Energy Efficiency Promotion in an Animal Feed Production Industrial Unit

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Abstract

Nowadays energy management is a key factor in order to achieve European Union mandatory targets for environmental sustainability but also with the purpose of cost minimization. The present dissertation is focused on a comparative analysis of different strategies defined with the purpose of improving the efficiency of Cooperativa Porto Alto – rações para animais, C.R.L.

This study aims at modeling the present situation and estimate the impacts of five improving scenarios in the energy performance of the considered plant. After studying several solutions, this analysis concluded that the elimination of certain operational anomalies, which could easily be underestimated, would reduce the plant specific consumption by 2,6% showing that energy performance is strongly related with operators and production management awareness and good habits. Also, the installation of variable speed drives in hammer mills and blowers would result in electricity specific consumption reductions of 4,3% and 2,3% respectively. The annual energy production of a self-consumption photovoltaic system with a peak-power of 58KWp has been estimated at 87,5 MWh of which 78% would be used to self-consumption and the remaining would be sold to the grid. Finally, the replacement of the current corn dosing system has been studied and the maximum initial investment for a valuable project has been quantified as 120000€.

If all the solutions were installed simultaneously, this would result in an annual reduction of 101,4 MWh and avoided emissions of 38,7 tonCO_{2eq}, while there would be a production increase of 8077 ton. Thus, the plant specific consumption could be reduced by 13,9% and the product specific cost could decrease by 25,1%, which corresponds to an annual saving of €57883.

Key Words: energy efficiency; variable speed drives, self-consumption photovoltaic system

1. Introduction

The economic development observed in the last decades has been characterized by an exponential increase of energy consumption produced with fossil fuels. In order to promote a sustainable development, the European Council adopted in 2008 more ambitious goals than those established at the global level in the Kyoto Protocol, by creating a set of goals called 20-20-20 targets. This plan set the target of achieving the following results by 2020: a 20% reduction in greenhouse gas (GHG) emissions compared to 1990; 20% improvement in energy efficiency compared to the projected value in 2007; 20% integration rate of Renewable Energy Sources (RES); and 10% integration rate of biofuels in the transport sector (1).

In the current context there is still potential for significant energy efficiency improvement in the industrial sector and in particular in the animal feed sector. According to research carried out by the organization "Carbon Trust" in 2010 (2), energy costs in this area represent a small share of the feeding stuffs' final cost, with the vast majority of expenditure being associated with the purchase of raw materials. However, this is a significant part of the operating costs (around 30%) and the optimization of its consumption has become a priority factor for the sector. Despite the trend towards process automation, energy performance indexes in this sector are still highly dependent on the human factor, particularly the control room operator experience and planning capacity, varying up to 40% with these factors (2).

In the specific case of mash feed specialized plants, the largest fraction of consumption is due to hammer mills (3). One of the most frequent energy wastes in this type of installation is the high idle time, which occurs between the processing of consecutive cycles or batches[1] and does not translate into added value for the final product (2).

The main energy vector of this type of installation is electricity and the most used engines in this industry operate at constant speed, however, the installation of variable speed drives (VSD) allows the dynamic adjustment of speed as

[1] The manufacture of compound feed is often organized in constant mass cycles to facilitate automation and traceability processes. Thus, the mass value of a batch will be a multiple of the predefined mass for each cycle.

needed. Thanks to this control, the idle energy costs can be reduced up to 60% depending on the engine type and machine to which it is coupled (3). There is a wide range of industrial equipment driven by electric motors that can benefit from the installation of VSD. The majority of the machines that make up a feed mill, such as: conveyors, fans, compressors, blowers and mills are among the many examples mentioned in the analysis carried out by Almeida et al (2000) (4). Thus, the challenge is to study the impact of this solution and consequent determination of the payback period in each case, in order to conclude whether such investment is feasible.

Besides the processes with higher specific consumption, it is convenient to analyze the remaining stages of the production system as the raw material dosing, which consists of two operations: transport between the storage silo and the scale and weighing. Nowadays, the most commonly used conveyors for short distances in animal feed milling plants are screw conveyors and chain conveyors or redlers. During the transport process, the energy is expended to overcome frictional forces, both between the material to be transported and the conveyor itself, as well as in the transmission mechanisms and supports of the respective shafts (smaller fraction) (5), (7).

In addition to the typical improvement opportunities for animal feed production units identified above, given the exponential reduction in acquisition costs that have occurred in the recent years, the installation of photovoltaic solar panels can be a valuable investment depending on energy needs and production schedules. In mature markets such as Portuguese, the profitability of this technology is completely related to the percentage of energy produced that is used for self-consumption. In this way, the design of the rated power must be based on the consumption needs of the installation, in order to minimize the payback period (5). In Portugal, the production of electricity for self-consumption using RES is subject to a set of legal requirements defined in Decree-Law 153/2014, October 20, complemented by Ordinance No. 14/2015, 23rd January (9). Presently, there are several Portuguese companies that have successfully implemented these types of systems in their industrial units, with payback periods estimated between 4 and 6 years, therefore it appears as a solution with economic potential (10), (11).

