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Original Article

Sustainable Energy Management in the Coffee Agroindustry: Diagnostic Assessment Prior to ISO 50001 Implementation

Gestión energética sostenible en la agroindustria del café: diagnóstico previo a ISO 50001

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Spanish version

Abstract

Introduction: Before implementing an Energy Management System in accordance with ISO 50001, a structured engineering diagnostic is required to identify significant energy uses, establish reliable baselines, and support technical decision-making.
Objective: This study aims to develop and apply an engineering-based diagnostic assessment to evaluate the initial energy performance and compliance with ISO 50001 of an agro-industrial coffee plant.
Methods: A cross-sectional, non-experimental, mixed-methods approach was used. The methodology integrated document analysis, semi-structured interviews, validated questionnaires, and historical energy consumption data (electricity, liquefied petroleum gas, and firewood) for the period 2020–2024.
Results: The diagnostic revealed an initial compliance level of approximately 28% with the requirements of ISO 50001 and identified drying and roasting as processes that consume significant energy, representing more than 50% of electricity consumption. An average energy baseline of 344,200 kWh eq/year was established.
Conclusions: The proposed diagnostic framework provides a reproducible engineering tool to support data-driven decision-making prior to the implementation of ISO 50001. The results demonstrate its applicability in agro-industrial contexts and its potential to guide energy efficiency strategies, investment planning, and sustainable energy management.

Keywords: Agro-industrial systems; Energy assessment; Energy efficiency; Energy performance indicators; ISO 50001; Sustainable energy management; Engineering framework.

Resumen

Introducción: Antes de implementar un Sistema de Gestión de la Energía conforme a la norma ISO 50001, se requiere un diagnóstico de ingeniería estructurado para identificar los usos energéticos significativos, establecer líneas de base fiables y respaldar la toma de decisiones técnicas.
Objetivo: Este estudio tiene como objetivo desarrollar y aplicar una evaluación diagnóstica basada en la ingeniería para evaluar el desempeño energético inicial y el cumplimiento de la norma ISO 50001 de una planta agroindustrial de café.
Métodos: Se empleó un enfoque transversal, no experimental y de métodos mixtos. La metodología integró análisis documental, entrevistas semiestructuradas, cuestionarios validados y datos históricos de consumo de energía (electricidad, gas licuado de petróleo y leña) durante el período 2020-2024.
Resultados: El diagnóstico reveló un nivel de cumplimiento inicial de aproximadamente el 28 % con los requisitos de la norma ISO 50001 e identificó el secado y el tostado como procesos que consumen energía de manera significativa, representando más del 50 % del consumo eléctrico. Se estableció una línea base energética promedio de 344 200 kWh eq/año.
Conclusiones: El marco de diagnóstico propuesto proporciona una herramienta de ingeniería reproducible para respaldar la toma de decisiones basada en datos antes de la implementación de la norma ISO 50001. Los resultados demuestran su aplicabilidad en contextos agroindustriales y su potencial para guiar las estrategias de eficiencia energética, la planificación de inversiones y la gestión energética sostenible.

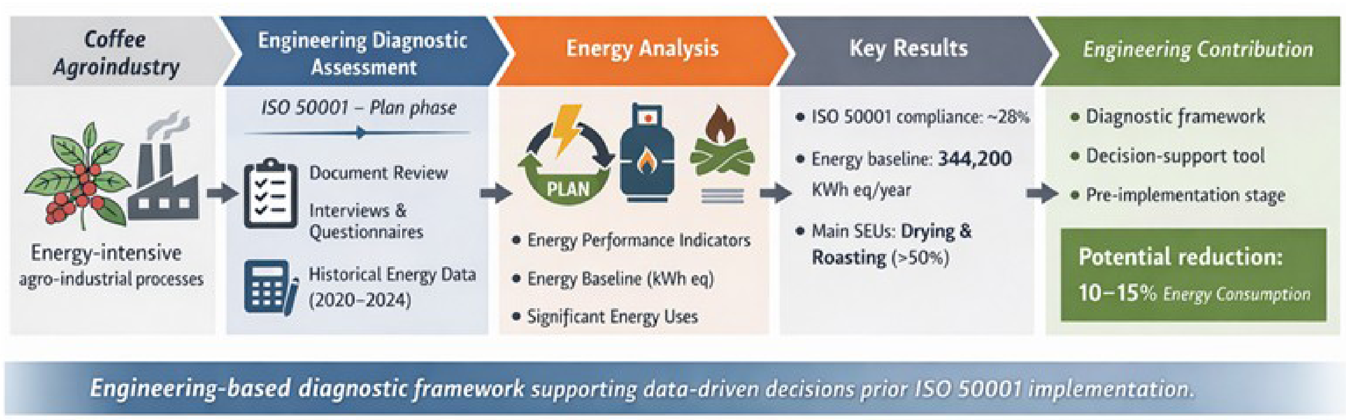
Palabras clave: Sistemas agroindustriales; Evaluación energética; Eficiencia energética; Indicadores de desempeño energético; ISO 50001; Gestión energética sostenible; Marco de ingeniería.

Contribution to the literature
This study contributes to the literature by proposing an engineering-based diagnostic framework for the preliminary evaluation of ISO 50001 implementation in the coffee agroindustry, integrating energy performance indicators, energy baselines, SWOT-CAME analysis, and scenario-based projections within a unified methodological approach. Additionally, it provides empirical evidence from a Latin American agro-industrial context, where studies related to energy management systems in coffee processing facilities remain limited.

The most relevant results include:
An initial ISO 50001 compliance level of approximately 28%, identifying planning, support, and improvement as the main areas requiring development. The establishment of an energy baseline based on historical consumption data from 2020–2024, considering electricity, liquefied petroleum gas, and biomass. The identification of drying and roasting as the most energy-intensive processes. Scenario-based projections indicating that energy efficiency measures could reduce total energy consumption by approximately 13% and mitigate around 16 tons of CO_2 equivalent emissions annually.

These results contribute to the following:
Strengthening methodological approaches for preliminary ISO 50001 assessments in agro-industrial systems. Supporting data-driven decision-making for energy planning and continuous improvement strategies. Demonstrating the relationship between energy efficiency and environmental impact mitigation in coffee processing industries. Providing a reproducible framework that can be adapted to other agro-industrial sectors seeking sustainable energy management practices.

Graphical Abstract



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Introduction

In the current global context, energy efficiency has become a key element for business sustainability, operational cost reduction, and climate change mitigation. Industries with energy-intensive production processes, such as those in the agro-industrial sector, face the challenge of optimizing their energy consumption without compromising productivity. In this regard, the adoption of structured energy management systems represents a viable and essential pathway to promote cleaner, more resilient, and more competitive operations.

