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ANALYSIS OF TECHNICAL-ECONOMIC VIABILITY OF WIND AND SOLAR ELECTRIC POWER GENERATION PROJECTS FOR SELF-CONSUMPTION APPLIED TO HEAVY INDUSTRY

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Heavy industry is frequently associated with the group of large consumers of electricity. For this reason and given the continuous increase of electricity prices observed in recent decades, this sector is immersed in a progressive search for improvements in the energy performance of its facilities to increase in competitiveness and reduce CO2 emissions. This objective has been fulfilled mainly through the implementation of improvements in the energy efficiency of the equipment used in the industrial production processes, but with the development of renewable energies experienced in last few years, we can begin to consider the scenario of using the renewable resources available in each factory for on-site production of electricity and self-consumption of the energy produced this way. In this context of seeking progress in competitiveness and in terms of environmental impact generated by heavy industry activity, this work analyzes some of the advantages offered by the implementation of large electricity generation facilities from renewable energies such as solar PV and wind power, along with the industrial production process, with the objective of a reduction of the energy consumed derived from the external network in large companies.

Keywords: *heavy industry; large energy consumer; renewable energies; self-consumption*

ANÁLISIS DE LA VIABILIDAD TÉCNICO-ECONÓMICA DE PROYECTOS DE GENERACICÓN ELÉCTRICA EÓLICA Y SOLAR PARA AUTOCONSUMO APLICADO A LA INDUSTRIA PESADA

La industria pesada está normalmente asociada al colectivo de grandes consumidores de energía eléctrica. Por este motivo y dado el continuo incremento de precios de la electricidad observado en las últimas décadas, este sector se encuentra inmerso en una progresiva búsqueda de mejoras en cuanto al rendimiento energético de sus instalaciones para aumentar en competitividad y disminución de emisiones de CO2. Este objetivo se ha ido cumplimentando mayoritariamente vía implantación de mejoras en eficiencia energética en los procesos industriales de producción, pero con el desarrollo de las energías renovables experimentado los últimos años, se puede empezar a considerar el escenario de utilización de los recursos renovables disponibles en cada factoría para producción in situ de electricidad y autoconsumo de la energía producida de este modo. En este contexto de búsqueda de avance en competitividad y en cuanto a impacto medioambiental generado por la actividad de la industria pesada, en este trabajo se analizan algunas de las ventajas que ofrece la implantación de grandes instalaciones de generación eléctrica mediante energías renovables como la eólica o la solar fotovoltaica junto al proceso productivo industrial, con objetivo de una reducción de la energía consumida procedente de la red exterior en grandes empresas.

Palabras clave: industria pesada; gran consumidor de energía; energías renovables; autoconsumo

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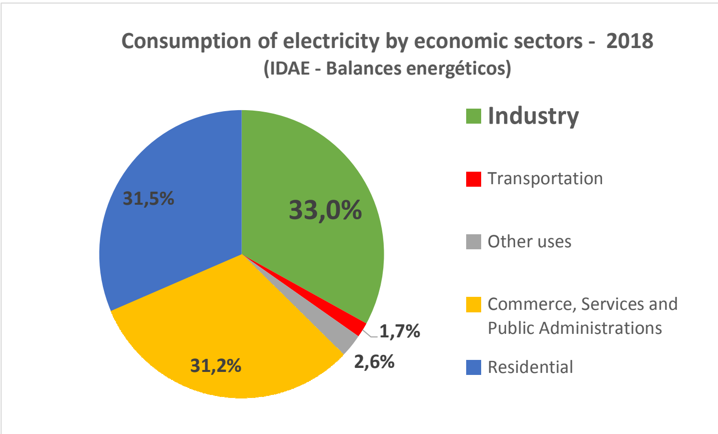
1. Introduction

The existence of big industrial companies is a key factor in the development of our society, as they constitute a fundamental base for the economies of all regions around the world. For the production of the goods that these companies sell in the markets, it is necessary the implementation of large factories (Hosseini, Brege & Nord, 2018), which are centers of high energy consumption, due to the capability of this model of massive industrial production for achieving low and competitive prices, through the large scale economies supply chain in which the design of these production plants is based on (Serpa, et al., 2020).

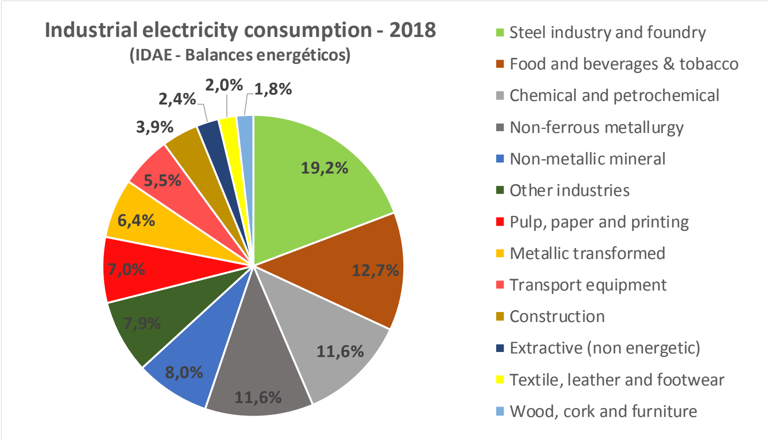
One of the most utilized form of energy in these factories is electricity (Moreno et al., 2014), because of its capability of being used for many different applications in the services and production processes carried out in modern industry, amongst other reasons. The figure 1 graph shown below displays the 2018´s distribution of consumption for the main electricity consumers by economic activities in Spain (Instituto para la Diversificación y Ahorro de la Energía [IDAE], 2020), where we can observe that industry took 33% of the total national electric supply. It can be generally acceptable to consider a figure around the 30% as the proportion of total electricity supply that is consumed by the industry of a developed country if we take these kind of data as an example of it (Red Eléctrica de España [REE], 2019).

