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Energy, Efficiency and Sustainability: Carbon Footprint Reduction in Industry through the Implementation of the ISO 50001 Standard.

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It determines that the implementation of ISO 50001 in industrial companies and projects its impact on sustainability through an approach based on data and studies in industrial companies, demonstrating how the standard can improve energy efficiency and reduce CO2 emissions, contributing to the Sustainable Development Goals (SDGs). It seeks to demonstrate the feasibility and benefits of integrating energy management practices to achieve sustainability goals. Case studies were conducted in various industries that have implemented ISO 50001. Quantitative methods were used to measure CO2 emission reductions and energy efficiency improvements. Data were collected through energy audits, sustainability reports and interviews with energy managers. The results indicate that the implementation of ISO 50001 has led to an average reduction of 10-20 % in CO2. emissions. A significant improvement in energy efficiency was observed, with a reduction in energy consumption of up to 15 %. ISO 50001 is an effective tool for the reduction of the carbon footprint in industry, its implementation not only improves energy efficiency, but also contributes to the environmental and economic sustainability of companies.

* 1. Introduction

Growing concerns about climate change and sustainability have led industries to look for ways to reduce their carbon footprint (Acha et al., 2021). Energy efficiency and sustainability (Cansino, 2020), have become key pillars for achieving the Sustainable Development Goals (SDGs, 2015). This article explores the interrelationships between energy, efficiency and sustainability (Carpintero and Frechoso, 2023), and how the implementation of energy management practices can contribute to reducing CO2 emissions and improving industrial sustainability (ISO 14083, 2023). Energy is an essential resource for the operation of industries (Torres and Lituma, 2023). However, inefficient energy use can lead to an unnecessary increase in greenhouse gas emissions (ISO 14064-1, 2018). Energy efficiency refers to the ability to use less energy to perform the same task, which not only reduces operating costs, but also reduces environmental impact (Cansino, 2020). The implementation of ISO 50001 provides a framework for energy management that helps organizations improve their energy efficiency (ISO 50001, 2018). This standard sets requirements for the implementation, maintenance and improvement of an energy management system (Bernabé et al., 2024), enabling companies to reduce their energy consumption and CO2 emissions (Finch et al., 2024). Sustainability in the industrial context implies the adoption of practices (Zeebroeck, 2011), which allow meeting present needs without compromising the ability of future generations to meet their own needs (Cardona et al., 2024). This includes efficient resource management, waste reduction and minimization of environmental impact (Hernández, 2023). Carbon footprint is a measure of an organization's environmental impact in terms of the amount of greenhouse gases it emits (ISO 14064-1, 2018). The implementation of energy efficiency practices (Cansino, 2020), such as those established by ISO 50001 (Birkeland, 2014), can contribute significantly to the reduction of the carbon footprint (Espíndola and Valderrama, 2012).

* 1. Theoretical framework

**2.1 Energy and Energy Efficiency.** Energy is a fundamental resource for the operation of industries (Aristizábal and González, 2021), inefficient energy use can lead to an unnecessary increase in greenhouse gas emissions contributing to climate change (Castrillón and González, 2018). Energy efficiency refers to the ability to use less energy to perform the same task (De Laire, 2015), which not only reduces operating costs, but also reduces environmental impact (Konrad, 2015). Improving energy efficiency in industries is crucial to reduce energy consumption and CO2 emissions (Man et al., 2020), thus contributing to environmental and economic sustainability (Feuillet et al., 2022).

**2.2 Sustainability.** Sustainability in the industrial context implies the adoption of practices that allow meeting present needs without compromising the ability of future generations, to meet their own needs (Martinez and Terranova, 2021). This includes efficient resource management, waste reduction and minimization of environmental impact (ISO/TC 176/SC 2, 2015). Sustainability has become a key objective for many industries as it not only enhances corporate reputation (LAW 1931, 2018), but can also lead to significant cost savings and the creation of new business opportunities (Finch et al., 2024). The United Nations Resolution 70/1 of 2015, known as the "2030 Agenda", establishes the 17 Sustainable Development Goals (SDGs, 2015), which promote a plan of action to benefit people, planet and prosperity (Paniagua and Durán, 2023).