The ISO 50001:2018 standard provides a systematic framework that enables organizations to develop policies, objectives, action plans, and monitoring mechanisms to effectively manage energy use, following the continuous improvement cycle known as Plan-Do-Check-Act (1, 2). The application of this standard has demonstrated its effectiveness across various industrial sectors by enabling reductions in operational costs, improvements in resource optimization, and decreases in greenhouse gas emissions (3, 4). These benefits are directly aligned with the Sustainable Development Goals, particularly Goal 7 (Affordable and Clean Energy), Goal 9 (Industry, Innovation and Infrastructure), Goal 12 (Responsible Consumption and Production), and Goal 13 (Climate Action), positioning energy management as a key factor in advancing global sustainability.

The energy diagnosis conducted before the implementation of an energy management system is fundamental for identifying significant energy uses, establishing baselines, and defining energy performance indicators that guide improvement strategies. In sectors such as water treatment, successful applications of the ISO 50001 standard have been documented, showing substantial efficiency improvements, although with limitations related to the lack of detailed descriptions of the diagnostic phase (5). In the food processing industry, the adoption of the standard has enabled the structuring of processes through the identification and control of significant energy uses, supporting its feasibility for other processing sectors such as coffee production (4, 6). However, within the Latin American context, there is a scarcity of studies that specifically document the diagnostic stage in companies dedicated to coffee processing, which represents an opportunity to generate knowledge that is both applicable and replicable in the sector.

From an engineering perspective, this work contributes a structured diagnostic framework that integrates energy baselining, energy performance indicators, and scenario-based projections within the context of ISO 50001. The proposed approach supports data-driven decision-making prior to system implementation and provides industrial engineers with a quantitative tool to prioritize energy efficiency actions, evaluate technological alternatives, and plan future investments in agro-industrial facilities.

The objective of this study is to present a structured energy diagnosis in a coffee processing agro-industrial company located in Costa Rica, to identify critical consumption areas, evaluate the initial level of compliance with the requirements of the ISO 50001 standard, and propose preliminary guidelines that serve as a foundation for continuous improvement. Although the implementation phase is not addressed in this work, the diagnosis conducted provides strategic information for decision-making and establishes a solid basis for progress toward energy efficiency and business sustainability. Additionally, this case study offers a useful reference for other organizations in the

doi: 10.25100/iyc.v28i2.15642

agro-industrial sector that are interested in transitioning toward production systems that directly contribute to the Sustainable Development Goals.

This study represents a unique contribution to the Latin American coffee sector by providing a detailed documentation of the diagnostic phase in accordance with ISO 50001:2018.

Methodology

This study was conducted under the continuous improvement philosophy established by the ISO 50001 standard, which is based on the Plan-Do-Check-Act (PDCA) cycle (7). Since the scope of the research focused exclusively on the diagnostic phase, all activities were concentrated in the “Plan” stage, which includes the energy analysis, the identification of significant energy uses, the definition of performance indicators, and the development of preliminary improvement actions.

Figure 1 illustrates the structure of the PDCA cycle applied to energy management, where leadership constitutes the central axis that integrates the stages of planning, execution, verification, and improvement. This model enabled the organization and delimitation of the diagnostic process carried out in this study, leaving the “Do”, “Check”, and “Act” stages as future phases for the complete implementation of the energy management system in accordance with ISO 50001(7).

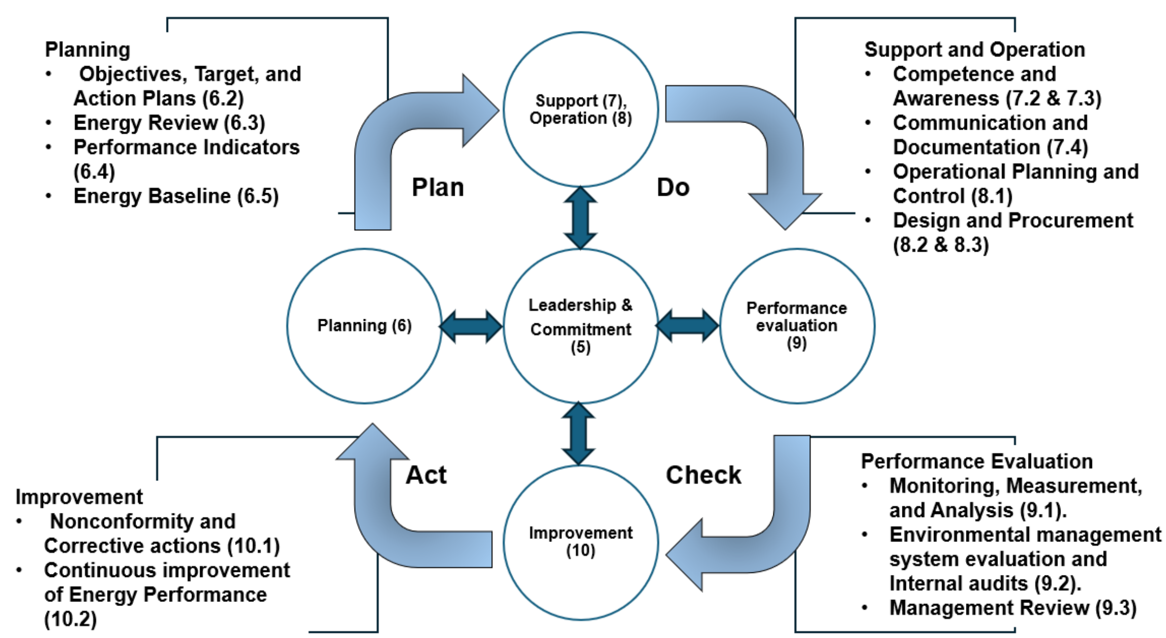

Figure 1. PDCA model applied to the energy diagnosis and future implementation of an energy management system in compliance with ISO 50001:2018. The figure illustrates the key phases and their interactions to sustain the continuous improvement of energy performance.

Studying Type

The research was carried out using a mixed methodology, integrating both quantitative and qualitative methods. A non-experimental cross-sectional design was applied, allowing the combination of historical energy consumption records with qualitative information obtained through interviews and questionnaires. This approach enabled a comprehensive diagnosis of the organization’s energy situation (8).

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Study Area

The diagnosis was conducted in an agro-industrial company dedicated to coffee processing, representative of the coffee sector in Latin America, and specifically located in Costa Rica. The organization operates under a cooperative model that involves hundreds of local producers, generating a significant economic and social impact in the region.

Its operations encompass the entire value chain, from the reception of raw material to the industrialization and commercialization of the final product in national and international markets.

The main processes include receiving and pulping the grain, fermentation and washing, drying, roasting, milling, packaging, and distribution. These stages are characterized by high energy consumption, particularly the drying, roasting, and internal transportation processes, which were identified as the most significant energy uses within the company.

The organization operates under an integrated management system that promotes quality, food safety, and sustainability, aligning with the Sustainable Development Goals, mainly Goal 7 (Affordable and Clean Energy), Goal 9 (Industry, Innovation and Infrastructure), and Goal 12 (Responsible Consumption and Production).