Figure 1: Distribution by sectors of electricity consumers of Spain in 2018



We can also observe in figure 2 the industrial electricity consumption for Spain in 2018 depicted in a graph of demanded electricity broken down by different types of industrial activities (IDAE, 2020). Steel industry was the most important consumer with 19,2% of total electricity supply destined to industry (37,2 % adding other metal industries), being another typically considered as heavy industry like chemical and petrochemical sector the third largest user with a consumption of 11,6 % of industrial electricity. So we can see that in a developed country like Spain, about a half of total electric energy that goes to industries is consumed by the heavy industrial sector, if we consider in these group all those that manufacture primary products that are used by other industries. Similar figures confirming this were published in the specific report about large electricity consumer demands on the system “Evolución sectorial de la demanda de electricidad en grandes consumidores” (REE, 2019), showing that the heavy industries of the group of energy intensive larger consumers, are responsible for around 1/3 of the total industrial electricity consumption in a developed country. Therefore, any important improvement in the reduction of electricity consumption of the energy intensive heavy industry from the general supply system will have a significant impact in the decreasing of the total national demand of electric energy.

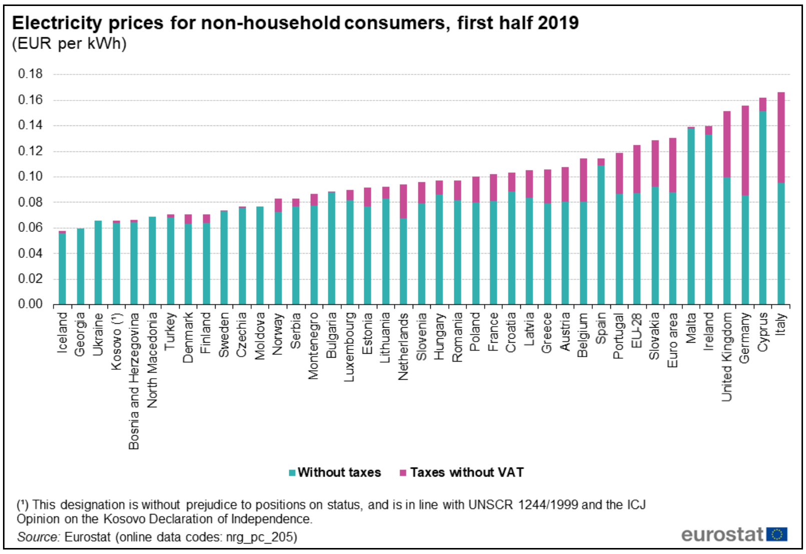
Figure 2: Electricity consumption distribution of Spanish industry in 2018



Indeed, companies catalogued as “big industrial consumers” by Spanish regulation in electric power matters, were acknowledged as being accountable for a quarter of the Spanish total electric power demand by REE in 1997: “the large industrial consumers are the segment with the greatest weight in the demand of the system, 25%, reaching an annual consumption of 37,563 GWh”, (REE, 1.998, Atlas de la demanda eléctrica española, page 37, paragraph 2).

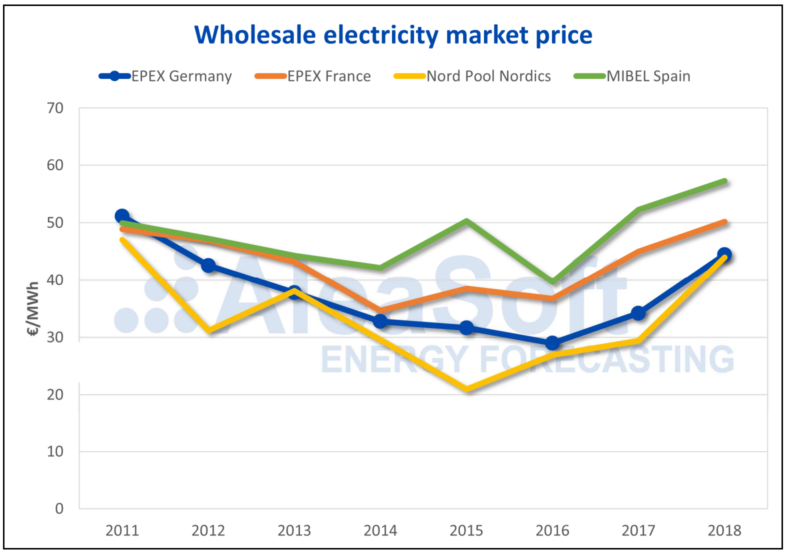
In the other hand and considering the European Union (EU) context regarding energy prices that affect to the industrial users of different countries, we can observe in figure 2 (Eurostat, 2020) that Spain is one of the most penalized countries for non-household electricity consumption, with the highest medium sized consumer electricity cost without taxes for bigger countries of the EU. Supporting this, figure 3 (Aleasoft Energy Forecasting website, 2019) displays the evolution of Spain´s wholesale electricity prices comparing it with other several EU zones. In fact, we can see that Spain has been for most of the last decade above other EU countries when it comes to electricity costs that heavy industries have to pay for their energy supply, since these wholesale prices are the reference for the electric bill as energy intensive consumers that normally this kind of industries are, due to the large scale production activities developed in their big factories.

