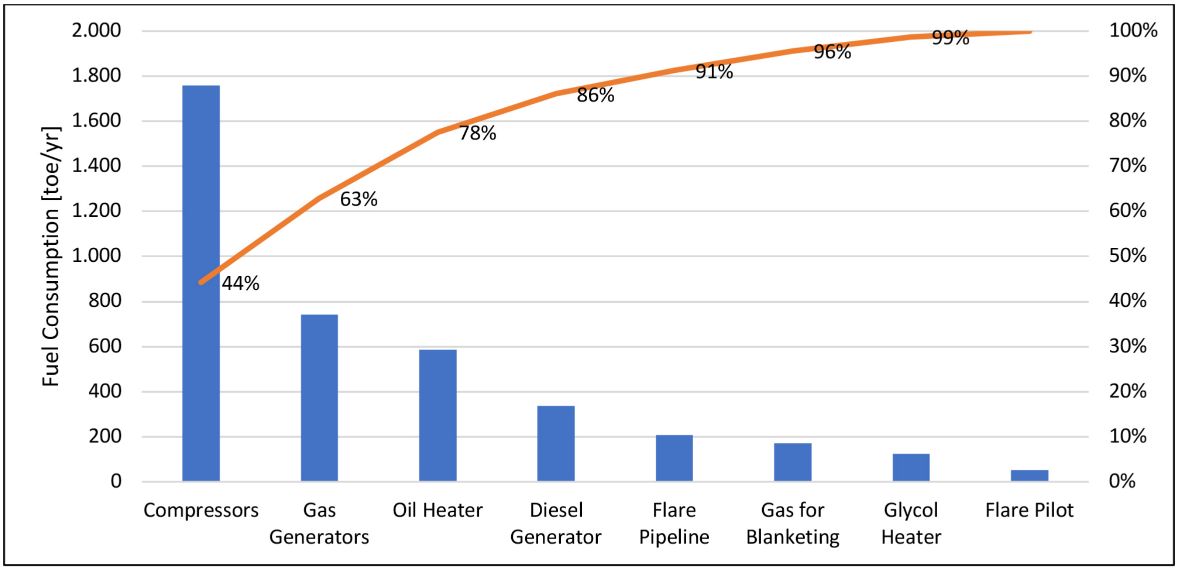


Figure 10. Pareto chart of EPF fuels consumption, including both fuel gas and diesel.

Although the two gas compressors consume 44% of the plant energy, the cost represents only 22% of the total cost associated with the fuel consumption. On the other hand, the diesel generator only consumes 9% of the total energy of the plant, but its associated cost is significantly higher, since the diesel consumption represents 55% of the total energy cost per year, as can be seen on Figure 12.

Similarly, major electric power consumers were identified and ranked. As can be seen on Figure 11, there is a significant number of systems that consume electricity within the EPF. 39 electric systems were assessed and only the top 13 consumers which account for 84% of the power demand are shown. The remaining 26 systems consumed only 16% of the power supplied by the gas and diesel generators. Remarkably, all pumping units within the facility consume 32% of the electric power. Tracing units are the second most relevant system in terms of electricity consumption, accounting for 17% of the total energy supplied by the generators. Together, pumping and tracing are responsible for 49% of the power demand of the plant.