Due to confidentiality restrictions, specific names, locations, and exact production figures are omitted.

Figure 2 presents the general process flow of the coffee production line evaluated in this study.

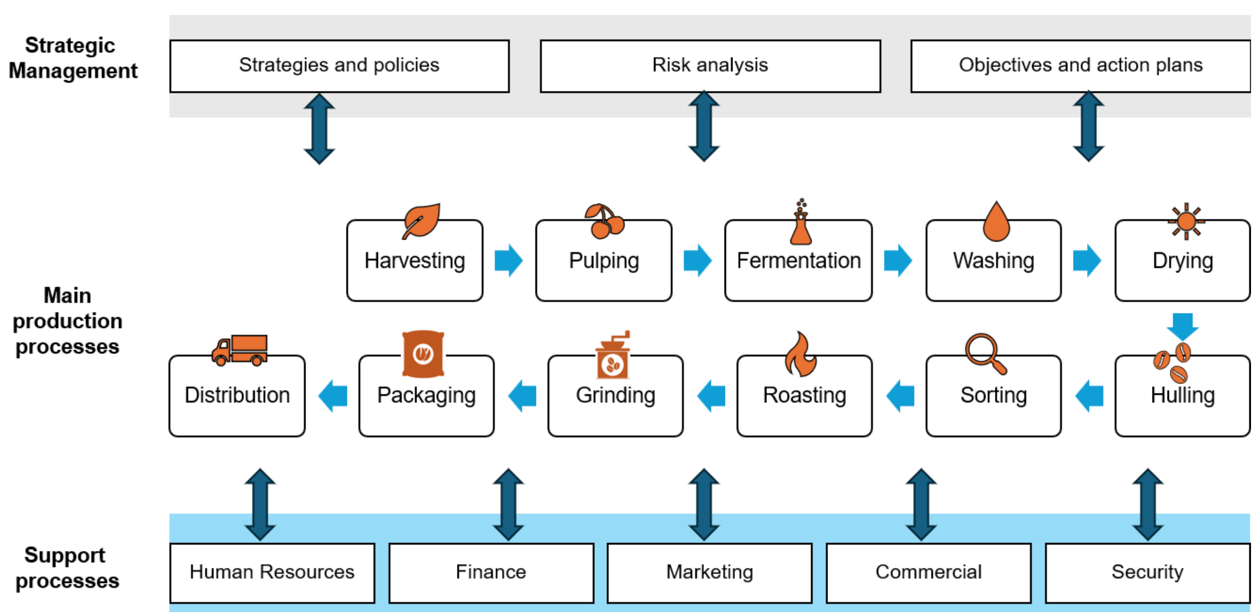

Figure 2. General process map of coffee production

Data Collection (Plan Phase)

Information gathering was conducted through three main lines of action:

a. Document analysis: review of internal policies and historical records of energy consumption

doi: 10.25100/iyc.v28i2.15642

(electricity, biomass, and liquefied petroleum gas) during the period 2021–2024.

b. Interviews and questionnaires: the instruments were validated through expert judgment and a pilot test with operational personnel.
c. Historical measurement and monitoring: collection of direct measurements and production reports to identify patterns of energy consumption.

Population and Sample

The study population consisted of both strategic and operational personnel of the company.

The sample was selected using intentional sampling, prioritizing individuals with direct knowledge of the energy-related processes and the operation of critical equipment:

Semi-structured interviews: conducted with eight personnel members responsible for administration, production, quality, and maintenance areas.

Questionnaires: applied to twenty-five operational workers, focused on identifying practices and perceptions regarding the use of energy.

Diagnostic Tools

Strengths, Weaknesses, Opportunities, and Threats (SWOT) Matrix**:** to identify internal and external factors affecting energy management (9).

Corrective, Adaptive, Maintenance, and Exploratory (CAME) Matrix**:** to structure improvement strategies based on the factors identified (9).

Energy performance indicators**:** selected in accordance with ISO 50001 for critical processes such as drying, roasting, and internal transportation.

Energy baseline**:** established using the average consumption from the past three years, considering periods of maximum productive activity.

Statistical Analysis

Projections and trend identification were carried out using linear regression and moving average techniques to estimate the expected behavior of future energy consumption. The comparison of energy performance indicators was based on metrics such as kilowatt-hours per fanega of processed coffee, liters of liquefied petroleum gas per kilogram of roasted coffee, and cubic meters of biomass per fanega.

The regression analysis was conducted using historical energy consumption data from the period 2020–2024, corresponding to five years of available and validated records. Although the dataset is limited in size, it is representative of the plant's operational conditions and allows the identification of general consumption trends. Data processing and analysis were performed using Microsoft Excel® for initial consolidation.

doi: 10.25100/iyc.v28i2.15642

In this context, the regression model is not intended to provide highly precise long-term predictions, but rather to support scenario-based analysis and strategic planning within the framework of ISO 50001. This approach is consistent with diagnostic studies, where the objective is to identify tendencies and potential improvement opportunities rather than to develop predictive models with high statistical complexity.

Projection Toward Future Phases

Although this study focuses exclusively on the Plan stage, the results obtained will serve as a basis for:

Do: implementation of corrective measures and personnel training.

Check: internal audits and verification of energy performance.

Act: continuous improvement actions based on feedback and results.

Results

Strategic Context and Energy Policy

The strategic analysis was carried out in two stages. The internal diagnosis was developed through semi-structured interviews with managers, personnel responsible for critical operational areas, and production staff. The external analysis was performed through the documentary review of corporate reports, national regulatory frameworks, and sectoral energy performance indicators.

The information collected was consolidated into a SWOT analysis to identify the internal and external factors influencing the current energy performance of the organization. Based on these elements, strategic actions were formulated during a participatory workshop with the management team using the CAME methodology. These sessions were facilitated by the research team and documented through meeting minutes and photographic records.

Table 1 presents the integrated SWOT–CAME synthesis, which links the diagnostic factors with strategic lines of action intended to guide the future implementation of an Energy Management System aligned with ISO 50001:2018. The commitments defined in the Energy Policy were evaluated against the requirements of the standard and demonstrate alignment with Sustainable Development Goals 7, 9, 12, and 13.

Table 1. SWOT–CAME synthesis for the energy management diagnostic.