Figure 3: Electricity prices for industrial consumers in European countries in 2019



Similar graphs and data can be obtained from EU official statistics resources, which verify the particularly negative competitive situation with respect to other European nations that the Spanish -and also Italian- heavy industries have been used to deal with during the 2010-2020 decade (Eurostat database, 2020).

Figure 4: Evolution of wholesale electricity price in various EU zones. Source: Aleasoft (2019)



Deepening the analysis of the impact for heavy industry of high energy prices, Moreno et al. (2014) stated that in the production costs of some main industrial products as may be steels or chemicals, the part attributable to energy required for its manufacture can even triply the labor costs and half of it for the electricity expenditure. These costs are also steadily increasing due to the rising trend of the associated electricity bill to input them. Thus, as big consumers of electricity that large industrial companies are, because of the characteristics of their factories and given the importance of electric energy for many of the industrial processes carried out in their working centers, all effective measures taken to reduce the electricity consumption may suppose a competitive difference in front of the competitors and in any case, they will become an improvement in their financial results due to the reduction of long term costs of production processes (Moreno, et al., 2014). The aim of this paper is to analyze the possibilities for implementation of self-consumption solutions for the heavy industry via renewable energy sources (RES) and to reduce the electricity bill required for these energy-intensive industries in the explained context. In the long term this would help to increase competitiveness, once they have monetized the implemented investments, while contributing to getting closer to international commitments by decreasing the risk of global warming due to emissions of greenhouse gases.

2. Objectives

The extraction of Renewable Energy (RE) from natural existing resources has been traditionally accomplished through a process of analysis and by selecting locations with the best conditions or places considered particularly favorable when taking into account renewable resource available at the eligible location Mur (2009), Peña (2011). This is a logical process to follow for achieving maximum energy production through REs generation facilities and thus recover investment in the shortest possible period of time possible for the applied technology, in order to encourage investors to engage in and support these initiatives. However, and taking into account the recent years significant progress in regards of cost of investments for the two most extended technologies of RE generation systems (International Renewable Energy Association [IRENA], 2019), solar and wind, and the experience achieved at the present time about these kind of facilities, it can be explored now the possibility of implementing RE generation facilities for self-consumption of large-scale industries taking advantage of some favorable conditions that we can find in the heavy industry, diminishing this way the risks of investors so that they consider to put their capital in future new projects of this type. These advantages are the following, among others:

- Availability without additional cost of space for medium-large sized RE on-site generation plants, avoiding this way renting expenditures for the lands that are normally assumed for these projects.
- High energy demand very frequently in proximity to the hypothetical on-site RE electricity production center.
- Avoidance of costs charged by the electric supply company and public administrations like, distribution, non-recoverable taxes and any other added cost not attributable to energy production that is however paid in the electrical bill.
- Avoidance of the cost of a long high voltage line to connect the new generation system to the general supply grid, as it occurs in many other RE generation plants located in specifically chosen place for its favorable RES conditions.
- Permanent on site presence of industrial maintenance teams with technically qualified personnel, which allows for a continual progressive reduction of the RE plant’s O&M costs, in comparison with other similar facilities located far away from maintenance companies.
- Reduced administrative and legal barriers, since the new generation system is integrated in the production process facilities as a part of it, inside the industrial existing environment.

All the previously mentioned may be, in combination with the character of large size multinational enterprise that typically heavy industrial companies use to hold, with access to important financial resources if the investment is proved to be interesting in a proper economic cycle, enough positive conditions to put in balance against the fact that the “chosen” location for the proposed RE generation facility has been forced to be at the available area of the industrial production factory and not a better place. Such an approach, which has not been found to be developed so far in scientific reviewed literature by the authors, is presented in this paper as a contribution to the development of new alternative solutions for increasing the penetration of RE consumption in the industrialized world, diminishing the pressure on electricity generation required from the general supply grid and with the correspondent economic benefits for the company engaged in such a project through the savings achieved in energy costs, specially once the investment is recovered.

From another perspective it is also important to note that industries are affected by the continuous demand of reduction of greenhouse gas emissions through international agreements achieved in this matter with the purpose of taking control on the climate change. In this regard, the European Commission (EC) actions and planning of environmental targets are now more difficult to achieve for a short-medium term like 2030 milestone than they were in 2014, due to a policy of increasingly higher efforts required to be applied on this direction to all EU countries. In fact, we can see that renewable energy share target has been increased from 27% in 2014 to a 32% (EC website, 2020). To achieve these environmental requirements imposed by the authorities any significant contribution to a reduction of energy consumption or partial substitution of the energy supply from the national electric grid by RE self-generated by the users, is positive to overcome the challenging objectives fixed by the governors, so actions like the studied in this paper can be a step ahead in the way to the fulfillment of the mandatory environmental conditions that any company must accept to keep in business in the medium-long term.