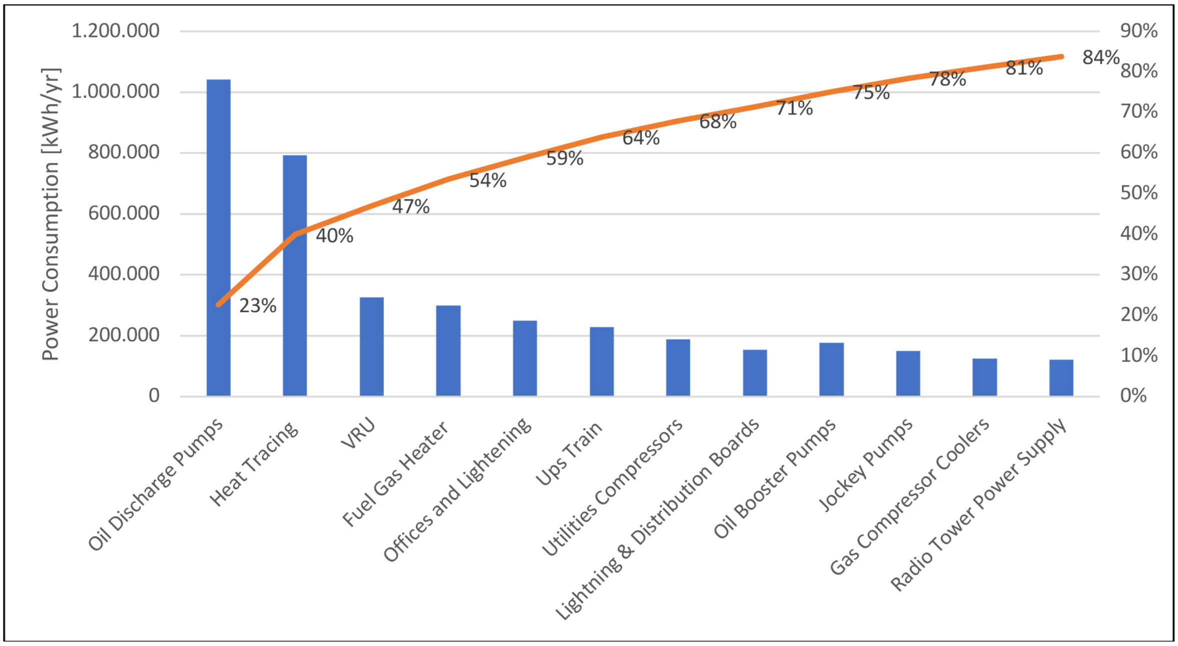


Figure 11. Pareto chart of EPF electric energy consumption. Equipment consuming less than 2% of the total energy consumed were not included in the figure.

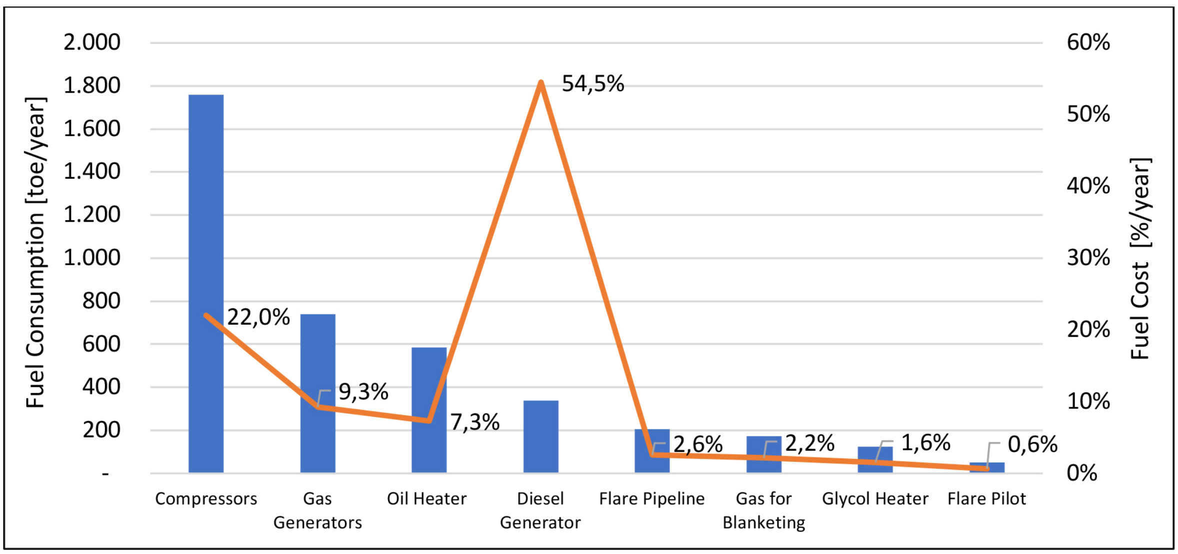


Figure 12. Fuel Consumption and Cost. Total cost is calculated as the sum of diesel and fuel gas costs.