SWOT Element	Strategic Action (CAME)
Weakness: Absence of real-time energy monitoring and incomplete documentation of consumption records.	**Correct (C)**: Implement real-time metering and standardized energy reporting supported by personnel training in ISO 50001 requirements.

doi: 10.25100/iyc.v28i2.15642

Weakness: Dependence on fossil fuels and firewood for thermal processes.	**Correct (C)**: Develop a transition roadmap toward renewable or hybrid thermal systems to reduce fuel dependency.
Opportunity: Availability of financial incentives and technological programs supporting energy efficiency.	**Adapt (A)**: Apply for external funding to support modernization projects and incorporate industrial automation tools for monitoring and control.
Opportunity: Growing global demand for sustainable certified products.	**Adapt (A)**: Strengthen environmental marketing strategies and position certification as a competitive advantage.
Strength: Existing Integrated Management System aligned with quality, safety, and environmental performance.	**Maintain (M)**: Integrate energy performance indicators into current management procedures and strengthen internal communication on sustainability.
Strength: Strong regional identity and social commitment.	**Maintain (M)**: Promote community sustainability programs and enhance corporate visibility through social responsibility initiatives.
Threat: Price volatility of fossil fuels and changes in regulatory requirements.	**Explore (E)**: Conduct feasibility studies on renewable energy alternatives and pilot energy recovery or storage projects.
Threat: Climate variability and production risks associated with coffee supply chains.	**Explore (E)**: Develop joint collaboration projects with universities and research institutions on climate adaptation and resilient production technologies.

Historical Energy Consumption (2020–2024)

To standardize the information, all records were limited to the period 2020–2024, which corresponds to the years with complete and verifiable data for electricity, liquefied petroleum gas, and biomass (Table 2).

The consumption records were obtained from utility bills, production reports, and internal energy inventory databases, all of which were verified by the company's certification department.

The electricity consumption shows a slightly upward trend until 2022, followed by a stabilization period. The liquefied petroleum gas consumption presents high variability, reflecting the fluctuating demand of the coffee roasting process. Firewood consumption remains at a moderate level, with small reductions attributable to improvements in thermal efficiency.

doi: 10.25100/iyc.v28i2.15642

Table 2. Historical energy consumption by source for the period 2020–2024.

Year	Electricity (kWh)	Liquefied Petroleum Gas (L)	Firewood (m^3)	Production (fanegas)
2020	305,800	2,672	1,402	38,000
2021	320,100	3,331	1,228	35,214
2022	358,000	2,753	1,527	40,032
2023	354,750	3,988	1,140	33,365
2024	340,200	1,762	1,240	36,579
Energy baseline average	335,770 kWh/year	2,901 L/year	1,308 m^3/ year	36,238 fanegas/year

Energy Performance Indicators and Definition of the Energy Baseline

The energy analysis of the production process enabled the establishment of energy performance indicators for each of the main stages of the system, considering the consumption of electricity, liquefied petroleum gas, and firewood during the period 2020–2024. These indicators were calculated in accordance with the methodology of the ISO 50001:2018 standard, which suggests relating energy consumption to the most representative production variables (fanegas, kilograms of processed coffee, or illuminated area) (7).

Calculation of Energy Performance Indicators

The energy performance indicators were obtained from the ratio between the energy consumed and the corresponding unit of production, using Equation 1:

$$IDE = \frac{E_c}{P} \quad (1)$$

where:

corresponds to the energy consumed in each stage (kilowatt-hours, liters, or cubic meters), and

corresponds to the amount of product or associated service (fanegas or kilograms of processed coffee).

The information was collected from electricity bills and internal records of fuel consumption, verified by maintenance personnel and the environmental

management department. The values were consolidated into equivalent units and standardized to the homogeneous period 2020–2024, considering the seasonality of coffee production (Table 3).

These indicators make it possible to identify the significant energy uses, highlighting drying and roasting as the most energy-intensive stages of the production process. This analysis constitutes the basis for defining efficiency measures and planning future energy audits.

doi: 10.25100/iyc.v28i2.15642

Table 3. Energy performance indicators

Area or process	Type of energy	Average annual consumption (2020–2024)	Production variable	Energy performance indicator
Pulping and fermentation	Electricity	7,000 kWh/year	800 fanegas	8.8 kWh/fanega
Washing and drying	Electricity + firewood	12,000 kWh + 1,200 m³/year	1,000 fanegas	0.036 m³/fanega
Roasting	Liquefied petroleum gas	3,200 L/year	42,000 kg of roasted coffee	0.075 L/kg
Lighting and infrastructure	Electricity	4,000 kWh/year	400 m² illuminated	10 kWh/m²
HVAC and offices	Electricity	3,000 kWh/year	—	18 kWh/m²

Definition of the Energy Baseline

The energy baseline represents the quantitative reference point of the organization's energy performance, from which future variations can be evaluated due to changes in efficiency or operational conditions.

According to ISO 50001:2018, section 6.4, the energy baseline must be determined using representative historical data and expressed in a common energy unit (7). In this study, the energy baseline was defined based on the annual average of total energy consumption during the period 2020–2024, considering the three main energy inputs used in the facility: electricity, liquefied petroleum gas, and firewood.

Conversion to Equivalent Energy (kilowatt-hours equivalent)

Since the energy inputs are measured in different physical units (kilowatt-hours, liters, and cubic meters), a conversion to kilowatt-hours equivalent was performed to enable comparison and aggregation of the consumptions.

The conversion factors were selected from technical references recognized by the United States Department of Energy and the Intergovernmental Panel on Climate Change (10, 11), and were adjusted to reflect the actual efficiency of use in the industrial processes (for example, the combustion efficiency of firewood). The conversion factors are presented in Table 4.

doi: 10.25100/iyc.v28i2.15642

Table 4. Conversion factors for energy equivalence

Energy source	Base unit	Calorific value (MJ/unit)	Equivalence (kWh eq/unit)	Efficiency used(η)	Reference
Electricity	1 kWh	—	1.00 kWh eq	1.00	Direct measurement
Liquefied petroleum gas	1 L	25.3 MJ/L	7.03 kWh eq/L	1.00	(10)
Tropical dry firewood	1 m³	6 000 MJ/m³	1 667 kWh eq/m³	0.20 – 0.25 (effective use)	(11)

For firewood, the conversion factor was reduced by applying the average thermal efficiency of the drying process (approximately 20–25%), so that the useful energy contribution is comparable to that of electricity or liquefied petroleum gas used in equivalent processes.

Calculation Methodology

The total annual energy consumption was calculated based on the methodology proposed by ISO 50006:2014, adapting the conversion factors from the guidelines of the United States Department of Energy and the Intergovernmental Panel on Climate Change (10, 11), according to Equation 2:

$$E_{total,eq} = E_{el} + (V_{GLP} \cdot 7.03) + (V_l \cdot 1667 \cdot \eta) \qquad (2)$$

where:

- : electricity consumption (kWh),
- : annual volume of liquefied petroleum gas (L),
- : annual volume of firewood (m³),
- : combustion efficiency of firewood (0.20–0.25).

The resulting values were expressed in kilowatt-hours equivalent for each year in the 2020–2024 period.