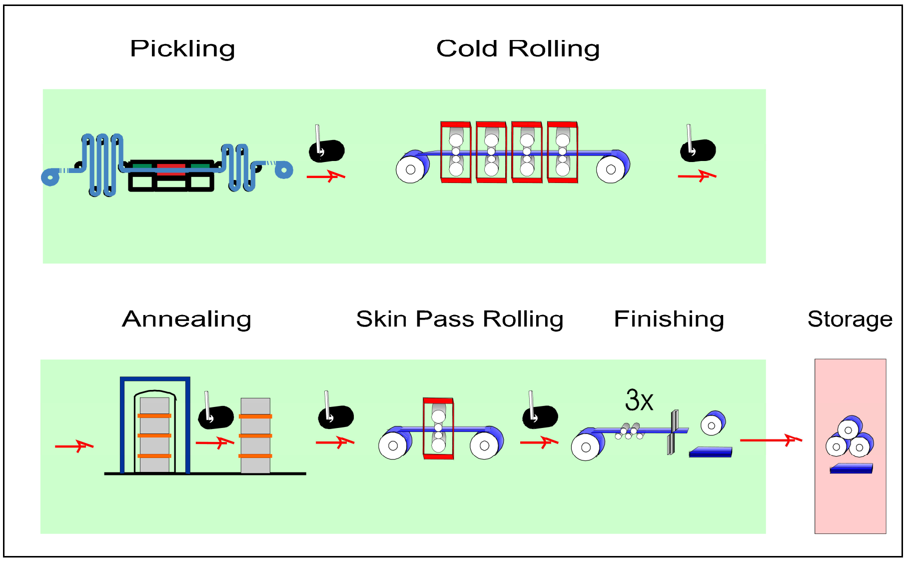
Thus, following the explained before approach for achieving an economic and environmental improvement in the heavy industry by assessing the possibilities of implementation of RE for self-consumption, a case study of a large steel cold rolling factory as energy intensive consumer example (Rodrigues da Silva, Carvalho, & Valdir, 2018) is taken and analyzed. Several options are exposed of hypothetical electricity on-site generation facilities that could be planned and integrated in the industrial plant, connecting the RE generation system to the middle-high voltage internal grid of the factory that feeds the industrial facilities and therefore decreasing this way the total energy consumption of the company from the external provider of electric energy. To obtain a useful analysis and exposition of the viability of this type of facilities in the described industrial environment, the following objectives are set:

- Assessing of main advantages and disadvantages to take into account for the integration in the existing infrastructure when deciding the implementation of one of the two considered technologies: wind or solar PV.
- Description of the main characteristics of the case study's example factory and laying out the energy requirements of the main facilities with major potential interest to derive the on-site RE electricity produced. Moreover, establishing a minimum objective of energy savings in order to achieve at least 15% of the total electrical energy consumed in the entire factory.
- Definition of 3 working hypotheses by proposing concrete solutions for contribution of energy supply to the industrial plant by integrating 3 possible alternatives of self-generation systems:
    - a wind farm with eight turbines and total rated power of 26.4 MW.
    - a photovoltaic (PV) facility of 25 Mwp installing plates on the ship deck and on ground level in available yards.
    - a combination of both systems.

3. Case Study

The case under consideration is a steel finishing plant of medium-large size with a production capacity of 2 million tons per year of rolled steel strip, located close to the eastern Spanish cost, which belongs to a multinational steel making company that produces all kinds of steel products for construction, railways, household appliances and automotive sector (AM website, 2020). The fact of being a so called finishing plant is significant given that unlike the primary plants, where hot and melted steel is processed from the iron ore until obtaining the different rolled steel products through many high temperature processes that are mainly run using direct combustion of fossil fuels like gas or coal, a steel finishing plant is characterized by using overall the electric energy for the production processes that are developed in the factory. This case has been chosen as example of large-scale production industrial plant of the heavy industry sector included in the group of the considered energy intensive consumers, due to the very high level of electric power that this kind of facilities require for its operation. In this type of factories, the coils of metal strip is received in a format range that is normally between 1 to 1,80 m a thickness from 3 to 6 mm approximately (which have been previously hot-rolled in primary steel workshop), and are transformed by compression into cold-rolling tandem mill until the strip is converted into relatively thin-thickness sheet metal band (0.3, to 0.6 mm) that is consumed by the automotive sector (main customer) or other industries such as furniture, household appliances, workshops or construction.

Figure 5: Typical configuration of cold rolled steel mill. Source European Commission (2001)



The factory is powered by a high voltage line (220 kV) of the general distribution grid, that supplies a general open-air transformer substation inside the plant which reduces the voltage to 20 KV, distributing this way the electric energy to the production lines that in turn have their own smaller substations within their warehouses, reducing again the voltage to 380 V or to the specific voltage required by each machine or for the process in which it works.