In this context, the goals of this study are, firstly, to characterize in detail the base case situation in order to, secondly, identify energy efficiency improvement opportunities in the specific case of the “Porto Alto - Rações para Animais” factory, reducing specific energy consumption as well as GHG emissions and the integration of RES. In this way, through the evaluation of alternative scenarios, the aim is to quantify the impacts in terms of energy saved and emissions avoided in absolute and specific terms (per mass unit of final product), as well as to perform a technical-economic analysis for each one of the solutions presented.

2. Methodology

a. *Characterization and Scenarios Presentation*

The industrial unit of the Porto Alto - Animal Rations Cooperative, CRL, has adopted a continuous improvement philosophy in the last few years, and has begun the process of implementing a new data monitoring platform, with the purpose of performing a detailed analysis of energy consumption by process and equipment in the near future. However, during the period of this stage, the mentioned platform was not yet in operation. Hence the first phase of this project consisted in modeling the plant energy distribution in order to identify possible inefficiencies and improvement opportunities. Energy distribution was then modeled using the available data:

- Total operating time of each equipment, recorded in the current data acquisition software (without distinction between on-load and no-load time);
- Instantaneous current intensity, measured with a multimeter at each phase of each three-phase motor;
- Main equipment on-load time, measured using a chronometer and a multimeter or a chronometer in conjunction with the real-time control software in the control room.

Two different methods were used to calculate the power: the surveying of each machine’s rated power and the current measurement (on-load and no-load) followed by the active power calculation of each three-phase motor using the following equation (12):

$$P = \sqrt{3} \times I \times V \times \cos\phi \quad (1)$$

Where “P” represents the instantaneous power (W), “I” symbolizes the current intensity (A) and V is the voltage (V). This calculation was carried out taking into account that in this plant voltage applied to all electric motors is 400 V and the mean value of the $cos\emptyset$ is 0.8.

The software currently used in the control room only records the total running time of each machine, making no distinction between periods of on-load and no-load operation. The survey of these times was carried out in two separate weeks, the ones with the largest and the lowest production in the last two years (March 7 to 11, 2016 and February 20 to 24, 2017, respectively) in order to analyze the impact of production volume on the energy distribution by equipment.

The next step consisted in estimating the on-load running time fractions per equipment type. This parameter is calculated by the quotient between the measured running load time and the "cycle time" (time period between the arrival at the final product storage silos of two consecutive cycles of 2200 kg), recorded by the production management. The result obtained are shown in Table 1. It should be noted that when on-load operating times were timed, frequent anomalies were detected and were responsible for increasing the average cycle time.

Table 1 - On-load running time fractions per equipment type

	Average Cycle Time [min]	Average on-load running time [min]	On-load running time fractions [%]
Bucket Elevators	6,44	3,35	52%
Redlers	6,44	3,27	51%
Fans	6,44	3,45	54%
Blowers	6,44	0,85	13%
Hammer Mills	6,44	3,45	54%
Others	6,44	3,42	53%
Mixers	6,44	2,58	40%

Analyzing the results obtained for the on-load running times by process, it is verified that the production rate is currently limited by the raw materials dosing operations (transportation to the scale, weighing and discharging), so the only way to increase it goes through the improvement of this stage.

For the purposes of estimating energy consumption using the active power calculation, it has been considered the energy consumption (kWh) calculated using the current intensity (A) of an equipment "i", measured both on-load and no-load (E_{ic} and E_{iv} respectively) weight averaged by the on-load and no-load running time fractions (f_{kc} and f_{kv} respectively) of the corresponding equipment type, "k", as shown in the following equation:

$$E_i = E_{i_v} \times f_{k_v} + E_{i_c} \times f_k \qquad (2)$$

Figure 1 shows the energy distribution by equipment type obtained for the two power measurement methods used and for the two weeks under analysis.

