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Energy efficiency in industry starts with the team that operates the plant, not with the purchase of new equipment.

Industrial energy efficiency starts with the team that operates the plant rather than with the purchase of new equipment

Energy efficiency in industry begins with the equipment that operates the plant and not with the purchase of new equipment

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ABSTRACT

Industrial energy efficiency is often associated with equipment replacement and the adoption of new technologies. However, the literature on the so-called energy efficiency gap demonstrates that a significant portion of the potential for savings depends on organizational, managerial, and behavioral factors, including how facilities are operated and maintained.

This article aims to discuss the role of operation and maintenance teams in improving the energy performance of process plants, with an emphasis on the chemical, petrochemical, and energy sectors. The research adopts a qualitative approach, based on a narrative review of the scientific literature and an analysis of technical standards and documents from international organizations. The discussion covers non-technological barriers to efficiency, energy management systems, continuous improvement, reduction of process variability, asset reliability, tacit knowledge of operators, and the multiple benefits of efficiency measures. The results indicate that operational practices, maintenance routines, technical competence, and indicators incorporated into daily work condition energy performance as much as the installed technology. It is concluded that investments in equipment produce limited results when they are not accompanied by structured management and training of the teams that make operational decisions daily.

Keywords: Energy efficiency; Energy management; Continuous improvement; Asset reliability; Process industry.

ABSTRACT

Industrial energy efficiency is commonly associated with equipment replacement and the adoption of new technologies. The literature on the so-called energy efficiency gap shows, however, that a relevant share of the savings potential depends on organizational, managerial and behavioral factors, including the way facilities are operated and maintained. This article discusses the role of operations and maintenance teams in improving the energy performance of process plants, with emphasis on the chemical, petrochemical and energy sectors. The research follows a qualitative approach, based on a narrative review of the scientific literature and on the analysis of technical standards and documents from international organizations. The discussion covers non-technological barriers to efficiency, energy management systems, continuous improvement, the reduction of process variability, asset reliability, operators' tacit knowledge and the multiple benefits of efficiency measures. The findings indicate that operating practices, maintenance routines, technical competence and indicators embedded in daily work shape energy performance as much as the installed technology. The study concludes that investments in equipment yield limited results when they are not accompanied by structured management and by the training of the teams that make operational decisions every day.

Keywords: Energy efficiency; Energy management; Continuous improvement; Asset reliability; Process industry.

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1 INTRODUCTION

The industry is among the world's largest energy consumers, and the chemical,
Petrochemical and refining industries are among the most intensive in this respect, as they depend on large amounts of energy.
Quantities of heat, steam, electricity, and fuels used to convert raw materials into products.
For a long time, the debate on energy efficiency in these sectors has focused on solutions.
technological advancements, such as high-efficiency motors, more efficient heat exchangers, and systems of
Cogeneration and thermal integration of processes. Abdelaziz, Saidur and Mekhilef (2011), in a review on
Energy saving strategies in the industrial sector have shown that these solutions coexist with
measures of a managerial and public policy nature, whose contribution to the final result usually
It receives less attention than the acquisition of new equipment.
Since the work of Jaffe and Stavins (1994), the economic literature has recorded the existence of a
persistent difference between the energy efficiency potential considered economically viable and
that which is actually carried out by companies. The problem that guides this study concerns
A portion of this potential does not depend on the purchase of technology, but on the way plants are grown.
are operated, maintained, and managed on a daily basis. Backlund et al. (2012) argued that the
Including energy management practices significantly expands the potential for savings, and
This finding supports the hypothesis that operations and maintenance teams occupy a position
crucial for industrial energy performance.
The objective of this article is to discuss, based on scientific literature, technical standards, and...
documents from international organizations, such as organizational factors, improvement methods
Continuous control of variability, asset reliability, and operational knowledge.
They influence energy efficiency in process plants. The text is organized into seven sections.
development, which deals with non-technological barriers, energy management, and improvement
continuous, process variability, asset reliability, tacit knowledge and
Multiple benefits of efficiency, followed by the conclusion.

2 METHODOLOGY

The research is characterized as qualitative, exploratory, and descriptive in nature, and was conducted by
A narrative literature review method combined with document analysis. The choice of narrative review.
This is justified by the interdisciplinary nature of the topic, which draws on contributions from chemical engineering,
from production engineering, energy economics, maintenance management and psychology

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organizational. This type of review does not intend to be exhaustive of the available scientific production nor estimating aggregate effects through statistical procedures, but it allows for the grouping of works from Reference, compare their arguments, and construct an articulate interpretation of the relationship between Operational practices and energy performance in industrial facilities.

The literature review considered databases with broad coverage in the field, such as Scopus, ScienceDirect and Web of Science, in addition to the reference lists of seminal studies, procedure which allowed for the identification of works frequently cited in subsequent reviews. The following were used descriptors in English and Portuguese, including energy efficiency gap, industrial energy management, barriers to energy efficiency, continuous improvement, total productive maintenance, tacit knowledge, industrial energy efficiency, and energy management. Articles published in were prioritized. peer-reviewed journals such as Energy Policy, Journal of Cleaner Production, Renewable and Sustainable Energy Reviews, Energy and Journal of Operations Management, as well as books by References recognized by the academic community.