From the available publications found in scientific literature addressing the energy issues for the heavy industrial sector (Rodrigues da Silva, Carvalho, & Valdir, 2018) and other published official reports (European Commission, 2001) and after verifying the findings through existing web commercial publications (AM website, 2020), press articles (Las Provincias, 2008) and consultations carried out to professionals of steel companies to upgrade the information received, some interesting data has been collected and can be used as representative of the energy consumption at a general level for the specific case under analysis. For this verification it has been estimated first the electrical energy needed for the main processes performed in this type of factories using the data contained in the report of the European Commission mentioned before (2001) about the “Best Available Techniques in the Ferrous Metals Processing Industry” in which energy consumption figures of many processes of these kind of industries is deeply described. The electrical power consumed by the plant varies every year depending on market demand and special production situations, so it is necessary to start stablishing a supposed long term mean level of production of the factory for the latter calculations, which is decided to be set in an 80% of the rated maximum production capacity of the plant. Thus, as the maximum yearly production is 2 MTn, it is considered a mean production level of 1.600.000 Tn/year of processed steel. In table 1 we can see the breakdown in different sections or industrial lines of the plant indicating the corresponding first important figures of the case-study for the development of the analysis. The results obtained after the completion of the table 1 give us a final average consumption of electrical energy of for every Tn of cold rolled steel produced in a scenario of 1,6 million tons of yearly production of 0,533 GJ, which matches properly with the figure provided by Rodrigues da Silva, Carvalho, & Valdir (2018) in their work analyzing energy issues of Brazilian steel industry, of energy used for cold rolling processes that is set in by Rodrigues et al. in 0,63. Due to the fact of the difficulty in regards of achieving a high level of accuracy in the real values for such complicated processes, the deviation in the obtained results of 0,097 GJ is considered acceptable.

Table 1. Annual consumption data of the main facilities for the case-study plant

	Process Facility	Production (MTn)	Electrical energy consumption level: Electrical energy per unit (GJ / Tn)	Electrical energy consumption level: Estimated e.e. consumption ($10^6 \cdot$ GJ)
	Picking Line	1,60	0,03	0,048
	Tandem Mill	1,60	0,23	0,361
	Annealing	0,65	0,10	0,067
	Temper Mill	0,65	0,04	0,025
	Finishing Lines	0,40	0,05	0,020
INDEPENDENT LINES	Electrogalvanizing Line	0,14	0,75	0,104
INDEPENDENT LINES	Galvanizing Plant	0,55	0,24	0,130
	Other auxiliary services	1,6	0,06	0,098
			TOTAL energy year ($10^6 \cdot$ GJ):	0,853 (237.230 MW·h)

Note: there are several interdependencies among the different industrial lines so the only total figure that can be added up is the total final energy consumed, not the rest of the values.

It is noted in table 1 that the installation that consumes the greatest amount of electricity is the tandem mill section, for its high level of production and also because there is where the cold rolling processes take place, applying huge pressures by means of working cylinders that compress the cold sheet metal until it becomes a product with a thickness 8-10 times smaller than the existing at the inlet strip in the rolling mill, requiring consumptions of the order of 100,000 MW·h per year. Other significant consumptions are given in the corrosion surface protection coating processes applied to the metal strip, which are carried out whether in a hot galvanizing by immersion of the strip in a melted zinc kettle where the coils are passed though, or by an electrodeposition line, with consumption figures of the order of 37,000 and 28,000 MW·h respectively in a normal year of production, even though these figures can vary depending on the changes of the demanded products. So in principle these 3 remarked facilities could be advisable to prioritize when considering any system of contribution of electrical energy from RE to feed their production processes, given that the special interest on those facilities on any significant energy reduction that could put the line in a better competitive position. In order to make a preliminary estimation of the proposed options' adaption to the existing situation, we will first take a look at the mean values of electric energy balance with the proposed figures in the objectives of this work. It is possible to establish the mean electric energy hourly consumption ($\bar{E}ch$) which is an equivalent value of the mean electric power needed to run the factory, as follows:

$$Pm = \bar{E}ch = Ecy / 8760 \text{ h} ; \qquad P = 237.000 / 8760 \approx 27 \text{ MW·h}$$

As the nominal power for proposed wind and solar energy generation facilities were 26,4 MW and 25 MW respectively, there is a maximum energy production capacity of 51,4 MW·h in the very rare case situation of both on-site RE generation plants producing at 100%, almost doubling the medium consumption of the factory. Supposing a scenario of a 25% of mean yield achieved for the combination of solar and wind generation systems if they were both implemented, this would give us 12,85 MW·h, which means that half of the average needed energy to run the factory would be self-generated. With these premises and to support the viability of RE self-generation projects, energy storage systems are not being considered due to the shown high level of average demand of energy that guarantees the self-consumption of all RE energy produced most of the time that the factory is in operation, avoiding this way the very important cost of storage systems needed to run large-scaled factories like this.