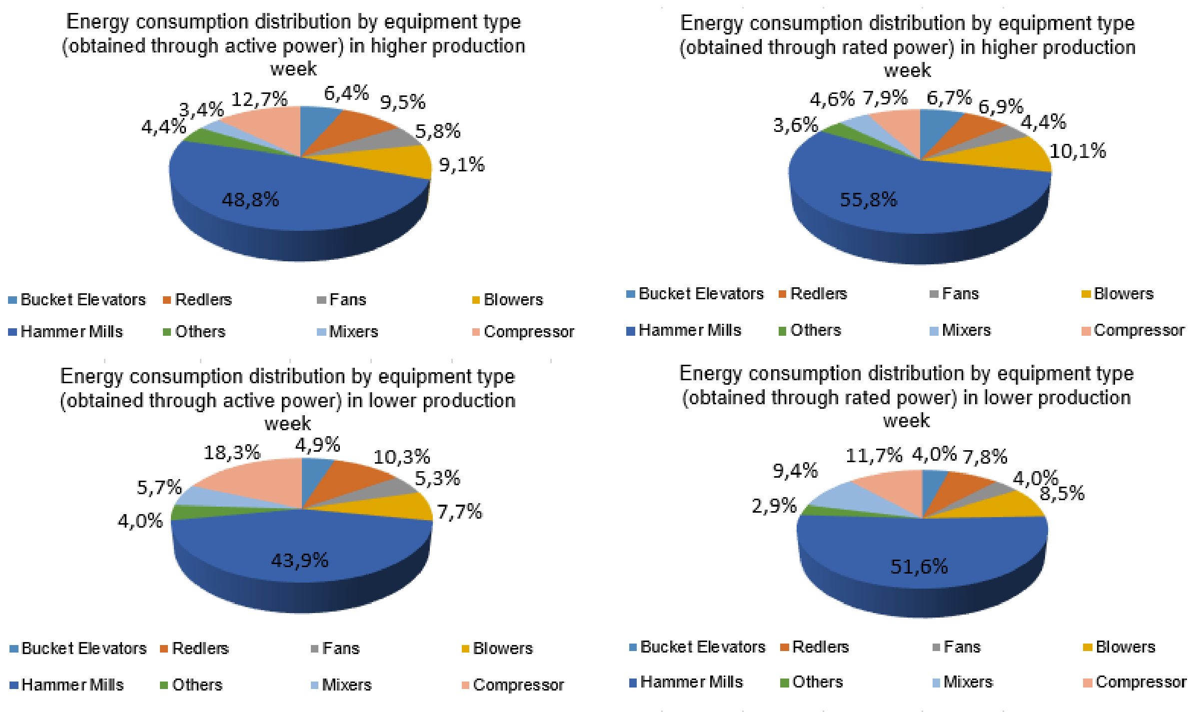

Figure 1- Energy consumption distribution by type of equipment

Analyzing the energy consumption distribution by type of equipment (Figure 1), it is observed that, as expected, the equipment with the highest energy consumption in this installation are hammer mills. Depending on the method used, the fraction assigned to this type of equipment varies between 43.9% and 55.8%. Comparing the two weeks under study, two main differences in the distribution of energy consumption are highlighted. The fraction consumed by the mixers was higher in the lower production, and the same happened with the compressor. The largest relative weight of mixers in the energy bill for February 2017 is due to the replacement of the main mixer in the previous month, with the installed equipment currently being double the rated power of its existing counterpart to date. Thus, even considering the highest efficiency of the new mixer, a higher energy consumption is expected. The smallest share of consumption attributed to the compressor in the higher production week is related to the change in operating schedule this week. Unlike most equipment, the compressor operating time is not directly proportional to the factory manufacturing time, so while in the week of greatest production most machines have been running for more than twice their average operating time, the compressor only extended its working hours by about half as a result of the third shift introduction. Thus, it can be concluded that, for the same operating conditions, the only machine that prevents the relative consumption by equipment of maintaining constant, for different production volumes, is the compressor.

By comparing the consumed energy calculation methods used, the main difference in the distribution obtained resides in the decrease of the hammer mills influence in the total consumption when the calculation counts the active power. This discrepancy is explained by the fact that the mills are the highest rated power equipment installed in the industrial plant, totaling 220 kW, although they are operating no-load for a substantial fraction of the time, using a power well below the rated one.

For the purpose of validating the energy distribution model, it was considered that the most coherent procedure would be to compare the electric bill value for the week of February 20th to 24th, 2017, and the value calculated by using the active power for the same period. This week's choice over the greatest production week (March 2016) for validation purposes is based on the fact that current intensity measurements were made during the first month of this internship (March 2017) and as such, the values obtained should be closer to the reality of the week taken as a reference. In addition, during the month of March 2016, the ventilation system of the mills was not functioning properly, which increased the energy expenditure compared to the expected value. Consulting the electricity bill, it can be verified that, in the week under study, the total of the electrical energy consumed in the factory was of 10718 kWh. According to the model elaborated, the weekly consumption would be 10713 kWh, so there is a default error of 0.05% and the model can be considered as representative of the factory's real energy consumption. A sensitivity analysis was also carried out on the fractions of time of operation in load, concluding that the model is very sensitive to them, since by varying these parameters, the weekly energy consumption error varied up to 23%.

The next step of the energy characterization of the plant under study consisted on the specific consumption calculation for each operation according to the data collected in the analyzed period. To that end, the results obtained in the energy distribution by type of equipment were compared with the energy and mass consumption of 2016 in order to estimate the annual and specific consumptions, both in relation to the total mass of output produced and in relation to the mass effectively processed in each equipment. The specific consumptions obtained by equipment type are presented in Table 2.