ISO 50001 defines significant energy use (SEU) as areas of substantial energy consumption and/or offering considerable potential for energy performance improvement (International Organization for Standardization, 2018). Based on the analysis carried out, the significant uses in the EPF were identified, as can be seen on Figure 13. The annual energy relative cost of the SEUs is calculated considering the total fuel cost plus the fuel cost diesel and gas generators. First, the main SEUs are Compressors and Diesel Generator. Compressors account for 44 % of total fuel consumption in toe and 13 % of the annual energy relative cost, while the diesel generator represents 8% of the total fuel consumption and 33% of the annual energy relative cost. The gas generators consume 19% of the total fuel, corresponding only to 6% of the annual energy relative cost. Finally, the crude oil heater represents 15% of the total fuel consumption, and 4% of the annual energy relative cost. Related to the consumption of electricity, the oil discharge pumps are identified as the main USE, with a consumption of 23%, which corresponds to a total cost of 4% of the annual energy relative cost.

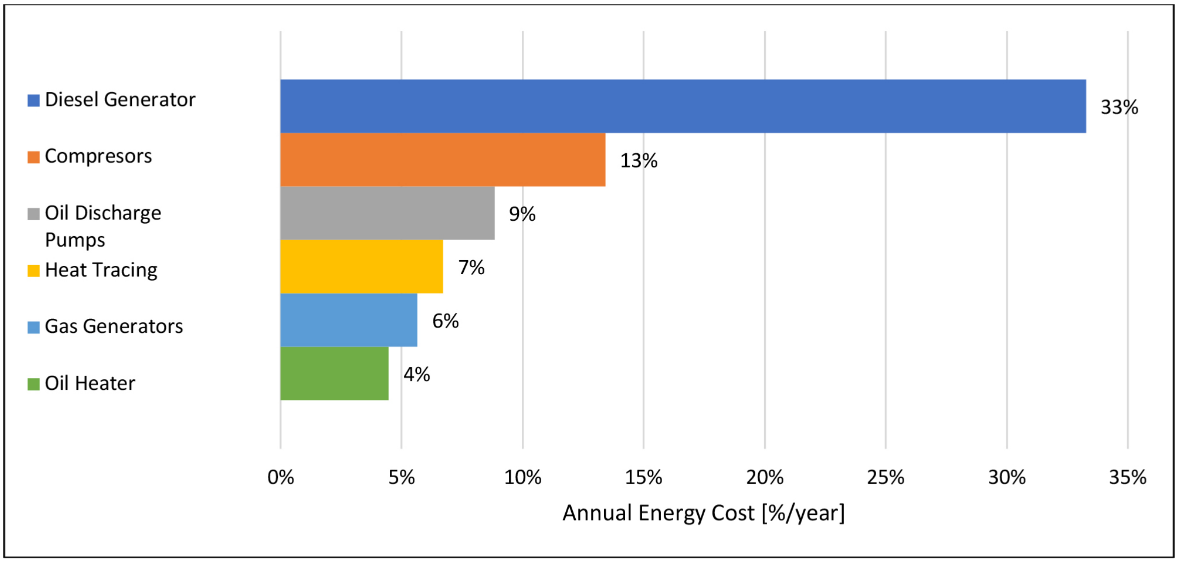


Figure 13. Annual Energy Relative Cost of the SEUs identified at the EPF. The total cost is calculated considering the fuel cost of direct fuel consuming equipment plus the diesel and fuel gas cost associated to the generators, which is assigned proportionally to the power electric consuming equipment based on specific power consumption.

