Energy, environmental and economic assessment of a manufacturing plant with practical solutions.

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Abstract. Considering the role that China has in the industry which triggers challenges in the environmental, economic and energetic sector. This study aimed to evaluate the energy consumption key points for a manufacturing factory located in Shanghai and propose practical projects to improve its performance. The methodology followed an inventory analysis and theoretical calculation in the three sectors mentioned, being the most representative the emissions of carbon dioxide, payback period and the standardization of the energy units. Among the results, the most energy-consuming areas and equipment were found; then, three projects were suggested to implement: the installation of a heat recovery system for the air compressor system, an insulation layer for the injection machine and installing a new air compressor, plus several common suggestions for manufacturing plants. Most of the projects presented a payback period lower than two years and relatively fast implementation for manufacturing plants.

1. Introduction

China is one of the cores of the manufacturing development of the world. However, the economic points are concentrated in specific areas, especially on the eastern coast, being Shanghai one of the essential pieces in the Chinese development. Shao, (2017) indicates that the average annual GDP growth rate China of equals to 10% since 1978 [1]. Simultaneously, the extensive consumption of energy has involved severe environmental loads since the primary source of energy is based on coal energy.

There are over 600 cities in China, of which fourteen, including Beijing and Shanghai, they possess the GDP over trillions of Yuan. However, the studies number is minimum, one of the most recent papers, found that the environmental efficiency (EE) performance over the Chinese cities is relatively low, and there are significant differences among them. [2]

A recent study which analyses the China’s economic sectors under environmental parameters found only seven sectors perform eco-efficiently; at the same time, more than 70% require meaningful improvements. Among the suggestion of the authors, it is pointed out that the Chinese Government should support mechanisms to introduce modern equipment and eject the necessary environment-protection measures to prevent and mitigate its environmental impacts. [3] Moreover, the adjustment of the industrial structure should be accelerated, by lowering the capacity of high energy consumption and low added value industries, to expand the service industry in GDP and develop alternatives for
coal energy like biofuels, biomass, solar, hydro and wind power. [1]

In this context, Sihag et al., (2019) appointed that during the last years, the industrial sector consumed more than 50% of the net global energy, being primary actors the manufacturing stage as well as the supply chain operations. In the present study, the location of the manufacturing plant reaches the required features of the authors, since it is located in the industrial park of Shanghai and it facilitates the delivery of their products within China and abroad. Furthermore, this work aims to evaluate from different perspectives the common critical energy-consuming areas and equipment of a manufacturing plant and propose practical projects that help to perform better economically, environmental and energetically.

2. Material and Methods
For studies related to energy-saving solutions, several parameters of energy consumption, environmental loads, and economic expenses are usually evaluated.

2.1. Energy efficiency evaluation
Energy-saving refers to the electricity, natural gas and water consumption, that can be avoided by the implementation of some projects. In order to facilitate the comparison of different units, the values are converted into a Tonne of Coal Equivalent (TCE), the calculation was based on the Equation (1):

\[ E_e = C_{ele}E_{ele} + C_{nat}E_{nat} + C_{wat}E_{wat} \] (1)

Where \( E_{ele}, E_{nat}, E_{wat} \) represent the saved electricity, natural gas, and water, respectively, which units are kWh, m³, kg; \( C_{ele}, C_{nat}, C_{wat} \) represent the coefficients for electricity \((0.1229 \text{ kg tce/kWh})\), natural gas \((1.2143 \text{ kg tce/m}^3)\) and water \((8.57 \times 10^{-5} \text{ kg tce/kgH}_2\text{O})\), respectively.

2.2. Environmental impact assessment
The accounting of carbon dioxide emission from the current situation was based on the Equation (2); as well for the emissions avoided measurement. However, the scope of the study reduces exclusively to the manufacturing plant and does not take into account other processes belonging to hazardous waste and wastewater.

Due to the differences in product and process flow between different plants, it is difficult to use formulas to calculate CO\(_2\) reductions [3]. Instead, the carbon dioxide emission factor is commonly used to convert it and calculated as follows:

\[ \Delta E_{m_{co2}} = \sum_l \Delta E_l \times NCV_l \times CEF_l \times COF_l \times N_{co2} \] (2)

Where \( \Delta E_l \) means the reduced usage of energy source, \( NCV_l \): The heat equivalent, \( CEF_l \) : The CO\(_2\) emission factor, \( COF_l \) : The CO\(_2\) oxidation factor, \( N_{co2} \) : The ratio of the CO\(_2\) molecular weight to the C atomic weight, 44/12

2.3. Economic evaluation
The economic indicators generally used, includes the payback period and the net present value.

2.3.1 Payback period
Usually, the payback period refers to “simple payback,” which is calculated as the following:

\[ \text{Payback period} = \frac{\text{Initial cost}}{\text{Annual saving}} \] (3)

The payback period is simple to calculate and understand. It is convenient for simple internal rules of thumb for making quick decisions to either reject a proposal or take the analysis further.

2.3.2 Net present value
Net present value (NPV) is an essential benchmark to determine the present value of an investment by the discounted sum of all cash flows. The formula can be written as:
\[ NPV = -C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \]  

(4)

Where \(-C_0\) represents the initial investment, showing that the money is going out as opposed to coming in. \(C_t\) is the future value of cash flow, and \(r\) is interest rate (also named as the discount rate).