**2.3 Implementation of ISO 50001.** It provides a framework for energy management that helps organizations improve their energy efficiency (Cooper, 2015). This standard sets requirements for the implementation (Gopalakrishnan et al., 2014), maintenance and improvement of an energy management system, which enables companies to reduce their energy consumption and CO2  emissions (Dall'O' et al., 2020). Implementation of ISO 50001 involves conducting energy audits, setting energy objectives and targets, and adopting continuous improvement practices (Smiljanic, 2017). Studies have shown that the adoption of ISO 50001 can lead to a significant reduction in energy consumption and greenhouse gas emissions (Cascella et al., 2016). Guiding energy management to optimize consumption in 4 approaches: management, operation, evaluation and review (Fiedler and Mircea, 2012).

**2.4 Carbon Footprint Reduction.** Carbon footprint is a measure of an organization's environmental impact in terms of the amount of greenhouse gases it emits (Harte and Thickett, 2024). The implementation of energy efficiency practices, such as those established by ISO 50001 (Bruton et al., 2018), can contribute significantly to the reduction of the carbon footprint (Oliveira et al., 2024). Reducing the carbon footprint is not only important for mitigating climate change (Scripcariu et al., 2019), but can also improve the competitiveness of companies by reducing operating costs and complying with environmental regulations (Olivera et al., 2013). ISO 14064:2015 establishes guidelines for carbon footprint determination using a Life Cycle Analysis (LCA) approach (Espíndola and Valderrama, 2016), considering the requirements and inventory design of GHG emissions at the organizational level; Quantification, monitoring and reporting on GHG reduction and elimination and validation of information (United Nations, 2018).

* 1. Methodology

To analyze the impact of ISO 50001 implementation on energy efficiency and sustainability (Fuchs et al., 2018), case studies were carried out in various industries. Quantitative methods were used to measure CO2 emission reduction (Canciano et al., 2020) and energy efficiency improvement (Colina-Calvo, 2024). Data were collected through energy audits, sustainability reports and interviews with energy managers (Lee et al., 2014). The study is based on a quantitative approach to assess the impact of ISO 50001 implementation on energy efficiency and carbon footprint reduction in industry**,** using statistical methods and power quality analyzer equipment. Performance indicators (KPIs) such as energy consumption per unit of production, tons produced and monthly turnover were calculated. To ensure the validity and reliability of the results, data triangulation was performed, comparing the findings of energy audits, sustainability reports, calibrated and certified equipment.

* 1. Results

The results demonstrate the feasibility and benefits of integrating energy management practices to achieve sustainability goals. Records of power quality parameters are made for 02 Transformers of 1000 Kva, 10-22.9/046 Kv.

*Table 1. Electrical Parameters Analyzed*

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Installed Power | Active Power-KW | Reactive Power-Kvar | Apparent Power Kva | Power factor PF | Voltage V | Current I | Flicker | THDv % | THDi % | K-Factor |
| Transformer 1000 Kva 10/0.46 - SSEE 1 | 519.20 | 239.0 | 576.88 | 0.90 | 440.00 | 757.00 | 1.200 | 4.2 | 15.7 | 1.90 |
| Transformer 1000 Kva 22.9 -10/0.46-SSEE 2 | 383.00 | 215.00 | 454.00 | 0.84 | 440.00 | 595.00 | 2.60 | 5.01 | 30 | 4.35 |
| Total | 902.20 |  | 1,030.88 |  |  | 1,352.00 |  |  |  |  |

In Table 1, data on low power factor and harmonic distortion (THDi) are recorded. During the 2024 energy audit, an average monthly consumption of 343,832 kWh was observed: 13,649 kWh were recorded due to low power factor; 11,139 kWh of consumption attributable to harmonic distortion and oversized equipment were identified. Another 10,245 kWh were recorded as energy losses.

Graph Nº 1: Contracted Power VS. Registered Power

The Active Power, during the energy monitoring, a total of 902,20 KW was recorded, despite not being at full load, which does not exceed the contracted power of 1,400 KW.

**B)**

**A)**

Graphic Nº1 : Transformer of the Electrical Sub station N° 01 and 02

Transformer 01 is using a power of 576 Kva, which represents approximately 58 % of its maximum capacity and a low power factor (090). Transformer No. 02 is currently operating at a load of 454 Kva, which represents 45.4 % of its maximum capacity, with energy losses due to a low power factor (0.84).