ENERGY BASELINE AND RELEVANT VARIABLES

The ISO 50.001 methodology includes the estimation of energy baselines [EnB(s)] (International Organization for Standardization, 2018). The energy baselines are used for the determination of energy performance objectives and the verification of improvement. Two energy baselines were determined for the EPF with monthly data: fuels consumption and electricity generation, shown in Figure 14 and Figure 15, respectively. The EnB(s) are associated with an average annual operation of the EPF at 88% of its capacity. The monthly fuel consumption was converted to tons of oil equivalent (toe). As it can be seen on Figure 14, the average monthly consumption was 245 toe of fuels in the period under analysis. EnB(s) do not include the month of April 2021 due to anomalies in the operation of the plant.

The power generation baseline includes the power provided by the different generators, in this case three gas generators and one diesel generation. This EnB is associated with all equipment driven by electric motors and electrical energy consuming equipment. As can be seen on Figure 15, the average monthly generated power was 383,000 kWh. EnB(s) represent the operational configuration of the EPF during the period under analysis. Any changes in the processes or operating conditions will affect them. Energy Baselines [EnB(s)] are related with energy performance indicators [EnPI(s)], which were defined for this facility as part of this analysis. The

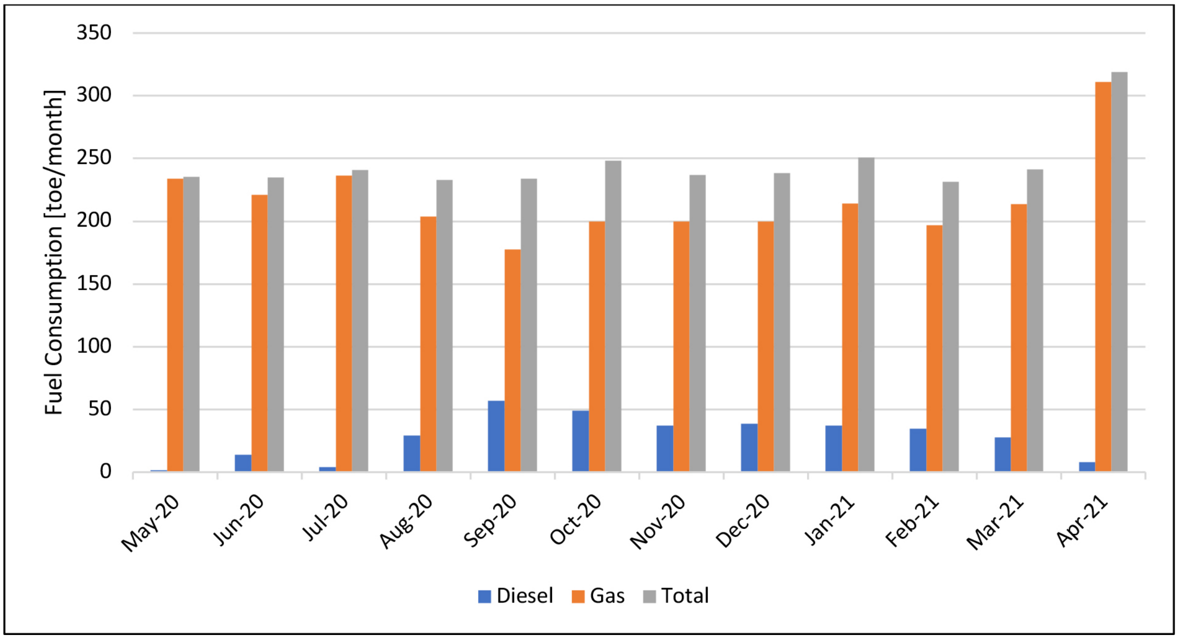


Figure 14. Energy baseline based on fuels consumption.