Table 2 - Specific consumption by equipment type

	Yearly Energy [kWh]	Yearly Mass Output [ton]	Specific consumption – equipment output mass [kWh/ton]	Specific consumption - global output mass [kWh/ton]
Bucket Elevators	41877	74618	0,56	0,56
Redlers	88530	74618	1,19	1,19
Fans	45148	0	-	0,61
Blowers	34169	74618	0,46	0,46
Hammer Mills	66084	2449	26,98	0,89
Others	377189	72137	5,23	5,05
Mixers	49234	74618	0,66	0,66
Compressor	157490	0	-	2,11
Total Electricity	859721	74618	-	11,52
Boilers	56554	1021	55,39	0,76
Natural Gas Total	56554	1021	-	0,76
Forklift Trucks	16981	2449	6,93	0,23
Total Propane	16981	2449	-	0,23
Total (Global)	933256	78088	-	12,51

In order to finish the industrial unit energy characterization, EDP Distribuição's energy monitoring platform was used in order to obtain the daily hourly load curve of the plant. The study of the hourly consumption profile was approached in two different ways: analysis of a typical day and calculation of average hourly consumption during weekdays, both cases being presented in Figure 2. After this energy characterization, it was possible to identify several improvement opportunities, for which 5 different scenarios were proposed and presented in Table 3.

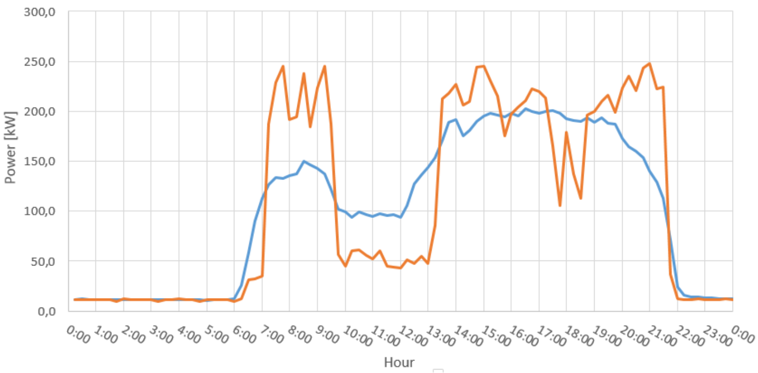

Figure 2 – Daily Load Profile (the red curve represents a typical day and the blue stands for an average profile)

Table 3 – Improvment Scenarios Presentation

Scenario		Goal
A	VSD installation in hammer mills	To reduce the energy wasting associated with the no-load operation of hammer mills (major energy consumers in this plant) and blowers, which, although having a lower relative weight in the factory consumption, have the shortest on-load running time fractions of the entire industrial facility.
B	VSD installation in blowers	
C	Corn dosing system replacement	To increase the production pace by decreasing the cycle time of the most time-consuming process.
D	Self-consumption photovoltaic system implementation	To change the energy vector of a significant fraction of the primary energy consumed, using a renewable, sustainable and lower cost source - solar energy.
E	Dosing system operational anomalies elimination plan	To increase the rate of production pace by reducing the time wastes with operational origin .

b. Scenario A - Impact Analysis

VSP Bitra et al. have studied the power required to operate an empty hammer mill, obtaining a function for its evolution with the rotation speed within the range of 1500 rpm to 3500 rpm (16), which when adimensionalized in terms of power, is presented as shown in equation 2:

$$\frac{P}{P_{nom}} = \frac{2{,}5965\times10^{-7}\times N^2[rpm]+3{,}3968\times10^{-4}\times N[rpm]+0{,}6549}{18} \qquad (2)$$

Where P represents the power (kW) and N symbolizes the rotation speed (rpm).

Knowing that the average no-load mechanical power of the existing mills is 24.9 kW (22.67% of its rated power) and its steady speed is 3000 rpm, the actual operation point is determined. As a first step, it was assumed, for the purpose of calculating energy savings that after the VSD installation in hammer mills, that they will start operating at 1500 rpm when they are not loaded, in order to avoid the regime of mixed lubrication in the bearings. According to equation (2), this 50% reduction in the rotation speed will generate a 57.1% decrease in power, compared to the present value, as shown in Figure 3. By denominating this percentage reduction in no-load power as "$\Delta P_{MMvazio}$", it is possible to evaluate the impact of this scenario on the hammer mills total consumption through equation (3) where the first term corresponds to the percentage of energy consumed by hammer mills without load, and η_{VEV} represents the VSD efficiency (%).