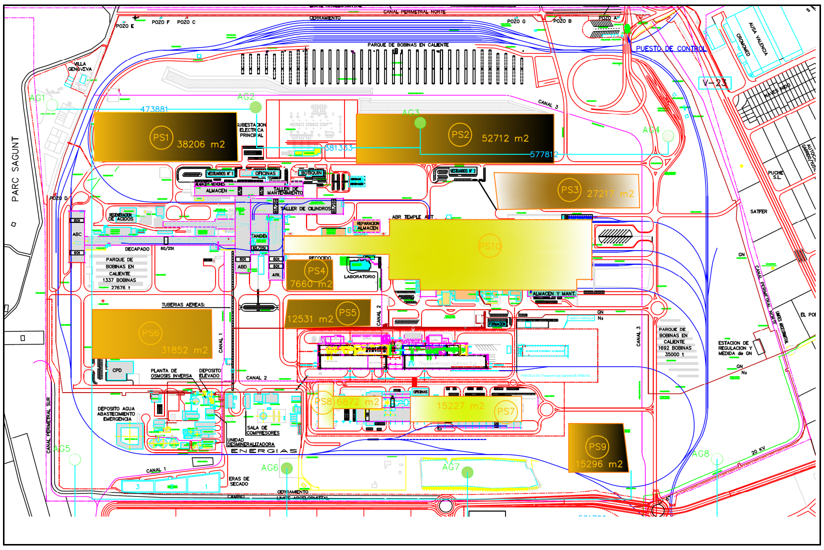
4. Development of alternatives

To start the exploration of alternatives is important to set the main physical characteristics of the case-study factory, that can be profitable for the purposes of self-generation of the consumed electricity, in particular availability of space for the RE generation facilities and the geographical location. In the case-study more than 105.000 m2 of unused roofs and another estimated over 205.000 m2 of free on ground yards could be available for proposals of installing RE facilities, so we have at least around 310.000 m2 of relatively free space that could be used to project a medium-large size PV solar generation plant or the implementation of several large wind turbines distributed in the existing area. The location is in this case in the eastern coast of Spain close to the city of Valencia, which in principle can be considered a place with medium to good renewable resource, given that it is included into the second highest level area of solar resource of the country and there are winds that are quite frequent but not particularly strong in comparison with other specially selected places for wind turbine installation. To get an idea of the typical features of factories like the described case-study, in figure 6 we can see several images of other steel factories similar to the case study, in which we can note the substantial available space on roofs and external yards surrounding the workshops that we can find often in these industries.

Figure 6: Aerial views of steel finishing factories similar to the case study analyzed

After an evaluation of the available space inside the industrial plant, it is concluded that it is possible to use 10 zones, 7 on ground level yards and 3 workshop roofs, once it has been determined that these are the areas with more favorable conditions for the implementation of the new RE generation facilities, because of the lack or very scarce verified existence of crucial installations into them to be maintained or that may need to be accessible, which would be an inconvenience that has to be well analyzed and previously minimized. Figure 7 shows the drawing obtained after this necessary previous study of available areas to project PV solar plants and where it has been also marked the position of the wind turbines alternative solution, so we have this way a RE generation plant for self-consumption integrated in the preexisting facilities.

Figure 7: Plant drawing of the case-study areas considered for new RE facilities



Note: AG indicate the proposed position of wind turbines and PS the plants for solar PV energy on available areas (yellow coloured on roofs and orange-black for the on-ground level yards).

For the estimation of the total solar power achievable using the available depicted areas and takin into consideration an acceptable mean value of 0,89 MWp / 10.000 m2 (Bautista, 2018), the provided installed power values of table 2 are obtained for both options of solar PV facilities, whether the plates are installed on ground level or over the workshop roofs:

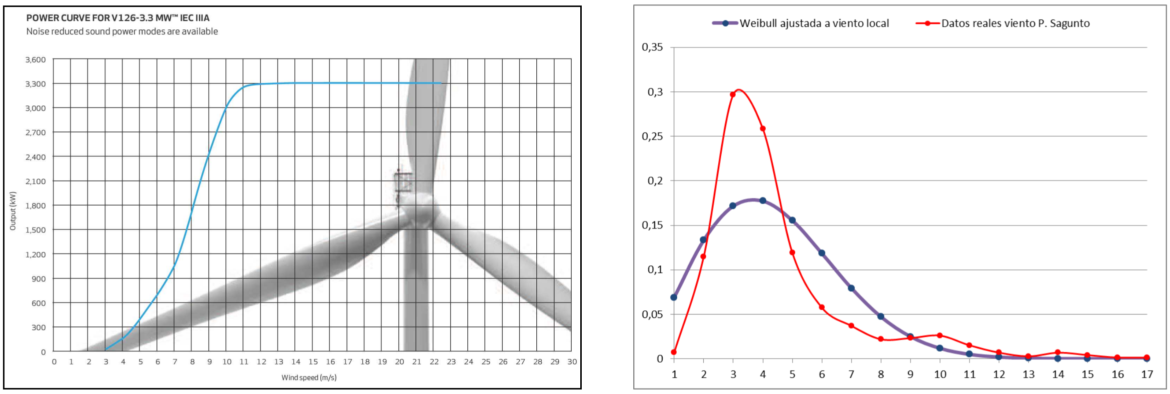
Table 2. Estimation of PV solar power generation facility

	Previous Assessment		Proposal	
	AREA (m2)	Power (MW)	Power (MW)	E/year (MW·h)
Ground level yards	205.474	18,29	17	27.849
On roofs	107.569	9,57	8	13.106
Solar PV Plant	303.043	27,86	25	40.955

Supposing a small technical curtailment when transforming this theoretical figure in a real project, it is assumed as correct for the dimensioning of the PV plant the possibility of implementation of 17 MWp for the ground level solar park and 8 for the roofs installation, which gives us a final number of 25 MWp of total possible installed PV power. For the determination of the energy input in the explained conditions, we resort to the PVGIS web application introducing the correspondent geographical coordinates of the case-study plant location (39°39'01.3"N, 0°14'13.7"W) with a final resulting yearly energy production of 40.955 MW·h from the PV plant, which is a significant amount of energy to take into account for the factory, representing the 17% of its total yearly electrical energy consumption and enough in global terms of total amount of energy consumption, to completely feed one of the facilities with highest electricity demand like the case of the galvanizing line.