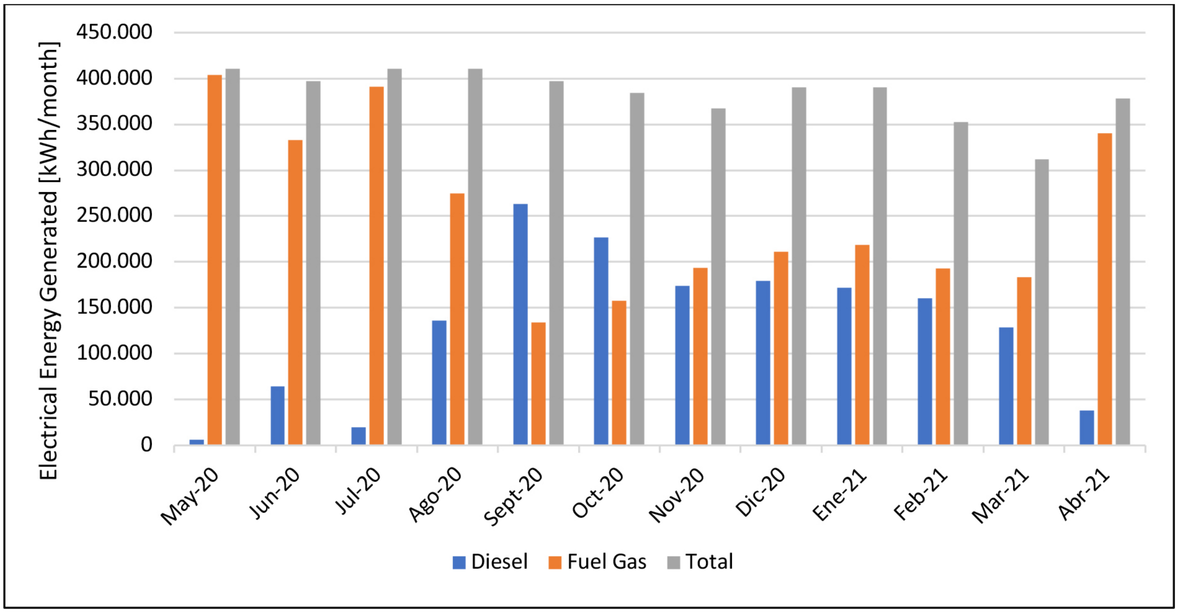


Figure 15. Energy baseline based on power generation.

follow-up of these two interrelated elements ensures effective and measurable results over time. It allows demonstration of energy performance improvement, quantifying operational deviations or savings.

In addition, relevant variables that affect the energy performance of the EPF were determined. The relevant variables are also associated with the significant energy uses (SEUs). The variables identified were the volume and characteristics of the processed fluids, and the climatic seasonality of the area (minimum temperatures). EnB(s) must be normalized with the behavior of these relevant variables to compare energy performance changes. The variables were evaluated against monthly energy consumption in tons of oil equivalent (toe) and electricity generation in kilowatt hour (kWh).

The best linear correlation found between two independent variables was the minimum temperature [°C] with the power generation [kWh/month]. That correlation is characterized by a R^2 of 0.53, as can be seen in Figure 16. In general, the correlations of the variables analyzed independently showed very low values of R^2 and cannot be considered as valid correlations. The energy consumption of the EPF is affected by different variables, and therefore a correlation against a single variable is not enough to obtain an acceptable R^2.