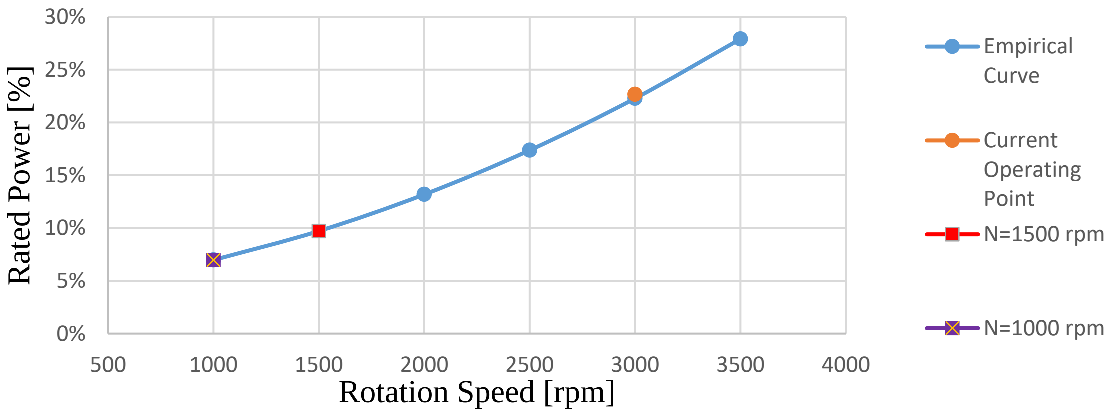

Figure 3 - Empty hammer mills empirical power curve and operation points before and after VSD installation (N = 1000 rpm and N = 1500 rpm)

$$\Delta E_{MMtotal}[\%] = \frac{E_{MMv} \times f_{MMv}}{E_{MMc} \times f_{MMc} + E_{MMv} \times f_{MMv}} \times \Delta P_{MMvazio}[\%] \times \eta_{VEV} \quad (3)$$

Knowing the hammer mills energy consumption's reduction and the no-load energy fraction in relation to the total consumption, presented in Figure 1, it is possible to estimate the impact of this scenario in the plant energy overall performance.

c. *Scenario B - Impact Analysis*

Scenario B also consists of the VSDs installation, so the methodology used in the impact analysis was similar to that presented in the previous chapter. The main difference lies in the load curve change. In this case it is an equipment with a constant torque load profile, which leads to a linear evolution of the power with the speed, as shown in Figure 4. According to the same figure, in this case, the required power decreases not only in the case of idle operation but also in the load regime (4) since there are no restrictions on the operation speed decreasing imposed by the process. Thus, in addition to the parameter ΔPMMvazio it will also be calculated, using a similar method, the differential in power (%) required when the equipment is loaded - ΔPMMcarga.

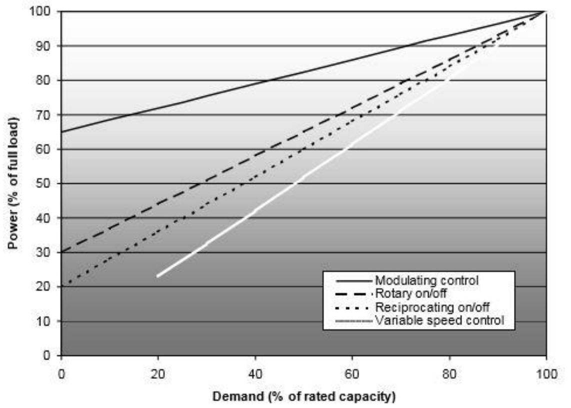

Figure 4 - Power (% of full load) variation with demand (% of rated capacity) in a constant torque load machine, with different flow control mechanisms (4).

For this purpose, one should use equations (4) and (5) which describe the curves present in Figure 3 regarding VSD control and reciprocal on / off control (this flow control method is the most similar to the one used in the three-lobed blowers present in the installation under analysis (13)).

$$P_{SP}[\%] = 0{,}8 \times Q[\%] + 20 \quad (4)$$

$$P_{SPVEV}[\%] = 0{,}95 \times Q_{VEV}[\%] + 5 \quad (5)$$

Then, equation (3) is used again, replacing the "MM" indices with "SP" (blowers), to estimate the energy gains obtained in no-load regime ($\Delta E_{SPvazio}$). Adapting the same equation for the load regime (switching the "c" and "v" indices and replacing the "vazio" index with "carga") becomes possible to calculate "$\Delta E_{SPcarga}$". Subsequently, the total change (%) in the blowers consumption is calculated using equation (6), where all variables are used in percentage and the impact of this scenario on the global consumption of the plant can be estimated.

