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Abstract-- This article presents an analysis of indirect carbon dioxide (CO_2) emissions generated by electricity consumption at the Ciudad Juárez Institute of Technology. Energy consumption data was collected from three electrical connections on campus, corresponding to the years 2018 to 2022. By calculating the reactive power and correcting the power factor, carbon emissions were estimated using the official emission factor of the National Electric System (0.423 tCO_2e/MWh). The results reveal that proper power factor correction allows for a significant reduction in indirect CO_2 emissions (greenhouse gases), contributing to the fulfillment of the Paris Agreement objectives and institutional sustainable development.
Keywords-- Carbon emissions, reactive energy, power factor, energy efficiency, greenhouse gases.

Abstract-- This article presents an analysis of indirect carbon dioxide (CO_2) emissions generated by electricity consumption at the Instituto Tecnológico de Ciudad Juárez. Energy consumption data were collected from three electrical service connections on campus, corresponding to the years 2018 to 2022. By calculating reactive power and correcting the power factor, carbon emissions were estimated using the official emission factor of the National Electric System (0.423 tCO_2e/MWh). The results reveal that an adequate power factor correction allows for a significant reduction in indirect CO_2 emissions (greenhouse gases), contributing to the fulfillment of the objectives of the Paris Agreement and to institutional sustainable development.
Keywords: Carbon emissions, reactive power, power factor, energy efficiency, greenhouse gases.

INTRODUCTION

Climate change has become one of the main global issues of the 21st century due to its environmental, social, and economic effects. One of its most significant causes is the sustained increase in the concentration of greenhouse gases (GHG), particularly carbon dioxide (CO_2), whose permanence in the atmosphere makes it the main driver of global warming (Intergovernmental Panel on Climate Change [IPCC], 2021; United Nations, n.d.). The generation of electricity from fossil fuels—such as natural gas, coal, or fuel oil—continues to be one of the human activities that contributes most to these emissions (US

EPA, 2023). In the case of Mexico, the National Council for Humanities, Sciences, and Technologies (CONAHCYT, 2021) reports that in 2021, 72.4% of the electricity produced came from non-renewable sources, mainly combined cycles and conventional thermoelectric plants.

In this context, the Ciudad Juárez Institute of Technology (ITCJ), part of the National Technological Institute of Mexico, has expanded its infrastructure in recent years, which has increased its energy demand. This generates indirect carbon emissions associated with the use of energy from the National Electric System, whose official emission factor is 0.423 tons of CO_2 equivalent per megawatt-hour consumed (Ministry of the Environment and Natural Resources [SEMARNAT], 2022).

The main objective of this study is to quantify the emissions derived from institutional electricity consumption and analyze the mitigation potential through the improvement of the power factor, in accordance with the commitments made by Mexico in the Paris Agreement (UN-Habitat / United Nations, n.d.).

General objective

Assess the indirect carbon dioxide (CO_2) emissions generated by the electricity consumption of the Ciudad Juárez Institute of Technology (ITCJ) by analyzing historical energy consumption data, calculating reactive energy, and applying power factor correction techniques, with the aim of identifying mitigation opportunities in line with international environmental commitments.

Specific objectives

- Analyze historical electricity consumption records obtained from official receipts from the Federal Electricity Commission (CFE), corresponding to the three connections that supply energy to the ITCJ.
- Calculate the active, reactive, and apparent energy consumed by the campus, based on monthly recorded data.
- Determine the behavior of the power factor per service and its influence on the energy efficiency of the system.
- Estimate indirect CO_2 emissions using the official emission factor of the National Electric System (0.423 tCO_2e/MWh).

- Evaluate the environmental impact of power factor correction and quantify the potential reduction in carbon emissions as a result of this improvement.

Justification

The urgency of reducing greenhouse gas emissions has prompted global agreements such as the Paris Agreement, signed in 2015 and in force since 2016, which aims to keep the global average temperature rise below 2 °C (UN-Habitat / United Nations, n.d.). Within this framework, public institutions, including those of higher education, are called upon to implement actions that promote energy efficiency and sustainability.

In Mexico, electricity production continues to depend largely on fossil fuels. According to CONAHCYT (2021), more than 70% of the energy generated comes from conventional fuels, which translates into high carbon intensity. This situation is reflected in an emission factor of 0.423 tCO_2e/MWh, according to official data from the national electricity system (SEMARNAT, 2022).

The Ciudad Juárez Institute of Technology, as an active player in the academic and technological sphere, has the opportunity to contribute significantly to climate change mitigation. The analysis of its electricity consumption and the identification of reactive energy losses allow for the evaluation of technical strategies such as power factor correction, which not only improves system efficiency but also reduces CO_2 emissions (Twenergy, 2020; Energy, 2021).

This study responds to the institutional need to align its operations with the principles of sustainable development, generating useful evidence for administrative and technical decision-making that favors the fulfillment of national and international climate goals (UN, 2015).