Finally, the energy baseline was defined as the average of total annual equivalent energy consumption for the period 2020–2024, following the guidelines of ISO 50001:2018 and ISO 50006:2014, as shown in Equation 3. The results are presented in Table 5.

$$LBE = \frac{\sum_{i=2020}^{2024} E_{total,eq,i}}{n} \qquad (3)$$

doi: 10.25100/iyc.v28i2.15642

Table 5. Total equivalent energy consumption per year

Year	Electricity (kWh)	Liquefied petroleum gas (L)	Firewood (m^3)	Total equivalent energy (kWh eq)
2020	305,800	2,672	1,402	320,600
2021	320,100	3,331	1,228	333,400
2022	358,000	2,753	1,527	349,900
2023	354,750	3,988	1,140	361,500
2024	340,200	1,762	1,240	356,000
Average (energy baseline)		—	— —	**344,200 kWh eq/year**

The value of 344,200 kWh eq/year is adopted as the organization's energy baseline. This value was smoothed through a simple moving average to reduce seasonal variability associated with the coffee harvesting cycle.

This procedure ensures traceability and consistency with ISO 50001 and ISO 50006 standards, providing a solid foundation for evaluating the impact of future energy efficiency actions.

The analysis reveals a slightly increasing trend in total energy consumption, mainly attributable to the rise in electricity and liquefied petroleum gas demand during 2022–2023.

The relative contribution to the energy baseline is approximately 88 percent electricity, 8 percent liquefied petroleum gas, and 4 percent firewood (useful energy). These results support prioritizing energy efficiency actions in drying, roasting, and lighting processes, which represent the highest reduction potential.

Initial ISO 50001 Compliance

A diagnostic questionnaire based on the relevant chapters of the ISO 50001:2018 standard (Chapters 4 to 10) was applied to technical and management personnel, complemented by a documentary review. The overall compliance level (approximately 28 percent) indicates that the organization remains in the planning stage of the continuous improvement cycle, reflecting partial progress toward the structuring of the energy management system. The main gaps were identified in planning, support, performance evaluation, and continuous improvement requirements.

The overall ISO 50001 compliance percentage was calculated as the arithmetic mean of the compliance scores obtained for the seven evaluated chapters of the standard (Chapters 4 to 10). Each chapter was assessed using a qualitative percentage scale ranging from 0 to 100 percent, where 0 percent indicates absence of evidence of compliance and 100 percent represents full implementation of the corresponding requirements. Intermediate values were assigned based on the availability of documented evidence, the degree of operational implementation, and alignment with ISO 50001:2018 guidelines. All chapters were considered with equal weighting, as the objective of this study was to perform an initial diagnostic assessment rather than a certification audit.

doi: 10.25100/iyc.v28i2.15642

Instrument Validation

The diagnostic questionnaire was validated through expert judgment and a pilot test. The validation process involved three specialists in energy management and quality systems, who evaluated clarity, relevance, and alignment of the ten items corresponding to the chapters of ISO 50001:2018, achieving more than 85 percent concordance. Subsequently, a pilot test was conducted in January 2024 with a small group of technical personnel, which allowed adjustments to item wording and ensured content validity before final application.

The percentage of compliance by chapter is presented in Table 6.

Table 6. ISO 50001 compliance radar

ISO 50001 Chapter	Compliance (%)	Main evidence
4. Context	40 %	Organizational chart, process description
5. Leadership	35 %	Energy policy and management review
6. Planning	25 %	Lack of formal energy review
7. Support	22 %	Lack of instruments and training
8. Operation	41 %	Partially documented procedures
9. Performance evaluation	20 %	No energy audits
10. Improvement	15 %	No records of corrective actions

Distribution of Electricity Consumption by Area (2023)

The analysis of electricity consumption distribution by area is a fundamental step within the diagnostic phase established by the ISO 50001 standard, because it allows the identification of significant energy uses and the definition of intervention priorities. Evaluating the consumption distribution beginning in 2023 was considered strategic, since this period represented a stable productive operation after the pandemic, with more consistent energy records and fully active processes across all production lines.

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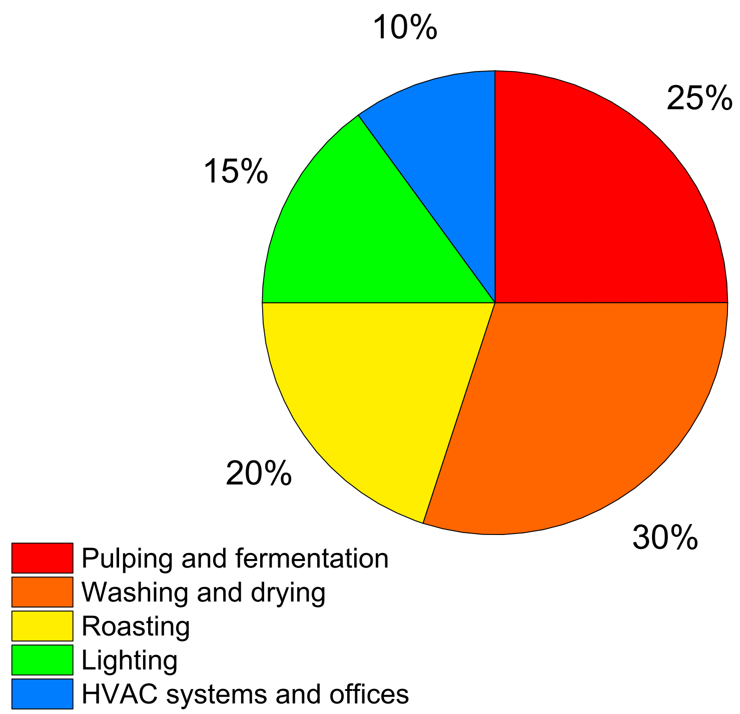

Figure 5. Percentage distribution of electricity consumption by area in 2023

During the technical visits to the facility, a detailed survey of the installed electrical load was conducted for each stage of the process, including pulping, fermentation, washing, drying, roasting, lighting, and heating, ventilation, and air-conditioning systems. This information was complemented by operational personnel interviews, partial utility bill review, and direct observation of daily operations. The collected data enabled the estimation of the monthly and daily distribution of electricity consumption by process stage. The detailed values are presented in Table 7, while Figure 5 illustrates the proportional contribution of each area to the total electricity demand, facilitating the identification of significant energy uses under an ISO 50001 approach.

Table 7. Electricity consumption distribution by process area in 2023.

Area	Estimated kWh/month	Estimated kWh/day
Pulping and fermentation	7,096.5	236.55
Washing and drying	8,515.8	283.86
Roasting	5,677.2	189.24
Lighting	4,257.9	141.93
HVAC systems and offices	2,838.6	94.62
Total	28,386	946.2

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The results show that approximately 50 percent of the total electricity consumption is concentrated in the washing, drying, and roasting processes, which involve the highest use of thermal equipment and high-power electric motors. This concentration of energy demand confirms the need to consider these areas as significant energy uses within the future energy management system, directing improvement strategies toward motor optimization, heat recovery, and the automation of thermal controls.