$$\Delta E_{SPtotal}[\%] = (\Delta E_{SPvazio}[\%] + \Delta E_{SPcarga}[\%]) \times \eta_{VEV} \tag{6}$$

d. *Scenario C - Impact Analysis*

Through a detailed analysis of the various dosing time portions (currently, dosing is limiting the production pace), it was verified that the largest portion (about 30%) is due to the transportation of corn to the scale. The actual maize dosing system has a number of inefficiencies, such as the large distance between the primary storage silos of corn and the balance and the excessive slope of the current conveyors, which end up decreasing energy efficiency up to 64% (7). In order to improve this process, increasing the production pace, three possible arrangements for a new corn dosing system were studied (Figures 5 and 6). After sizing each included conveyor required power, the obtained active power values were replaced in the spreadsheet used for the modeling of the energy consumption distribution, also updating the values of the on-load running time fractions characteristic of the new cycle time in order to obtain the estimated weekly energy consumption in kWh of each arrangement - "Eprevista" (kWh). The impact of each arrangement on overall plant consumption (ΔEtotal[%]) is estimated, by comparison with the actual weekly energy consumed value. This analysis is done assuming that despite the production pace increase, the factory will continue to operate the same number of yearly hours, leading to a production increase that can be calculated taking into account the new production pace (ton/ h) and the total number of annual operating hours.

Since scenario C implies lower cycle times, there is an increase in the on-load running time fractions. Thus, any of these solutions leads to an increase in absolute energy consumption, but there is also a production increasing (ΔProd[%])

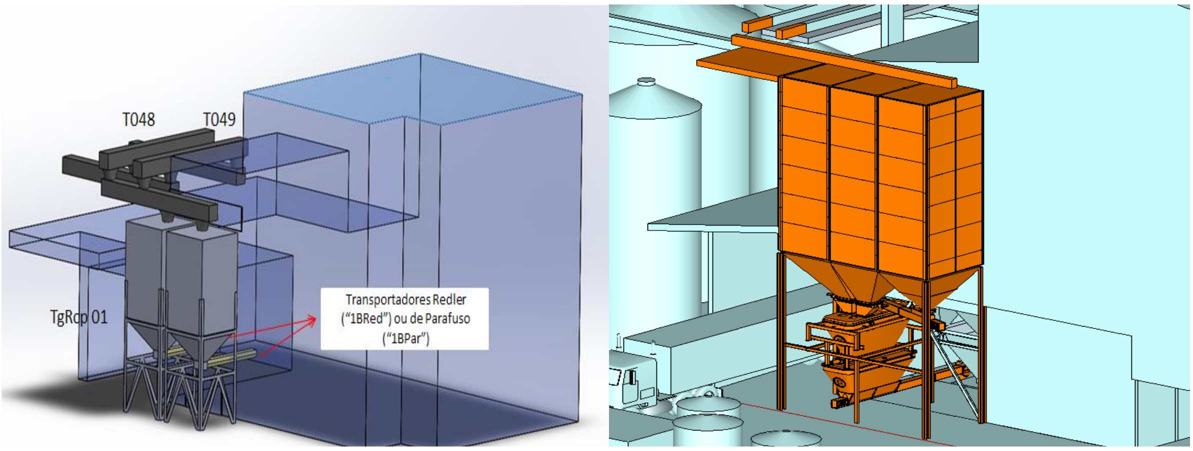

Figure 5 - Maize Dosing Arrangements Schematic Representation

, so the best way to have an overall perception of the impacts is through the analysis of the specific consumption variation (Δce[%]) , using the equation (7).

$$\Delta c_e[\%] = \frac{100\% + \Delta E_{total}[\%]}{100\% + \Delta Prod[\%]} - 100\% \ . \tag{7}$$

Considering that the energy cost per tonne produced is constant and equal to its average value, the variation in cost per tonne (ΔCe[%]) is equal to the specific energy consumption variation (Δce[%]). Thus, one can estimate the variation in energy costs caused by this proposal and consequently the associated financial gain. The financial impact of the extra production is estimated by the factory management considering a profit margin ("ml") of €5 / ton, so it is possible to calculate the net financial impact of this improvement scenario. The equations involved in the impacts calculation are presented below:

$$\Delta EnergyCosts = Prod_{forecast} \times Ce_{actual}(1 + \Delta c_e[\%]) - Prod_{actual} \times Ce_{actual} \tag{8}$$

$$ExtraProductionGains = \Delta Prod \times ml \tag{9}$$

$$Net\ Profit = Extra\ ProductionGains - \Delta EnergyCosts \tag{10}$$

e. Scenario D – Impact Analysis

The data on solar irradiation during the year used for energy calculation purposes in this study were obtained using Meteonorm 7.2.1 software. Using the data from the closer geographic location present in the database, an interpolation was made in order to estimate the values of the incident irradiation on a horizontal and inclined surface in 2018 on Porto Alto Rações location. The slopes range between 20º and 40º (14) was analyzed, and it was concluded that the maximum annual irradiation value is obtained between 30 and 35º, reaching 2015 kWh / m².