*Table 2. Energy consumption parameters recorded by scada*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Item | Fac. Monthly | Kwh | Monthly Cost S/. | Indicator |
| 1 | Dec-23 | 251,696 | 249,817 | 0.993 |
| 2 | Jan-24 | 184,561 | 258,885 | 1.403 |
| 3 | Feb-24 | 318,831 | 300,750 | 0.943 |
| 4 | Mar-24 | 318,001 | 297,251 | 0.935 |
| 5 | Apr-24 | 449,177 | 360,064 | 0.802 |
| 6 | May-24 | 389,129 | 323,654 | 0.832 |
| 7 | Jun-24 | 401,375 | 334,859 | 0.834 |
| 8 | Jul-24 | 393,234 | 261,255 | 0.664 |
| 9 | Aug-24 | 362,769 | 288,129 | 0.794 |
| 10 | Set-24 | 331,814 | 296,690 | 0.894 |
| 11 | Oct-24 | 347,291 | 292,409 | 0.842 |
| 12 | Nov-24 | 378,001 | 274,692 | 0.727 |

The ISO 50001 methodology allows the generation of energy indicators, such as kilowatt hours per unit produced, tons produced or costs per monthly billing. A decreasing value of the indicator (e.g. 0.664) suggests an efficient use of energy, while an increasing value (e.g. 1.403) indicates an increase in energy losses.

Graph No. 3: energy indicator according to ISO 5001 standard

When the indicator registers low parameters, this reflects an efficient use of energy. To maintain this level of efficiency, it is essential to apply lean and continuous improvement methodologies. These methodologies allow us to identify and eliminate waste, optimize processes and ensure that energy resources are used optimally, thus contributing to sustainability and reducing operating costs.

*Table 3. Energy consumption and carbon footprint parameters*

|  |  |  |  |
| --- | --- | --- | --- |
| Item | Fac. Monthly | Kwh | Carbon footprint |
| 1 | Dec-23 | 251,696 | 62,924.01 |
| 2 | Jan-24 | 184,561 | 46,140.25 |
| 3 | Feb-24 | 318,831 | 79,707.75 |
| 4 | Mar-24 | 318,001 | 79,500.25 |
| 5 | Apr-24 | 449,177 | 112,294.25 |
| 6 | May-24 | 389,129 | 97,282.25 |
| 7 | Jun-24 | 401,375 | 100,343.75 |
| 8 | Jul-24 | 393,234 | 98,308.51 |
| 9 | Aug-24 | 362,769 | 90,692.25 |
| 10 | Set-24 | 331,814 | 82,953.51 |
| 11 | Oct-24 | 347,291 | 86,822.75 |
| 12 | Nov-24 | 378,001 | 94,500.25 |
|  | Total | 4,125,879 | 1,031,469.78 |

To convert electricity consumption in kilowatt hours (kWh) to CO2 emissions, a specific emission factor is used. According to regulations and carbon footprint calculators, it is established that 1 kWh of electricity consumed generates approximately 0.25 kg of CO2 (HdC Calculation, 2005). In this process it was possible to validate the monthly average of 85,955 Tons of CO2, as well as to register the annual emissions of 1,031,469.78 Tons of CO2.

Graph Nº 4: Analysis of Carbon Footprint and energy consumption.

Electricity generation is one of the main sources of greenhouse gas (GHG) emissions. These gases include CO2, CH4, NOx, among others

* 1. Conclusions

The research has a significant positive contribution to the industry. Annual energy consumption was recorded at 4,125,879 kWh and annual CO2 emissions were quantified at 1,031,469.78 tons. The implementation of the ISO 50001 standard has enabled us to reduce energy consumption and CO2 emissions. By improving the power factor (3.87 %). Process improvement methodologies, oversized equipment (3.24 %), lean methodologies and continuous improvement (3.26 %) were applied. We also reduced our carbon footprint by 10.17 %. The adoption of ISO 50001 not only contributes to environmental sustainability, but also offers economic benefits by reducing operating costs in companies.

References

Acha, S., Soler, A., & Shah, N. (2021). Best practices to mitigate CO2 operational emissions: A case study of the Basque Country energy ecosystem. Ekonomiaz,99, 182-211.

Aga Van Zeebroeck, R. (2011). Research for the sustainability of the energy and chemical processing industry. Ingenieria Quimica (Spain),43(498), 248-261.