Additionally, having a disaggregated baseline of energy consumption by area facilitates inter-annual benchmarking, the calculation of specific energy performance indicators (kilowatt-hours/unit processed), and the monitoring of the effectiveness of the efficiency measures implemented as a result of this diagnosis.

Energy Projections for the Period 2025–2027

The prospective analysis of energy consumption constitutes an essential tool within the energy management framework established by ISO 50001:2018, as it enables anticipating demand trends, planning investments, and estimating the impact of efficiency measures. The projection of energy demand provides a quantitative overview of the expected behavior of energy resources under different scenarios and serves as the basis for defining future objectives of the energy management system and updating the energy baseline (7, 12).

As described in Section 2.5, the regression model was developed based on historical data from 2020–2024. To estimate the evolution of energy consumption during the period 2025–2027, linear regression models were applied to the unified historical data from 2020–2024. Three contrasting scenarios were developed to evaluate different levels of intervention in energy efficiency:

1. Conservative scenario: assumes moderate annual growth of 3 percent, maintaining current operating conditions.
2. Trend scenario: reflects the linear projection of historical trends from 2020–2024, without the application of efficiency measures.
3. Efficiency scenario: incorporates a progressive annual reduction of 5 percent, considering lighting replacement, electric motor control, and improved thermal insulation during coffee drying.

The regression model used for energy demand projection was evaluated using the coefficient of determination (R^2), which showed an acceptable level of fit, indicating that the model adequately captures the general trend of energy consumption over time.

Given the diagnostic nature of this study, the model was not intended for predictive optimization but rather for scenario-based analysis. Therefore, the projections are considered suitable for supporting strategic decision-making and identifying potential energy efficiency improvements, rather than for high-precision forecasting.

These projections are based on the general linear trend Equation 4:

$$E_t = E_{2024} + (t - 2024) \cdot \Delta E \tag{4}$$

where is the projected energy consumption for year , and represents the average annual change calculated from the baseline period (2020–2024).

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The consolidated results of the projections for the three main energy resources are presented in Table 8, while Figure 6 illustrates their expected behavior under different energy management scenarios for the period 2024–2027.

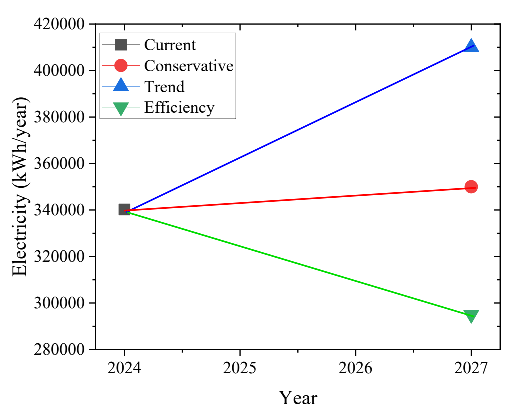
The projections indicate that, if current operating conditions are maintained (trend scenario), total energy consumption is expected to increase by between 18 and 22 percent by 2027, primarily due to rising electricity demand in the drying and roasting processes.

In contrast, under the efficiency scenario, which considers a systematic annual reduction of 5 percent, total consumption could decrease by approximately 13 percent compared with the 2024 base level. This reduction would represent an approximate decrease of 45,000 kWh/year, equivalent to an estimated mitigation of about ≈16 tons of CO_2 equivalent per year, considering an average emission factor of 0.36 kg CO_2/kWh (13). This result highlights the direct relationship between energy efficiency measures and the reduction of environmental impact, reinforcing the role of energy management as a key strategy for mitigating greenhouse gas emissions in agro-industrial processes.

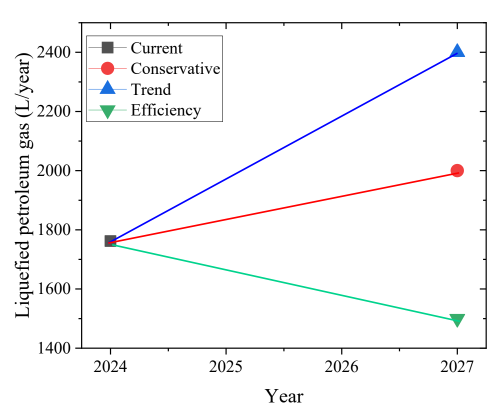
Table 8. Energy projection scenarios for the period 2025–2027

Energy source	Current 2024	Conservative 2027	Trend 2027	Efficiency 2027
Electricity (kWh/year)	340,200	350,000	410,000	295,000
Liquefied petroleum gas (L/year)	1,762	2,000	2,400	1,500
Firewood (m^3/year)	1,240	1,250	1,350	1,100

Therefore, the efficiency scenario aligns not only with the principles of continuous improvement promoted by ISO 50001 but also with Sustainable Development Goals 7, 9, and 13, by promoting responsible energy use and reducing emissions associated with the energy matrix.



a)



b)

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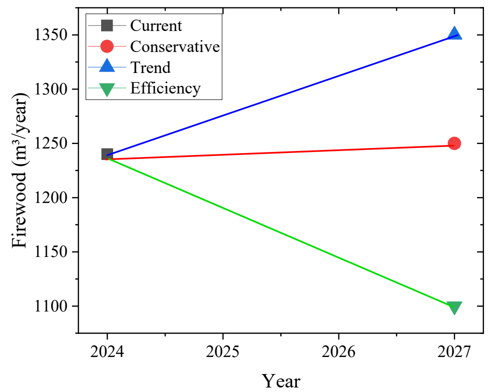

c)

Figure 6: Energy consumption projections under three scenarios for the period 2024–2027: (a) electricity (kWh/year), (b) liquefied petroleum gas (L/year), and (c) firewood (m^3/year). The trend scenario indicates an expected increase in energy demand, particularly due to thermal and mechanical processes, while the efficiency scenario suggests a progressive reduction associated with the implementation of systematic energy management measures aligned with ISO 50001.

Discussion

Interpretation of results and comparison with previous studies

The diagnostic results show that significant energy uses are concentrated in thermal processes such as drying and roasting, and that electricity dominates the annual energy demand (approximately 88 percent), with liquefied petroleum gas and firewood making smaller contributions. This pattern is consistent with sectoral evidence for the food and beverage industries, where process heat demand (sensible and latent heat) together with electric auxiliary equipment (grinding, ventilation, conveying, and control) explains most of the consumption. In fact, for the food industry, a taxonomy of end uses has been proposed to map processes, energy services, and indicators, which facilitates the prioritization of efficiency measures in line with high thermal loads such as drying or roasting (14).

Beyond the specific results obtained for the coffee agroindustry, the engineering value of this study lies in the integration of energy diagnostics, performance indicators, and forward-looking projections into a single analytical framework. This approach transforms descriptive energy data into actionable engineering information, enabling systematic prioritization of significant energy uses and supporting the design of technically feasible efficiency strategies.