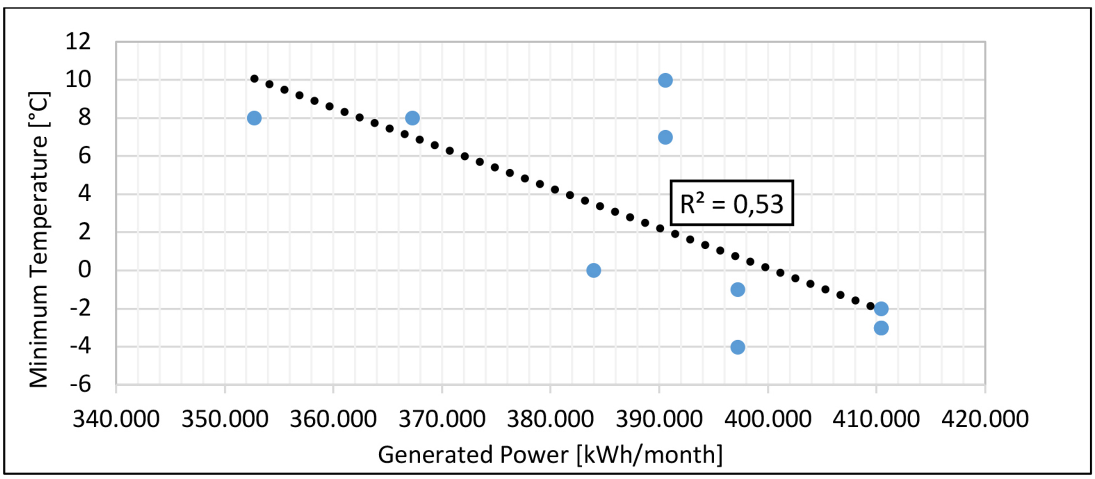


Figure 16. Linear correlation of the minimum temperature of the EPF location zone against the electrical power monthly.

Furthermore, it was identified that the ratio between fluids production (water and oil) normalized by monthly fuel consumption against the minimum temperature of the EPF location zone, yields a better R^2, close to 0.8, as shown in the Figure 17. This linear relationship would indicate that each ton of oil equivalent (toe) consumed in producing one cubic meter of fluid in the EPF has a certain degree of dependence on the temperature of the area.

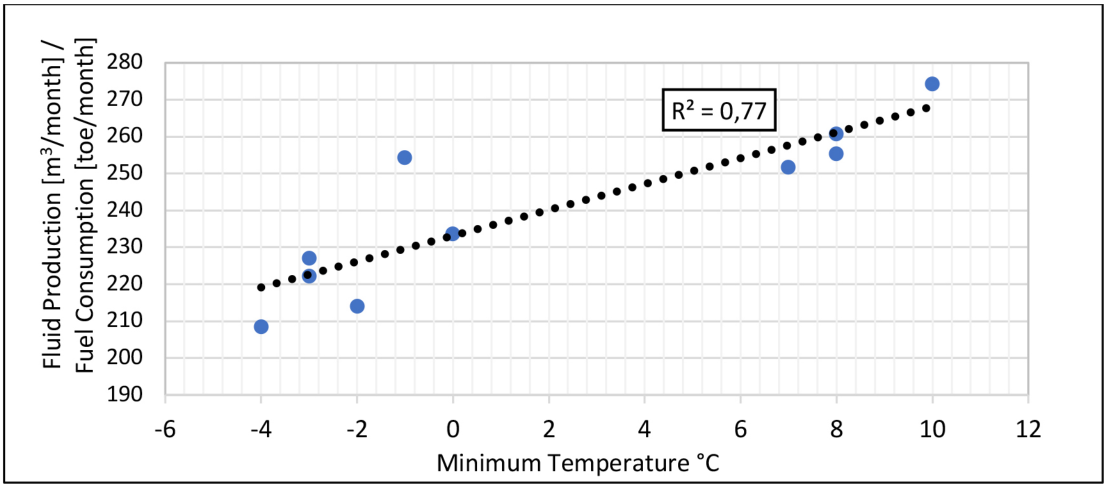


Figure 17. Fluids Production normalized by monthly fuel consumption against the minimum temperature of the EPF location zone.