3. Results

First, it was found the areas and equipment with higher electricity and natural gas consumption. Then, a list of options for saving energy was elaborated, based on installing a heat recovery system for air compressor, adding a new compressor, using insulation layers for injection machines and installing a solar roof.

![Figure 1 Overall energy consumption in TCE.](image)

The water consumption had the lowest consumption; contrarily, the electricity presented the highest one, followed by natural gas utilization. To be more accurate, the performance of the last year detected that the electricity consumption reached 66%, the natural gas around 34% and the water consumption tends to be zero in TCE.

The general tendency in manufacturing plants is an increase in electricity consumption. However, the consumption in the offices keeps relatively stable. Likewise, the seasons with more electricity consumption were summer (during July & August), and winter (November, December & January). Considering the natural gas use, there are also relevant picks of consumption on the winter season. On the other hand, water consumption can be established like an approximate average value, much lower than electricity and gas consumption in this study.

In the case of the air compressor, it is required a permanent control of leaks, maintenance in the function of the working hours, replacing of oil and filters and the continuous empty of water from the air compressors. In this case of study, it was calculated the pressure drops and was analyzed the performance over the time. The results showed a significant need for more air pressure for the machinery located at the end of the pipeline to avoid the renting of an air compressor to reach the requirements of the production line.

For an accurate calculation, correct device power value and corresponding running time are required. One of the common deficient of the manufacturing is the missing of meters installed and the recording of data for better management. Moreover, the table 1 summarized the main point related to the emissions avoiding and the key points of the economic assessment.

| Project Name               | Upfront Investment, Net of Rebates (USD) | NPV (USD) | Annual Savings (USD) | Annual Electricity Savings (kWh) | Annual Non-Electric Energy Savings (BTU) | Annual CO2e Reductions (metric tons) | Recommended timeline for implementation |
|----------------------------|------------------------------------------|-----------|----------------------|---------------------------------|----------------------------------------|--------------------------------------|----------------------------------------|
| Heat recovery for air compressor | 21,429                                   | 261,839   | 41,203               | 0                               | 2.377E9                                | 127                                  | Less than 6 months                    |
Install a new air compressor | 42,857 | 82,209 | 16,335 | 152,460 | N/A | 107 | Between 6-18 months |
Insulation layers for Injection machine | 1,714 | 5,616 | 1,157 | 10,800 | N/A | 8 | Between 6-18 months |
Solar roof | 571,429 | 37,271 | 63,122 | 455,520 | N/A | 320 | More than 18 months |

4. Discussion
The companies are facing new challenges; the industry 4.0 could be a favorable tool for several sectors; nonetheless, this new technology depends on the main components of the onsite manufacturing plant. The importance of this work regards to the saving in the manufacturing plants where supplement air and energy from heaters have the potential for being used. [5]

The air compressor system represents around 27% of the manufacturing’s electricity consumption, 94% can be loosed if there is no energy recovery. It can be done for the electrical energy conversion into compression heat. One of the alternatives is the recovery as hot water that can be utilized for: sanitary purposes, space heating or for industrial practices: using the hot water as boiler pre-feed or directly in processes (70-90 °C) it can reduce the energy, natural gas consumption and minimize the environmental impact regarding to the CO₂ emissions. [6]

In general, the appropriate temperature for the injection machines varies between 60 to 80 °C and there are several types in the injection machine; however, the difference is made in the way these two devices are organized [7]. One of the phases, the filling of the gas-assisted process is so critical and is susceptible to improvement. [8]. There are several strategies to Increase Energy Efficiency in Injection Molding [9]: use electric machines since they use lower power consumption (30 and 60 %) at start-up and lowers maximum demand requirements; implements barrel insulation jackets, it can save energy at around 50 % because they decrease start-up times; and implement electric servo motors, because it more energy-efficient than hydraulics for injection molding presses.

It was also explored the possibility of building a solar plant on the roof. The total area of the roof is around 20,000 m². Considering the buildings, the available area for solar panels will be 5000 m², which means the capacity of the solar roof will be 400 kW. Taking the subsidy into consideration, it turns out the investment in 4 million yuan, needing 12 years to payback.

For the case of heat exchangers, the potential recovery would be in function of many variables, mainly from the capacity of the plant and the potential uses of the recovered energy. For instance, in this paper, it is suggested the use of water in the kitchen rooms since there is a high demand for hot water for the preparation and cleaning of the instruments.

5. Conclusions
This paper starts with a data analysis and proposes four feasible solutions for energy saving and emission reduction in manufacturing plants. These optimization options are in line with national energy conservation and emission reduction requirements, also meet the actual conditions of the plant area and have an essential reference role for energy conservation and consumption reduction of the plant. The actual situation of different manufacturing plants might be different, but it could follow this assessment: starting from data analysis, looking for the most extensive energy-consuming equipment, and then proposing energy-saving solutions, this thinking has a substantial promotion value. Theoretical calculations and actual data also show that these projects can effectively reduce costs upon $121,817 and 562 CO₂e metric tons emissions annually.

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