The possibility of using the existing on-site wind resource for an immediate self-consumption of the energy produced by wind turbines is also interesting to be analyzed for a high-intensive industry like the case-study. As the intention is using large wind turbines over 100m height for the adequate capture of the existing wind resource and capable of providing enough energy to be taken into consideration for a factory with such high consumption levels or similar, a 2 years long wind data campaign using a weather station at the maximum possible height would be the desirable. The accomplishment of these wind measurement campaigns has an important cost specially due to the installation of the station tower, so we have to resort to surface level nearby weather stations data and use extrapolation formulae. In this case it has been collected data from two stations, one of them inside the factory which registers for more than 10 years are available and another from a station located at 4km of distance from the factory. In principle and according to the previously set objectives, it is selected for the study a commercial wind turbine with available power curve, choosing the VESTAS firm model with 3.3 MW of nominal power and 137m of hub height. This machine or an upgraded analogue one available in the market for a real project to be accomplished, can offer us mainly two desired characteristics: an important hub height over 100m for a good wind resource harnessing and a low cut in speed of 3m/s that is interesting in a coastal place with frequent presence of sea breezes, characterized to be not too strong winds but enough to take its energy for electricity generation. Once stablished the hub height through the selection of the wind turbine, and taking again a look to the physical main characteristics of the available site as it was done for the solar energy assessment to determine the hypothetical generation facilities that can fit correctly with the existing conditions, a distribution of 8 turbines is proposed in the locations indicated in the drawing of figure 7.

Figure 8: Weibull curve for case-study site and wind turbine power curve



Note: Power curve VESTAS (2018). Weibull distribution curve of own elaboration.

Using the power law with a roughness coefficient α=0,3 for the extrapolation of wind speed data recorded in the weather stations to the considered height hub, the Weibull distribution curve depicted in figure 9 is finally obtained after the correspondent adjustment as representative for the local existing winds, giving us the values of the scale and shape curve parameters of k=4,97 and c= 2,11 and a mean wind speed of 5,53 m/s is determined at the hub height, figure that is confirmed analyzing a more extended available data list from the external weather station (5,92 m/s) and through the Global Wind Atlas application (5,3 m/s). Finally, and after multiplying the expected number of hours of presence of winds according to the Weibull curve adjusted to local conditions by the powers for every wind speed defined in the power curve provided by the wind turbine supplier according to the graphs in figure 8, we can obtain an estimated yearly energy production of 4.007 MW·h per turbine, which gives us a total contribution of electricity by this route of 32.056 MW·h / year from the on-site available wind resource, which supposes the 13,5% of the total demand of electricity of the factory and over for example of the total electrical energy consumed by the electrodeposition line. Thus, after the exposed analysis and to end with a final perspective of the real possibilities of the RE, the described findings are summarized in the next table 3:

Table 3. Summary of studied alternatives

ALTERNATIVES	TYPE	Installed Power (MW)	Energy supply/year (MW·h)	% Factory electrical consumption	Cost of investment (M€)
A	Solar PV plant	25	40.955	17,3	17,3
B	Wind Farm	26.4	32.056	13,5	26,4
C	(A+B)	51.4	73.011	30,8	51,4

In terms of cost of investments and taking into account the evolution of solar PV energy in the last decade (IRENA, 2018) and after verifying through consulted professionals of this field, we can state that the actual for this scale of projects cost of investment would be around 1M€/MWp and a very similar figure would be obtained in principle for the wind energy proposed investment, which is also verified in the mentioned before IRENA report of 2018 about renewable power generation costs. Therefore, the cost provided for investments in the hypothetical RE generation facilities can be estimated in the figures shown in table 3. With the existing conditions in the case-study site, the most competitive option would be the solar plant which provides more yearly energy to the system per unit of investment (1.638 MW·h/M€ for solar PV in comparison to the 1.214 MW·h/M€ obtained for the wind farm). Nevertheless, this should not be interpreted as that the contribution of the wind system should not be considered, first of all due to the great difficulty in obtaining precise estimates of the wind resource without wind data available at meteorological stations at sufficient height to give us a better approximation and therefore On the other hand, the real costs can be lowered considerably in a real investment operation influenced by multiple factors such as market situations or the detailed study of the installation place of the wind turbines. In any case and taking the presented figures as valid, the of energy contribution obtained for the wind turbines (13,5%) is enough to be taken into account, especially for the particular technical advantage of this way of generation of total lack of interference with the company in terms of future plans of investments like expansion of workshops for new product lines of the business that would be much more constringed if more than 205.000 m^2 of ground level yards are occupied for 17 MWp of the total 25 MWp of the solar plant.

5. Conclusions

As it has been described, it is possible to widen the classic perspective for RE electrical generation, taking advantage of the profitable situations that we can find in medium-large or large sized electro-intensive industries, like the availability of free space for implementation of RE generation facilities and the very frequent high level of electrical consumption. This approach has not been developed so far by the big private industrial companies maybe because of the still remaining and generalized idea of the RE as a technology that is not capable to substitute fossil fuel centralized traditional system of powering large factories with really high energy consumption requirements to run their large-scale production processes.