The established energy baseline (344,200 kWh eq/year) and the energy performance indicators follow the recommendations of ISO 50006, which calls for linking energy performance indicators to relevant process variables and documenting their traceability for the monitoring and verification of improvements. In this sense, the explicit use of equivalent units and the normalization of energy performance indicators make it possible to compare periods with different fuel mixes and operating conditions, which is essential in agro-industries with marked seasonality (12).

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In terms of improvement potential, our conservative projection of a 10% to 15% reduction over three years aligns with ranges reported for the first iteration of the PDCA cycle in energy management systems. Compilations of ISO 50001 case studies (manufacturing and food sectors) in initiatives such as Better Buildings and studies of multinational companies (for example, 3M) document sustained savings from the high single digits to the low double digits after systematic implementation of the energy management system and internal audits. This supports the plausibility of 10% to 15% targets when accompanied by a clear roadmap and appropriate measurement and verification practices (15, 16).

Methodologically, the calculations and analyses conducted in measurement, indicators, and continuous improvement are consistent with the evolution of the standard: since the 2018 revision, ISO 50001 and the ISO 50006 guide emphasize a robust architecture of energy performance indicators and their integration with management tools to close performance gaps. Recent literature also shows that synergies with operational excellence approaches—such as Lean Six Sigma—can accelerate the identification of energy losses and standardize process controls, thereby increasing the effectiveness of the energy management system in industrial environments (4).

With respect to the coffee sector, recent studies explore complementary strategies to decarbonize roasting and associated processes—for example, optimization based on activity-based costing with a focus on emissions by roasting profile, and the integration of thermal energy storage for instant coffee plants (17, 18). Although these approaches differ from an energy management system, they reinforce two messages that are directly useful in this case:

Energy management should be closely aligned with process design (recipes, thermal profiles, and the fuel–electricity mix), and Electrification and the recovery and storage of heat open additional margins for reducing energy consumption and carbon dioxide emissions.

These lines of evidence justify the prioritization of drying and roasting as significant energy uses and suggest concrete technological pathways for future phases of the plan.

Regarding small and medium-sized agro-industrial enterprises, typical barriers—such as limited technical capacity, fragmented data, and capital constraints for technological upgrades—condition the pace of improvement. Nevertheless, recent reports on energy efficiency in small and medium-sized enterprises indicate that explicit frameworks for the governance of energy data and decision-making based on transparent energy performance indicators improve the adoption of measures and their persistence over time, in line with the architecture proposed by this diagnosis (19).

Limitations and Implications

This study is limited to the diagnostic stage (Plan), meaning that the projected savings are estimates and depend on effective implementation (Do–Check–Act) and on the quality of measurement practices. In addition, the conversion of biomass (firewood) to kilowatt-hours equivalent introduces uncertainty due to variability in calorific value and efficiency. This uncertainty is mitigated by the use of conservative factors, although literature recommends complementing this approach with in-situ measurements and thermal balances in critical stages of the process. Nevertheless, this case study provides:

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Normalized energy performance indicators and a reproducible energy baseline consistent with ISO 50006. A clear prioritization of significant energy uses in thermal coffee processes.

A quantified pathway with realistic and verifiable savings targets, aligned with technological transitions already being explored in the sector (electrification and thermal storage) (14, 18).

However, the absence of full implementation does not reduce the engineering validity of the proposed diagnostic framework. On the contrary, the methodology is intentionally designed to support technical decision-making prior to capital-intensive interventions, reducing uncertainty and improving the effectiveness of subsequent implementation stages.

Practical and Energy Policy Implications

The results of the energy diagnosis in the coffee agro-industry offer relevant practical implications for the design and implementation of energy management systems in small and medium-sized agro-food companies in Latin America. First, the methodological structure based on ISO 50001:2018 demonstrates its replicability in production contexts dominated by thermal processes such as drying, roasting, or pasteurization, provided that energy performance indicators are adapted to local variables such as seasonality or fuel type. This is consistent with documented experiences showing the feasibility of the Plan–Do–Check–Act approach even in facilities with basic infrastructure, as long as measurement, personnel training, and operational awareness are prioritized (15, 16).

From an industrial and operational perspective, the findings allow the establishment of an internal energy efficiency roadmap in the short and medium term. The calculation of the energy baseline and the prioritization of significant energy use constitute tools that enable companies to define verifiable targets, justify investments in technological upgrades (such as electrification or heat recovery systems), and support action plans within a continuous improvement framework. In this regard, the National Commission for the Efficient Use of Energy (CONUEE) in Mexico has reported that the application of ISO 50001 systems contributes to sustained savings of 5 to 20 percent in manufacturing and service sectors, reinforcing the relevance of implementing these mechanisms in regional agro-industries (20). At the level of public policies and sectoral programs, the replicability of this type of energy diagnosis is directly aligned with Sustainable Development Goals 7, 9, 12, and 13, promoting responsible energy use, technological innovation, and climate change mitigation. The National Strategy for Energy Transition and Sustainable Use of Energy in Mexico (21) and the regional guidelines of the Community of Latin American and Caribbean States (22) suggest that energy policies should include tax incentives, access to green financing, and voluntary certification schemes for small and medium-sized enterprises adopting energy management systems, facilitating their adoption in low-technology agro-industrial sectors.

In addition to the operational and economic benefits, the projected reduction in energy consumption is directly associated with a measurable decrease in CO_2 equivalent emissions. This reinforces the role of energy management systems not only as tools for improving efficiency but also as strategic mechanisms for reducing the environmental footprint of agro-industrial activities. In this context, the integration of energy performance indicators with environmental impact metrics strengthens decision-making processes aligned with sustainability goals.

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Finally, the results also identify opportunities for inter-institutional cooperation among universities, government agencies, and companies, particularly in relation to training and certification of energy managers. The creation of learning networks on energy efficiency—such as those promoted in Europe and replicated by the United Nations Industrial Development Organization in Latin America—may accelerate the diffusion of ISO 50001-based models in agro-food value chains. Together, these actions strengthen an integrated approach to energy management, sustainability, and competitiveness, enhancing both productive resilience and decarbonization in the Latin American primary sector.

Conclusions

The energy diagnosis conducted in the coffee processing company provided a comprehensive understanding of the current energy performance and the improvement opportunities within the framework of ISO 50001:2018. The results show that the significant energy uses, particularly the drying and roasting stages, account for more than 50% of the total electricity consumption, making them priority areas for the implementation of efficiency measures.

Normalized energy performance indicators were defined, and an average annual energy baseline of 344,200 kWh eq/year was established, which will serve as a reference point for the monitoring and evaluation of future consumption. The initial level of compliance with ISO 50001 was approximately 28%, placing the organization in the Plan phase of the PDCA cycle, with strengths in leadership and documentation control but with opportunities for improvement in planning, support functions, and performance evaluation.