Aristizábal, & González, J. (2021). Review of measures for energy efficiency and sustainability in the cement industry worldwide. UIS Ingenierías,20 (3), 91-110. DOI:10.18273/revuin.v20n3-2021006

Bernabé-Custodio, M. W., Gonzales-Salazar, G. R., Campos-Díaz Ángel, H., Lioo-Jordán, F. M., Vellón-Flores, V. I., Garivay-Torres de Salinas, F. M., Solano-Armas, T., & Caro-Soto, F. G. (2024). Project management based on ISO 21500, to improve productivity in the industry. Health, Science and Technology - Conference Series,3. DOI:10.56294/sctconf2024928

Birkeland, P. W. (2014). ISO 50001 implementation cautions & tips. 1451-1456.

Bruton, K., O'Donovan, P., McGregor, A., & O'Sullivan, D. D. D. T. J. (2018). Design and development of a software tool to assist ISO 50001 implementation in the manufacturing sector. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,232(10), 1741-1752. DOI: 10.1177/0954405416683427

HdC Calculation. (2005). CeroCO2-We help you in your decarbonization path. ZeroCO2 - We help you on your decarbonization path. Consulted on 15/05/2024.

Canciano, J., Reinosa-Valladares, M., Hernández-Garcés, A., Núñez-Hernández, M., & Ramírez-Díaz, L. (2020). Carbon footprint estimation in glass production in Cuba. Mining and Geology, 36(4), 1-10.

Cansino, J. (2020). The challenge of energy efficiency in Europe and the risk of the rebound effect. Araucaria,22 (45), 269-289. DOI: 10.12795/araucaria.2020.i45.11

Cardona, D., Tamayo, J. A., & Eslava-Garzón, J. S. (2024). Towards a sustainable energy matrix in Colombia. A systematic review of the literature. Información Tecnológica,35 (5), 1-16. DOI: 10.4067/S0718-07642024000500001

Carpintero, Ó., & Frechoso, F. A. (2023). Energy, sustainability and transition: New challenges and unresolved issues. Arbor,199(807). DOI: 10.3989/arbor.2023.807001.

Cascella, G. L., Cupertino, F., & Davide, C. (2016). Energy metering optimization in flour mill plants for ISO 50001 implementation. EESMS 2016 - 2016 IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems, Proceedings. DOI: 10.1109/EESMS.2016.7504810

Castrillón, & González. (2018). Methodology for energy planning based on the ISO 50001 standard. Editorial Universidad Autónoma de Occidente. < https://books.scielo.org/id/d56ks>Consulted on 15/05/2024.

Castro et al, Y. (2023). The path towards sustainability in universities. Case: Universidad Autónoma de Bucaramanga (Colombia). Human Review,17 (1), 1-20. DOI: 10.37467/revhuman.v12.4710

Colina-Calvo, A. O. (2024). A Comprehensive Review of Peru's Energy Scenario: Advancing Energy Access, Sustainability, and Policy Implications. Revista Kawsaypacha: Sociedad y Medio Ambiente,14. DOI: 10.18800/kawsaypacha.202402.D006

Cooper, A. (2015). ISO 50001-From implementation to integration. WEEC 2015 - World Energy Engineering Congress.

Dall'O', G., Ferrari, S., Bruni, E., & Bramonti, L. (2020). Effective implementation of ISO 50001: A case study on energy management for heating load reduction for a social building stock in Northern Italy. Energy and Buildings,219. DOI: 10.1016/j.enbuild.2020.110029

De Laire, M. (2015). ISO 50001 implementation in the chilean industry. WEEC 2015 - World Energy Engineering Congress.

Espíndola, & Valderrama, J. O. (2016). AbaniCO2: A Simple and Effective Method for Decision Making on Carbon Footprint Adoption in Sustainable Emissions Management in Companies. Technological Information,27 (3), 35-52. DOI: 10.4067/S0718-07642016000300005

Feuillet, J., Andrés Correa-García, J., & Ceballos-García, D. (2022). Financial and operational performance of the Colombian energy sector in the context of the Sustainable Development Goals. CEA Journal,8 (18), 1-37. DOI: 10.22430/24223182.2022

Fiedler, T., & Mircea, P.-M. (2012). Energy management systems according to the ISO 50001 standard-Challenges and benefits. 2012 International Conference on Applied and Theoretical Electricity, ICATE 2012 - Proceedings. DOI: 10.1109/ICATE.2012.6403411

Finch, L., Powell, T., & Wilson, H. (2024). Reducing Energy Use Through Behavioural Change: Carbon Literacy Training for Archives in the UK. Studies in Conservation,69 (sup1), 91-97. DOI: 10.1080/00393630.2024.2339726

Fuchs, H., Aghajanzadeh, A., & Therkelsen, P. (2018). Using industry's own words to quantify the benefits and challenges of ISO 50001. 2018-June, 333-343.