However and after proposing several hypothetical generation facilities from RE integrated into the factory, we can see that it is possible to partially feed the facilities electricity needs in a very significant proportion also for this kind of heavy industries, so that they can reduce the final consumption from the general external supply grid achieving this way an interesting reduction in the electricity expenditures, which would enable this type of projects to be financially successful due to the fact that the electro-intensive industries have per definition a structural dependency of electricity in the profitability of the business. As it has been shown after the analysis of 3 hypothetical generation facilities from RE, the factory can save through the implementation of a 25 MWp solar plant around a 17% of the electrical consumption and additional 13% installing 8 wind turbines of 3,3 MW rated power. A combination of both systems would reach the very significant figure of 30% of self-produced and consumed electricity respect the total mean level of consumption of the industrial center. In the particular case-study developed, the final results of the performed analysis it could be concluded that, if we consider an equal cost per installed on-site RE power in principle the most advantageous technology to apply is the solar

The research on the industrial production processes of the case study has been improved from previous works in this field (Bautista, 2020) by new findings on the detailed data about the analyzed subject that allow exposing in a justified way figures of energy consumption available in official reports about the steel cold rolling industry (EC, 2018) that can be used as a valid reference. Then and following the explained methodology of assessment of RE energy generation systems adapted in the best possible form to the existing factory, the method can be applied to other case studies of the same type of industry or similar industries of high consumption of electrical energy, being another additional way to achieve an improvement in competitiveness by reducing energy costs and an advance to reduce the environmental impact generated through the activities developed in this kind of industries.

6. References

Aleasoft Energy Forecasting website. (2019). European electricity markets panorama: Germany. Retrieved April 26, 2020, from: https://aleasoft.com/european-electricity-markets-panorama-germany/

ArcelorMittal website (2020). AM Spain – Flat Products. Retrieved April 29, 2020, from: https://spain.arcelormittal.com/what-we-do/productos-planos/sagunto.aspx

Bautista, J. A., M.S. García-Cascales, A. Molina-García (2018). Application of renewable energy source integration into industrial plants of steel sector: comparison; analysis and competitiveness improvement. *22nd International Congress on Project Management and Engineering* (pp. 1377-1389). Madrid: AEIPRO, Spain.

C.M.R. (2008, January 26). ArcelorMittal se mantiene líder en laminación en frío con productos diferentes. *Las Provincias.* Retrieved from https://www.lasprovincias.es/valencia/20080126/morvedre/arcelormittal-mantiene-lider-laminacion-20080126.html

European Commission (2020). Climate strategies & targets: https://ec.europa.eu/clima/policies/strategies/2030_en

European Commission (2001) Integrated Pollution Prevention and Control (IPPC). *Reference Document on Best Available Techniques in the Ferrous Metals Processing Industry.* Retrieved April 29, 2020, from: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/fmp_bref_1201.pdf

Eurostat. (2020). Database – Environment and Energy, Electricity prices statistics – Prices of natural gas and electricity. *Electricity prices components for non-household consumers - annual data (from 2007 onwards) (nrg_pc_205_c)*. Retrieved April 26, 2020, from: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205_c&lang=en

Eurostat. (2020). Electricity prices statistics. *Electricity prices for non-house consumers, first half 2019.* Retrieved April 26, 2020, from: https://ec.europa.eu/eurostat/statistics-explained/images/d/d6/Electricity_prices_for_non-household_consumers%2C_first_half_2019_%28EUR_per_kWh%29.png

Hosseini, M., Brege, S. & Nord, T. (2018). A combined focused industry and company size investigation of the internationalization-performance relationship: The case of small and medium-sized enterprises (SMEs) within the Swedish wood manufacturing industry. *Forest Policy and Economics, 97*, 110-121.

Instituto para la Diversificación y Ahorro de la Energía [IDAE]. (2020). Estudios informes y estadísticas – Balances energéticos. Retrieved April 26, 2020, from: http://sieeweb.idae.es/consumofinal/

International Renewable Energy Association [IRENA] (2019). RENEWABLE POWER GENERATION COSTS IN 2018: https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018

Moreno, B., García-Álvarez, M. T., Ramos, C. & Fernández-Vázquez, E. (2014). A General Maximum Entropy Econometric approach to model industrial electricity prices in Spain: A challenge for the competitiveness. *Applied Energy, 135*, 815-824.

Mur, J. (2009). Curso de energía eólica – Universidad de Zaragoza. Obtenido de http://www.windygrid.org/manualEolico.pdf

Peña, R. (2011). Energía eólica – Universidad CEU San Pablo - IMF. Ediciones Roble, S.L.

Red Eléctrica de España [REE]. (1998). Proyecto Indel – Atlas de la demanda eléctrica española. Retrieved April 26, 2020, from: https://www.ree.es/sites/default/files/downloadable/atlas_indel_ree.pdf

Red Eléctrica de España [REE]. (2019). *El sistema eléctrico español 2018*. Retrieved April 26, 2020, from: https://www.ree.es/sites/default/files/11_PUBLICACIONES/Documentos/InformesSistemaElectrico/2018/inf_sis_elec_ree_2018.pdf

Red Eléctrica de España [REE]. (2019). *IRE No 72. Evolución sectorial de la demanda de electricidad en grandes consumidores*. Retrieved April 26, 2020, from: https://www.ree.es/sites/default/files/01_ACTIVIDADES/Documentos/IRE/InfomenIRE_Dic19.pdf

Rodrigues da Silva, R., Carvalho, F.R., Valdir, S. (2018). Potential energy efficiency improvements for the Brazilian iron and steel industry: Fuel and electricity conservation supply curves for integrated steel mills. *Energy*, 153, 816-824.

Serpa, Y. R., Nogueira, M. B., Rocha, H., Macedo, D.V. & Rodrigues, M. A. (2020). An interactive simulation-based game of a manufacturing process in heavy industry. *Entertainment Computing, 34*, 100343

Vestas (2018). Retrieved from https://es.wind-turbine-models.com/turbines/695-vestas-v126-3.3#powercurve

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