Additionally, multiple linear regressions were evaluated to correlate the variables that affect the energy performance of EPF. Multiple linear regression allows generating a linear model in which the value of a dependent variable "Y" is determined from a set of predictor variables (X_1, X_2, X_3,…, X_n). A multiple correlation was identified for each EnB, i.e., one associated with fuel consumption and another associated with power generation.

The first multiple linear regression was built with the fuel gas consumption [Nm^3/month] as dependent variable, as well as gas production [kSm^3/month], oil production [m^3/month] and water production [m^3/month] as predictor variables. The following equation presents the mathematical relationship between these 4 variables. It was obtained a coefficient of determination R^2 of 0.8 and an adjusted R^2 of 0.7 for this correlation. These values indicate a high dependence between the variables.

$$Y_i = 416565.16 + 44.72X_1 - 7.26X_2 + 0.03X_3$$

Where:

Y = Fuel gas consumption [Nm^3/month]

X_1= Gas production [kSm^3/month]

X_2=Oil production [m^3/month]

X_3= Water production [m^3/month]

The second multiple linear regression was based on electricity consumption. The power generation [kWh/month] was set as dependent variable, and gas production [kSm^3/month], oil production [m^3/month] and water production [m^3/month] as predictor variables. The following equation presents the mathematical relationship between these variables. For this correlation, a coefficient of determination R^2 of 0.77 and an adjusted R^2 of 0.65 were obtained. These values also indicate a good dependency between the variables.

$$Y_i = -873070.4 + 109.1X_1 - 021.5X_2 - 9.2X_3$$

Where:

Y = Power generation [kWh/month]

X_1= Gas production [kSm^3/month]

X_2= Oil production [m^3/month]

X_3= Water production [m^3/month]

If this regression is performed excluding the gas production variable (X_1), the R^2 and the adjusted R^2 decrease to 0.57 and 0.45, respectively. In other words, gas production affects to some extent the energy consumption of EPF.

Finally, it can be concluded that the load and characteristics of the processed fluid (oil production, associated gas production and water cut) and the climatic seasonality of the area (minimum temperatures) were identified as the relevant variables that will affect the energy performance of the EPF. As previously mentioned, these variables are directly associated with the SEUs of the plant. In this case, the relevant variables should be evaluated as a whole and not independently.

ENERGY PERFORMANCE MONITORING PLAN

Energy performance indicators are an efficient way to supervise, analyze and optimize any kind of energy relevant process. Based on the parameters evaluated and conclusions obtained in the previous sections, the following monthly performance indicators are proposed for evaluating the energy performance of the facility.

Facility Level Key Performance Indicators

1. EPF Total Energy Consumption

$$EPF\ energy\ consumption\ [\frac{toe}{m^3}]_{month\ i} = \frac{fuels\ consumption\ [toe]_{month\ i}}{volume\ of\ processed\ fluids\ (oil, water\ and\ gas\ equivalent)\ \ [m^3]_{month\ i}}$$

2. EPF Total Electricity Consumption

$$EPF\ electricity\ consumption\ [\frac{MWh}{m^3}]_{month\ i} = \frac{\frac{generated\ kWh\ _{month\ i}}{1000}}{volume\ of\ processed\ fluids\ (oil, water\ and\ gas\ equivalent)\ \ [m^3]_{month\ i}}$$

3. EPF Cost of Energy

$$EPF\ energy\ cost\ [\frac{USD}{m^3}]_{month\ i} = \frac{fuels\ cost\ [USD]_{month\ i}}{volume\ of\ processed\ oil\ [m^3]_{month\ i}}$$

4. EPF Cost of Electricity

$$EPF\ electricity\ cost\ [\frac{USD}{MWh}]_{month\ i} = \frac{electricity\ cost\ [USD]_{month\ i}}{\frac{generated\ kWh_{\ month\ i}}{1000}}$$