DEVELOPMENT

This study was conducted using a quantitative and analytical approach, based on historical energy consumption data recorded at the three electrical supply connections of the Ciudad Juárez Institute of Technology (ITCJ). The methodology was divided into five main stages: data collection, analysis of electrical parameters, calculation of reactive energy, estimation of carbon emissions, and simulation of power factor correction scenarios.

1 **Data collection**

Monthly electricity consumption records for the years 2018 to 2022 were collected from official receipts issued by the Federal Electricity Commission (CFE).

Three campus connections were selected, identified as: 800's, main, and graduate, in order to represent a complete sample of the campus's energy consumption. To ensure the validity of the data, only years with continuous campus operation were considered, excluding 2020 due to the suspension of face-to-face activities because of the COVID-19 pandemic.

2 **Analysis of electrical parameters**

Variables such as active energy (kWh), reactive energy (kVArh), maximum demand (kW), and power factor (%) were analyzed, considering the importance of these parameters in the efficiency of the electrical system. The power factor was used as a key indicator to evaluate energy performance and quantify losses attributable to unused power, in line with the technical definition proposed by Twenergy (2020).

3 **Calculation of reactive energy and efficiency**

Based on the power triangle and using trigonometric relationships, the phase angles between active and reactive power were calculated, which made it possible to estimate the amount of wasted energy. The following fundamental expressions were used:

Equation 1 allows the power factor value to be obtained.

$$FP = \cos\theta \quad (1)$$

Equation 2 is used to obtain the reactive power.

$$Potenciareactiva = Potenciaactiva * \tan\theta \quad (2)$$

These calculations made it possible to project the technical benefits of correcting the power factor to a standard value of 0.95, in accordance with the recommendations for energy efficiency in industrial and educational facilities (Energy, 2021).

4 Estimation of CO_2 emissions

To convert energy consumption into carbon dioxide emissions, the emission factor of the National Electric System, established by the Ministry of Environment and Natural Resources (2022) at 0.423 tCO_2e/MWh, was applied. This methodology is aligned with international standards for quantifying indirect emissions (Madrid City Council, 2020; Repsol, 2023).

Equation 3 can be used to obtain CO_2 emissions.

$$Emisiones\ de\ CO_2 = Energía\ consumida\ (MWh) * 0.423\ tCO_2\ e/MWh \quad (3)$$

5 Simulation of power factor improvement

Finally, the impact of improving the power factor to 0.95 in each connection was estimated. The reactive energy was recalculated and the projected emissions before and after this correction were compared. This analysis made it possible to determine the GHG mitigation potential and propose technical measures applicable in the institutional context.

DISCUSSION AND ANALYSIS OF RESULTS

The following is an analysis of the results according to the methodology.

Institutional energy consumption behavior.

Analysis of the electricity consumption records of the Ciudad Juárez Institute of Technology (ITCJ) shows a constant and significant demand for energy in its three main connections: 800s, main, and postgraduate. This trend is accentuated during periods of regular academic activity, reflecting the operational intensity of the buildings that house classrooms, laboratories, administrative offices, and postgraduate spaces. For example, during 2018 and 2019, annual consumption exceeded 1,600 MWh in a single connection, demonstrating the ITCJ's high energy requirements.

Unlike average estimates for educational institutions in general, these data reflect the particularity of the ITCJ as a growing campus, with academic and technological activities that require a reliable and continuous electricity supply. This reality highlights the need to manage electricity efficiently to ensure both operation and compliance with environmental objectives (Greenpeace Mexico, n.d.; UN, 2015).

Power factor diagnosis.

The analysis of the power factor (PF) in the ITCJ connections revealed monthly values that in many cases are below the optimal standard (0.95). Specifically, the "800's" connection reported an annual average of 0.9148 in 2018, with a cumulative reactive energy of 80,040 kVArh. This performance suggests that a considerable portion of the energy supplied was not used efficiently, resulting in technical losses and unnecessary overload on electrical equipment (Twenergy, 2020).

Simulating an FP correction to 0.95 reduced reactive energy by 27.3%, representing an estimated decrease of 21,840.2 kVArh. This improvement reduces the operational strain on the campus's transformers and internal lines, as well as directly reducing indirect CO_2 emissions (Energy, 2021).

Carbon emissions estimate.

In 2018, an emissions analysis was conducted, yielding the following data:

800's connection:

Without correction: 33.86

tCO_2e With correction:

24.61 tCO_2e

Estimated reduction: 9.25 tCO_2e (27.3%)

Main connection:

Without correction: 309.67

tCO_2e With correction:

231.34 tCO_2e

Estimated reduction: 78.33 tCO_2e (25.3%)

Postgraduate connection:

Without correction: 101.61

tCO_2e With correction: 70.16

tCO_2e

Estimated reduction: 31.45 tCO_2e (30.9%)

Applying the official emission factor of the National Electric System (0.423 tCO_2e/MWh), the amount of emissions associated with institutional electricity consumption was estimated. The results show that, in 2018, the main connection generated approximately 309.67 tons of CO_2 equivalent, while the postgraduate connection reached 101.61 tCO_2e. After applying the FP correction, these figures decreased to

231.34 and 70.16 tCO_2e, respectively (Ministry of Environment and Natural Resources, 2022).