In order to calculate the energy production associated with the photovoltaic system to be installed, the simplified calculation model presented by Castro in 2011 was used (15). Although this model does not directly contemplate the PV cells efficiency variations with irradiance and temperature, it allows obtaining an energy produced estimation, with a reduced error compared to the real value. This model consists of the annual energy calculation resulting from the solar energy conversion into electrical energy ("Ein" in kWh) considering that it is obtained through the product between the average annual irradiation corrected by the air mass factor, "H_{AM}" in kWh / m², the energy conversion efficiency of the modules, $\eta_{modules}$ (%), corrected for the local irradiation and temperature conditions by the loss factor "f_{GT}" and the total area of the modules to be used, expressed in m² (equations 11) and (12)).

$$E_{in} = H_{AM} \times \eta_{módulos} \times A \tag{11}$$

$$\eta_{módulos} = \eta_{módulosSTC} \times (1 - f_{GT}) \tag{12}$$

Next, the energy that is actually supplied to the grid, "Eout" (kWh), is calculated by considering the losses between the point where the solar panels are located and the grid delivery point (quality, compatibility, ohmic and inverter losses), to which is assigned the notation f_i where "i" is the designation of losses to be quantified, as shown in equation (13).

$$E_{out} = E_{in} \times (1 - f_{qualidade} + f_{compatibilidade} + f_{ohmicas}) \times \eta_{inversores} \tag{13}$$

After calculating the energy supplied to the grid, it is necessary to correlate the hourly energy production to the hourly energy consumption, in order to define, for the three potencies under study, which fractions are consumed and sold to the RESP, once energy produced is remunerated in different ways depending on the purpose for which it is intended.

For this purpose, the hourly irradiation distribution, present in the PVsyst software database, characteristic of this location, was used for a representative day of each month and this information was crossed with the monthly radiation values collected using the software Meteonorm 7.2, in order to obtain an estimate of the typical hourly photovoltaic production profile for each month. Thus, it was possible to compare the production of monthly hourly energy with the energy consumption profile of the plant on working days and non-useful days, assumed as constant throughout the year, thus estimating the energy quantity used for self-consumption and the surplus sold to the grid every month.

The annual economic benefits of the implementation of this technology are considered to be the result of the sum between the savings associated with the energy used for self-consumption, the reduction of the overcost associated with power acquired daily at peak hours and also the direct gains resulting from the sale of the energy surplus for each studied peak power (50 kWp, 100 kWp and 200 kWp).

f. Scenario E – Impact Analysis

During this study it was concluded that production anomalies led to a 14.6% increase in the average cycle time of the sample analyzed. Thus, the resolution of this problem will have a very significant impact on the production pace. Further to this analysis, it was verified that the totality of the production delays registered were due to operational problems and were not related to failures in the technology currently implemented. The most frequent contingencies were: control room operator change; sudden production plan changes; change in the expedition silo during the production of a lot; dosing cell momentarily without raw material; delay in the manual administration of raw material; and raw material stuck in Big Bag.

The various anomalies presented can be grouped into two main categories: problems related to production management (first three points) and contingencies related to operational failures in the dosing process (remaining ones). By grouping the contingencies in this way, it is possible to conclude that 73% of the time losses are related to production management and 27% of them are due to operational failures during the process. The first category of delays had already been identified prior to the completion of this internship and the installation of a new manufacturing, production planning and order receipt software, where there is an information cross-referencing of these three sectors is already underway, so that the manufacturing process is less susceptible to human error and planning is optimized. The present improvement scenario aims at eliminating the last three identified sources of production anomalies, thus having the potential to increase production cadence by 3.9%.

For that purpose, a set of operational measures were elaborated and named "Plan for the Elimination of Dosing Anomalies", being presented below:

• Inclusion of the task of providing secondary raw materials data inputs in the production management software in the operators daily routine;

• Acquisition of a tablet and an internet access point, so that the control room operator can enter the raw material data in the system in a practical way, whenever he restores the stock;

• Installation of a horn next to the manual raw material addition point, which emits a beep if the product has not been loaded and the warning button pressed 20s ahead of time;

• Providing training to the operators on the impact of these small actions on the plant productive cadence and how to use the tools at their disposal.

By increasing the rate of production, this scenario will change the running on-load time fractions, so the methodology for calculating the energy and financial impacts of this measure will be similar to that used in scenario C.

3. *Results and Discussion*

Evaluating each of the scenarios according to the methodology presented above, the results are presented in Table 4, where the following performance indicators are presented: annual energy consumption change in kWh (ΔEtotal), annual variation of emission of GGE (ΔGEE) in tones CO_{2eq}, annual production variation in tones, differential (%) of specific consumption (Δce), differential (%) of specific cost (ΔCe), Initial Cost, "CI" (€), and PRI (years).