Gopalakrishnan, B., Ramamoorthy, K., Crowe, E., Chaudhari, S., & Latif, H. (2014). A structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector. Sustainable Energy Technologies and Assessments,7, 154-165. DOI: 10.1016/j.seta.2014.04.006

Harte, A., & Thickett, D. (2024). Calculating the Carbon Footprint of Interventive and Preventive Conservation at English Heritage, UK. Studies in Conservation,69 (sup1), 323-332. DOI: 10.1080/00393630.2024.2336814

ISO 14064-1. (2018). ISO 14064-1:2018(en), Greenhouse gases-Part 1: Specification with guidance, at the level of organizations, for the quantification and reporting of greenhouse gas emissions and removals. Consulted on 15/05/2024

ISO 14083:2023. (2023). Carbon footprint: Measuring and reducing our environmental impact. ISO. Consulted on 15/05/2024

ISO 50001. (2018). ISO-50001 - Energy management. ISO. Consulted on 15/05/2024

ISO/TC 176/SC 2. (2015). What is ISO Technical Committee (TC) 176 Sub-Committee (SC)2 ? Consulted on 15/05/2024

Konrad, W. (2015). Making sense of sustainability, energy policies and citizens' related domestic behaviour. A case study in Germany. Papers,100(4), 453-476. DOI: 10.5565/rev/papers.2230

Lee, J., Yuvamitra, K., Guiberteau, K., & Kozman, T. A. (2014). Six-Sigma Approach to Energy Management Planning. Strategic Planning for Energy and the Environment,33 (3), 23-40. DOI: 10.1080/10485236.2014.10781519

LEY 1931. (2018). Law 1931 of 2018-Regulatory Manager. <https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=87765>Consulted on 15/05/2024

Man, Y., Li, J., Hong, M., & Han, Y. (2020). Energy transition for the low-carbon pulp and paper industry in China. Renewable and Sustainable Energy Reviews,131, 109998. DOI: 10.1016/j.rser.2020.109998.

Martínez, M. S., & Terranova, C. A. V. (2021). Diagnosis of the quality of life of the Zonal Planning Units (UPZ) 35 and 36 of the city of Bogotá, taking into account the impact of electrical substations from the quantification of the carbon footprint. DYNA,88(218), Article 218. DOI: 10.15446/dyna.v88n218.90450

Olivera, A., Saizar, C., Martínez, G., Scala, M., Lima, C., & Armanetti, E. (2013). Carbon footprint management. Innotec Gestión, 5, 6-21.

Paniagua, F.-J., & Durán, Á. (2023). The communication of the sustainable energy agenda in social networks. Mediterranean Journal of Communication / Revista Mediterránea de Comunicación,14 (2), 53-68. DOI: 10.14198/MEDCOM.24308

Prasara-A, J., Bridhikitti, A., Srinon, M., Thuayjan, T., Ragsasilp, A., & Silalertruksa, T. (2024). Carbon footprint reduction measures for a higher educational institution: Lessons learned from COVID-19 pandemic. Chemical Engineering Transactions, 111, 667–672. DOI: 10.3303/CET24111112

Scripcariu, M., Bitir-Istrate, I., Gheorghiu, C., & Neniu, A. (2019). The Environmental Impact Reduction obtained by implementing an Energy Management System. The advantages of using Energy Management and Energy Savings Standards when performing Industrial Energy Audits. E3S Web of Conferences,112 , 04007. DOI: 10.1051/e3sconf/201911204007

SDGS (2015). Sustainable Development Goals. Sustainable Development. < https://www.un.org/sustainabledevelopment/es/energy/> Consulted on 15/05/2024

Smiljanic, R. (2017). ISO 50001 implementation without or with DOE support. 2934-2948.

United Nations. (2018). Paris Agreement HdC. <https://unfccc.int/documents/54060> Consulted on 15/05/2024