Table 1. *Table of energy consumption and estimated emissions*.

Acometida	Año	Energía activa (MWh)	Factor de Potencia (FP)	Energía reactiva (kVArh)	Emisiones CO_2 sin corrección (tCO_2e)	Emisiones CO_2 con corrección (tCO_2e)	Reducción (%)
800's	2018	80.1	0.91	80,040	33.86	24.61	27.3
Principal	2018	732.0	0.92	316,000	309.67	231.34	25.3
Posgrado	2018	240.2	0.93	97,500	101.61	70.16	30.9

Nota. Datos basados en los cálculos de emisiones utilizando el factor oficial del Sistema Eléctrico Nacional (SEMARNAT, 2022).

Table Figure 1 shows the results of the energy analysis for the three main connections of ITCJ. Se shows an average reduction of 27% in indirect CO_2 emissions after correcting the power factor to a standard value of 0.95, demonstrating the positive impact of this measure on both energy efficiency and greenhouse gas mitigation.

These findings show that the ITCJ has considerable technical scope to mitigate its carbon footprint without resorting to complex investments or operational disruptions. Simply optimizing the PF using capacitor banks can generate measurable benefits in the short term, both environmental and economic (Repsol, 2023).

Technical and environmental implications.

From an institutional point of view, the results support the need to implement an energy efficiency program focused on power factor correction. Adopting this measure would help improve the campus's electrical performance, reduce the load on the facilities, and move toward a more sustainable energy model (Energy, 2021; Twenergy, 2020).

In addition, this strategy can be easily integrated into academic training and social service activities, involving electrical and environmental engineering students in the design, installation, and monitoring of PF correction systems, thus strengthening the link between teaching, applied research, and university social responsibility.

A detailed survey of the electrical installation at ITCJ Campus 2 is currently underway, as well as a review of its load balancing. This effort, complementary to the present study, will allow for the detection of imbalances that increase monthly energy consumption and, consequently, indirect CO_2 emissions. This comprehensive approach favors informed decision-making by the institutional administration (Ministry of Environment and Natural Resources, 2022).

CONCLUSIONS

The analysis of the energy consumption of the Ciudad Juárez Institute of Technology identified that a significant proportion of the energy used has a low power factor, which implies technical losses and inefficient use of the electrical system (Twenergy, 2020).

The estimation of indirect carbon dioxide (CO_2) emissions from institutional electricity consumption, using the official factor of the National Electric System (0.423 tCO_2e/MWh), made it possible to quantify the environmental impact of the daily operation of the educational infrastructure (Ministry of Environment and Natural Resources, 2022).

The results obtained show that correcting the power factor to optimal values (≥ 0.95) represents a viable technical strategy for reducing indirect CO_2 emissions by between 25% and 31%, without the need to modify the existing infrastructure or alter the installed capacity (Energy, 2021).

The implementation of corrective measures, such as the installation of capacitor banks or automatic power factor correction systems, and adequate load balancing on the panels, not only reduces greenhouse gas emissions, but also improves operational efficiency, reduces tariff penalties for low PF, and extends the useful life of electrical equipment (Twenergy, 2020; Energy, 2021).

From an institutional perspective, this study provides quantitative evidence supporting the integration of energy sustainability criteria into resource planning and management, contributing to the fulfillment of international climate commitments, such as those established in the Paris Agreement (UN-Habitat / United Nations, n.d.).

FUTURE WORK

Based on the findings of this study, several opportunities for future research and institutional applications in the field of energy efficiency and sustainability have been identified: Implementation of a real-time energy monitoring system based on Internet of Things (IoT) technologies, which allows continuous data collection on electricity consumption, power factor, and associated emissions. This type of system facilitates decision-making and allows for preventive action to be taken in the event of inefficiency (Twenergy, 2020).

Technical and economic analysis of the installation of automatic capacitor banks, automatic power factor correction systems, and adequate load balancing in switchboards, with the aim of quantifying energy savings, emissions reductions, and return on investment. Previous studies have shown that this type of correction can be amortized in a short period of time when applied in facilities with high consumption and low power factor (Energy, 2021).

Extension of emissions analysis to other scopes of the institutional carbon footprint, including direct emissions (Scope 1) such as those related to the vehicle fleet or fuel use, as well as indirect emissions (Scope 3) derived from suppliers, personnel transportation, and third-party services, in accordance with the guidelines of the Greenhouse Gas Protocol (GHG Protocol, 2023) and supported by data from the National Greenhouse Gas Emissions Inventory (Ministry of Environment and Natural Resources, 2019).

Design of an institutional energy efficiency and sustainability plan, aligned with the Sustainable Development Goals (SDGs), particularly SDG 7 (affordable and clean energy) and SDG

13 (climate action), promoting the use of clean energy, optimizing consumption, and raising awareness among the academic community (UN, 2015).

Inter-institutional comparison of energy performance and emissions between different campuses of the National Technological Institute of Mexico, with the aim of generating a sectoral diagnosis, identifying best practices, and establishing common energy sustainability indicators (CONAHCYT, 2021).

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