Table 4 - Key performance indicators for each improvement scenario

Scenario	ΔEtotal [kWh]	ΔGEE [tonCO_{2eq}]	ΔProd [ton]	Δce	ΔCe	CI [€]	PRI
A	-38579	-14,7	-	-4,5%	-4,5%	23075	4,5
B	-21125	-8,1	-	-2,5%	-2,5%	7800	3,3
C	+14443	+5,5	+5136	-4,7%	-4,7%	12000*	5,0
D	-68002	-26,0	-	-	-12,5%	77700	7,0
E	+9440	+3,6	+2941	-2,6%	-2,6%	200	0,0

*Maximum initial investment for a simple payback under 5 years

Observing the table presented, it is concluded, that priority is given to the implementation of scenario E, since this measure presents an initial investment practically null and a potential cost reduction as high as that of scenario B, that is, 3 cents per ton. The capital invested in the adoption of proposal B (€ 7800) will be recovered in about 3.3 years, allowing a reduction of 3 cents per ton. Given the low initial investment and payback, this proposal comes second in the priorities hierarchy. Following the same criteria, scenario A should be the next investment to be made.

The remaining improvement scenarios should be viewed from a long-term perspective, since they involve higher initial investments and, consequently, a possible need for financing. The adoption of proposal D represents an initial investment of € 77700, resulting in a 7-year payback, but the useful life of this project is 25 years, representing a NPV of € 163000, thus it is clearly a value investment. Scenario C is the only solution presented that makes it possible to increase production cadence through the implementation of technology, so if, in a future scenario, the production needs increase beyond the current factory capacity, this change may prevent the opening of a third shift and consequent associated costs. Thus, to this proposal is adjacent an improvement potential that exceeds the analysis performed in this study. However, since the study was conducted with the purpose of determining a maximum investment value so that the simple payback period did not exceed 5 years, instead of analyzing a specific, it is not possible to establish precisely the position of this proposal the hierarchy of priorities.

Finally, some of the presented solutions can be considered together, so it makes sense to analyze the joint effects of the scenarios presented. To that end, it was necessary to take into account the relationship between the impacts of the various solutions, since, if one of the proposed scenarios, which implies the cycle time change, is adopted, the on-load running time fractions of the various equipment will be changed and consequently, the energy distribution will be different, changing the energy impact of each proposed scenario.

Thus, the first step consists in estimating the production pace resulting from the different proposals simultaneous application (only scenarios C and E influence this parameter). Considering that all the proposed improvements are implemented, cycle time is reduced by 33 seconds to 5:00 minutes, which is equivalent to a production pace of 26.4 [ton/h]. Based on the new on-load running time fractions the energy consumption distribution by equipment corresponding to the new production rate was obtained. Considering the new energy consumption profile and new on-load running time fractions, energy, environmental and financial impacts were estimated according to the methodology previously exposed. Through this analysis it is concluded that if all the solutions were installed simultaneously, this would result in an annual reduction of 101,4 MWh and avoided emissions of 38,7 ton CO2eq, while there would be a production increase of 8077 ton. Thus, the plant specific consumption could be reduced by 13,9% and the product specific cost could decrease by 25,1%.

4. Conclusion and Future Work

In summary, it is concluded that energy efficiency in the industrial sector is an indicator increasingly emphasized by the management. However, in factories whose processes have a lower energy density, such as the animal feed production ones, this paradigm is recent and there is still a lot of room for improvement.

In relation to the current performance, it is verified that the limiting process of the production cadence is the raw material dosing, taking, in average, 3 minutes and 48 seconds to process each cycle of approximately 2200 kg. The biggest consumers of the facility are the hammer mills, responsible for about half of the energy used globally. It is also important to point out that the energy consumption is very sensitive to the on-load running time fractions variation of each equipment type, that is to say, the percentage of their total operation time in which they are processing material.

One of the main problems identified was the high energy waste associated with periods of idle operation, especially in the case of machines with high power and practically uninterrupted operation during manufacturing time, such as hammer mills and blowers. There are also operational factors responsible for decreasing the production pace, namely a set of human-origin failures in the dosing process which are directly responsible for a loss of approximately 4%, or 0.9 tones per hour in the production cadence.

In order to minimize the payback period, the priority is to adopt the plan for the plan for the elimination of dosing anomalies, since this measure presents an initial investment that is practically zero. Next, the VEV's installations in hammer mills and blowers are prioritized, allowing the investment to be recovered in 3.3 and 4.3 years, respectively. The Self-consumption photovoltaic system implementation is an interesting investment, since its NPV is 163000 €, although this has to be seen as a project with a longer time horizon, since it presents a payback period of 7 years. It is also recommended that the replacement of the corn dosing system so that at least 31 seconds are reduced in this process, provided that the initial investment does not exceed €120000.

Finally, it is expected that the study and implementation of more efficient solutions will continue with a view to continuous improvement, leaving as a suggestion of future work to perform an inspection of air leaks in the compressed air circuit and, if necessary, the elaboration of a corrective maintenance order, since compressed air currently accounts for about 17% of the total plant consumption.

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