Based on the results obtained, the full implementation of the energy management system could reduce energy intensity by between 10% and 15% over the next three years. This would represent an approximate saving of 45,000 kWh/year and a reduction of nearly 16 tons of CO_2 equivalent annually, considering an emission factor of 0.36 kg CO_2/kWh.

A key limitation of the study is that the analysis focused exclusively on the diagnostic phase and relied on historical consumption records whose accuracy depends on internal measurement systems. However, the findings constitute a solid basis for planning energy audits and corrective actions within the Do–Check–Act cycle as part of continuous improvement.

Finally, it is recommended to move toward the automation of energy monitoring, the progressive substitution of fossil fuels with renewable alternatives, and the training of personnel in energy efficiency. The methodological model developed in this study can be replicated in other Latin American agro-industrial sectors, strengthening competitiveness and contributing to Sustainable Development Goals 7, 9, 12, and 13 through the transition toward sustainable and resilient energy management.

Furthermore, the proposed approach contributes not only to improving energy efficiency but also to reducing the environmental impact of the production process, particularly through the mitigation of CO_2 equivalent emissions, supporting the transition toward more sustainable and resilient agro-industrial systems.

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References

1. Pandin M, Sumaedi S, Yaman A, Ayundyahrini M, Supriatna NK, Hesty NW. ISO 50001 based energy management system: a bibliometric perspective. Int J Energy Sect Ma. 2024;18(6):1938-63. doi: 10.1108/Ijesm-08-2023-0001.

https://doi.org/10.1108/IJESM-08-2023-0001

2. Alotaibi S, Alogaili H, Alawwad K, Aljarallah S. The Environmental and Business Benefits of Implementing the ISO 50001 Energy Management System in Government Buildings: A Case Study of the Saudi Standards, Metrology and Quality Organization (SASO). 2025;17(11):5131.

https://doi.org/10.3390/su17115131

3. Fuchs H, Therkelsen P, Miller WC, Siciliano G, Sheaffer P. ISO 50001-Based Energy Management Systems as a Practical Path for Decarbonization: Initial Findings from a Survey of Technical Assistance Cohort Participants. 2023;16(14):5441.

https://doi.org/10.3390/en16145441

4. Trubetskaya A, McDermott O, McGovern S. Implementation of an ISO 50001 energy management system using Lean Six Sigma in an Irish dairy: a case study. The TQM Journal. 2023;35(9):1-24. doi: 10.1108/TQM-08-2022-0252 %J The TQM Journal.

https://doi.org/10.1108/TQM-08-2022-0252

5. Arabeyyat OS, Ragha LA. The use of energy management ISO 50001 to increase the effectiveness of water treatment plants: An application study on the Zai water treatment plant. MethodsX. 2024;12:102661. doi: https://doi.org/10.1016/j.mex.2024.102661.

https://doi.org/10.1016/j.mex.2024.102661

6. Stephen MS, Valsalan SA. Energy efficiency and ISO 50001:2018 implementation in seafood processing industries: A comprehensive analysis and strategic framework. Clean Energy Syst. 2025;10:100173. doi: 10.1016/j.cles.2025.100173.

https://doi.org/10.1016/j.cles.2025.100173

7. International Organization for Standardization. ISO 50001:2018. Energy management systems - Requirements with guidance for use. Geneva, Switzerland2018.

https://www.iso.org/standard/69426.html

8. Yin Robert K. Case study research and applications: Design and Methods. Sixth Edition. United Kingdom: SAGE Publications, Inc.; 2017.

https://www.google.com.mx/books/edition/Case_Study_Research_and_Applications/6DwmDwAAQBAJ?hl=es-419&gbpv=0

9. Vega MAV, Peña DR. Procedimiento para la identificación de los factores internos y externos que definen el contexto de la organización según norma ISO 50001. Opuntia Brava. 2022;14(3):344-58.

https://research.ebsco.com/plink/6abd578c-a276-3d6f-8698-642669a0a279

10. U.S. Department of Energy: Energy performance baseline guide. (2021)

https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-05-chg1-admchg/@@images/file

11. IPCC: IPCC Guidelines for National Greenhouse Gas Inventories. (2006).

https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

12. International Organization for Standardization: ISO 50006:2023. Energy management systems — Evaluating energy performance using energy performance indicators and energy baselines. (2023)

https://www.iso.org/standard/79367.html

13. IEA: CO2 Emissions in 2023.

https://www.iea.org/reports/co2-emissions-in-2023

doi: 10.25100/iyc.v28i2.15642

14. Kanchiralla FM, Jalo N, Thollander P, Andersson M, Johnsson S. Energy use categorization with performance indicators for the food industry and a conceptual energy planning framework. Applied Energy. 2021;304:117788.

https://doi.org/10.1016/j.apenergy.2021.117788

15. Clean Energy Ministerial: ISO 50001 Energy Management System - Case Study 3M Company. (2022).

https://www.cleanenergyministerial.org/content/uploads/2022/09/cem-em-casestudy-3m-global.pdf

16. Clean Energy Ministerial: Energy Management Case Studies | Better Buildings Initiative. (2022)

https://www.cleanenergyministerial.org/content/uploads/2022/09/cem-em-casestudy-3m-global.pdf

17. Tsai W-H, Lee K-H, Huang C-C. Energy Efficiency and Carbon Emission Reduction in Coffee Roasting: Approach of Activity-Based Costing (ABC) Methodology. 2025;18(5):1018.

https://doi.org/10.3390/en18051018

18. Olmedilla Ishishi H, Laukkanen T, Syri S. Energy assessment of the integration of seasonal thermal energy storage in an instant coffee production plant. Case Studies in Thermal Engineering. 2025;75:107238. doi: https://doi.org/10.1016/j.csite.2025.107238.

https://doi.org/10.1016/j.csite.2025.107238

19. Gennitsaris S, Oliveira MC, Vris G, Bofilios A, Ntinou T, Frutuoso AR, et al. Energy Efficiency Management in Small and Medium-Sized Enterprises: Current Situation, Case Studies and Best Practices. 2023;15(4):3727.

https://doi.org/10.3390/su15043727

20. CONUEE: Informe Anual de Avances en Eficiencia Energética 2023.

https://www.gob.mx/conuee/documentos/informe-de-actividades-de-la-conuee-2023

21. SENER: Estrategia Nacional de Transición Energética y Aprovechamiento Sustentable de la Energía 2020-2030. (2020)

https://www.gob.mx/sener/documentos/estrategia-nacional-de-transicion-energetica-y-aprovechamiento-sustentable-de-la-energia

22. CELAC: Plan de Acción Regional para la Transición Energética Justa y Sostenible 2022-2030. (2022)

https://www.cepal.org/es/enfoques/integracion-energetica-transicion-justa-america-latina-caribe-oportunidades-desafios-2050

doi: 10.25100/iyc.v28i2.15642