5. EPF Operation Carbon Intensity

$$EPF\ carbon\ intensity\ [\frac{tCO_2}{m^3}]_{month\ i} = \frac{CO_2\ emissions\ [tCO_2]_{month\ i}}{volume\ of\ processed\ oil\ [m^3]_{month\ i}}$$

<u>Equipment Level Key Performance Indicators</u>

1. Electricity Generators Fuel Consumption

$$Generators\ fuel\ consumption\ [\frac{toe}{m^3}]_{month\ i} = \frac{generators\ fuel\ consumption\ [toe]_{month\ i}}{volume\ of\ processed\ oil\ [m^3]_{month\ i}}$$

2. Compressors Fuel Gas Consumption

$$Compressors\ fuel\ gas\ consumption\ [\frac{toe}{m^3}]_{month\ i} = \frac{compressors\ fuel\ gas\ consumption\ [toe]_{month\ i}}{volume\ of\ processed\ gas\ [m^3]_{month\ i}}$$

3. Heater Treater Fuel Gas Consumption

$$Heater\ treater\ fuel\ gas\ consumption\ [\frac{toe}{m^3}]_{month\ i} = \frac{heater\ treater\ fuel\ gas\ consumption\ [toe]_{month\ i}}{volume\ of\ processed\ oil\ [m^3]_{month\ i}}$$

4. Oil Discharge Pumps Electricity Consumption

$$Oil\ discharge\ pumps\ electric\ consumption\ [\frac{kWh}{m^3}]_{month\ i} = \frac{pumps\ electric\ consumption\ [kWh]_{month\ i}}{volume\ of\ processed\ oil\ [m^3]_{month\ i}}$$

5. Heat Tracing Electricity Consumption

$$Heat\ tracing\ electric\ consumption\ [\frac{kWh}{m^3}]_{month\ i} = \frac{heat\ tracing\ electric\ consumption\ [kWh]_{month\ i}}{volume\ of\ processed\ oil\ [m^3]_{month\ i}}$$

CONCLUSIONS

This analysis allowed the identification and quantification of the significant energy uses in the Early Production Facility, which is key information that can be used to prioritize and define improvement opportunities to optimize the energy performance of the plant.

An important gap that was identified was the need for a more sophisticated measurement system in order to quantify specific fuel gas use in at least the top three fuel consuming systems (compressors, generators and heater treater). Furthermore, due to the relatively small cost that it implies, it is also recommended to install specific electric meters in all electric systems.

Additionally, the study provides the organization an energy baseline to compare the future energy performance of the plant which is the basis to implement an energy management system and to quantitatively measure improvements on energy efficiency. Initial estimates suggest savings potential of 10% compared to the baseline[2].

Improvement opportunities were identified for significant energy uses, by analyzing possible operative/maintenance changes or technology replacement. Identified opportunities were qualitatively ranked regarding the impact in energy performance and implementation cost. Those implying high energy performance improvement at low implementation cost were ranked first as the most cost-effective opportunities e.g., flare purge reduction and modification of control scheme for oil export by means of variable frequency drives instead of control valves. Following the ranking, other opportunities were found such as monitoring parameters and performing more frequent maintenance in critical equipment. Opportunities involving technology replacement were placed in a lower rank due to higher implementation cost. These opportunities include plant electrification and, essentially, compressor gas engines replacement by electric motors.

There is a firm decision to replace power generation in the EPF by external power supply coming from a renewable source. The notional plan is to have this implemented before the end of 2024. Energy efficiency will still play an important role, as compressor drivers and oil heater may be electrified at a later stage.

It is estimated that the total cost of energy exceeds 20% of the total OPEX required to run the plant. Therefore, the implementation of a proper energy management system could lead not only to a significant reduction on Scope 1 emissions but also to a significant cost reduction for the organization.

This work is easily replicable and scalable to similar installations, so the methods and criteria used as well as improvement opportunities identified will be shared, with the aim of reducing Scope 1 & 2 GHG emissions and operative costs at industry level for upstream operations.

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