The document analysis encompassed technical standards and publications from governmental bodies and international standards were examined. The ABNT NBR ISO 50001 standard, which establishes requirements for energy management systems, the ISO 50006 standard, which guides the construction of baselines and Energy performance indicators, the International Energy Agency's report on the Multiple benefits of energy efficiency and technical guidelines published by government agencies The United States has been studying steam systems and the integration of lean production and energy. These studies... The documents were selected for their institutional legitimacy and public availability. because of the influence they exert on practices adopted in the industry.

The collected material was subjected to analytical reading and organized into thematic categories, namely, the Non-technological barriers to energy efficiency, energy management systems, improvement continuous process variability, asset reliability, tacit knowledge, and Automation and the multiple benefits of efficiency measures. One recognized limitation is... the non-exhaustive nature of the narrative review, as well as the predominance of studies conducted in Europe and North America. Some of the evidence comes from distinct industrial sectors of chemical industry, which calls for caution in generalizing the results and indicates the need for Specific empirical studies in continuous process plants.

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3. The Energy Efficiency Gap and the Barriers That Are Not TECHNOLOGICAL

Jaffe and Stavins (1994) systematized the concept of the energy efficiency gap by discussing by that technologies that appear to be economically advantageous are not adopted on a large scale predicted by engineering analyses. The authors distinguished different notions of optimal level of efficiency, depending on whether only market failures that can be corrected by policies are considered. public factors, as well as factors such as hidden costs, heterogeneity among consumers, and uncertainty. This distinction showed that part of the gap can be explained by elements that the calculations of Engineering doesn't capture this, and it opened up space for investigations into the mechanisms that prevent it. realization of potential within the organizations themselves.

Sorrell et al. (2004) further explored this discussion in a study on barriers to investment in Energy efficiency in European organizations. The authors proposed a classification that includes risk, imperfect information, hidden costs, access to capital, divided incentives and rationality limited, and examined the problem from three complementary theoretical perspectives, the economic, behavioral, and organizational. The central contribution of the study was to demonstrate that the barriers do not act in isolation and that factors such as the position of energy in the structure of The company's power, the available managerial attention, and established routines influence decisions. as much as the calculated profitability of the projects.

Cagno et al. (2013) proposed a taxonomy that distinguishes external barriers, associated with market, to suppliers, to the government and to financial institutions, of internal barriers, classified as economic, behavioral, organizational, competency-based, and awareness-based. The separation between these groups has practical value, as it indicates that many of the difficulties faced because companies are under their own control. Trianni and Cagno (2012), in an empirical study with Small and medium-sized industrial companies showed that the perception of barriers varies according to... the characteristics of companies and that, in addition to access to capital, factors related to information and... Internal technical skills influence the identification and implementation of opportunities for efficiency.

Fleiter, Worrell, and Eichhammer (2011) examined how energy demand models Bottom-up industrial models represent barriers to efficiency. The authors found that these models, widely used to estimate potential savings and guide public policies, They tend to address barriers in a simplified way, often through discount rates. high or generic restrictions on technological diffusion. This simplification leads to estimates that

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They describe what would be technically possible, but provide little information about the conditions. organizational structures are necessary for the potential to be realized, which reinforces the importance of to understand the internal processes of companies.

Backlund et al. (2012) advanced this debate by proposing the concept of the extended efficiency gap. The authors argued that traditional analyses primarily consider the energy. adoption of efficient technologies, while including energy management practices, such as Systematic monitoring of consumption, defining responsibilities, and changing routines. operational aspects reveal significant additional potential. This formulation shifts some of the attention from equipment to people and work processes, and supports the argument that a fraction The relevance of industrial energy efficiency depends on how the facilities are managed. in everyday life.

4. Energy Management as an Organizational Practice

The ABNT NBR ISO 50001 standard establishes requirements for organizations to implement, Maintain and improve energy management systems, based on the plan, do, check, and act cycle (Brazilian Association of Technical Standards, 2018). Among their...

The key elements include energy review, identification of significant energy uses, and definition. of energy performance indicators and baselines and the establishment of objectives and targets. The standard also requires that people whose work affects energy performance be competent and aware of the impact of their activities, a requirement that formally recognizes the The role of operational teams in the outcome achieved.

The ISO 50006 standard complements this framework by guiding the construction of baselines and... energy performance indicators (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 2014). The document emphasizes the need to standardize consumption in depending on the relevant variables that influence it, such as production volume and conditions. Climatic factors and raw material characteristics are taken into account, so comparisons over time are possible. reflect real performance changes and not just load variations. This guidance has This has a direct implication for operations, as poorly constructed indicators can attribute gains to the team. or losses resulting from factors external to their actions.

Schulze et al. (2016) conducted a systematic literature review on energy management in industry. and proposed an integrative conceptual model composed of five elements, namely, strategy and Planning, implementation and operation, control, organization and culture. By including the organization

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and culture among the elements of the model, alongside the technical and control dimensions, the authors
They acknowledged that energy performance also depends on accountability structures and...
shared values among employees. This formulation is relevant because it indicates that...
The existence of formal procedures does not, in itself, guarantee that energy performance is...
incorporated into the daily decisions of those who operate energy-consuming systems.
Palm and Thollander (2010) advocated an interdisciplinary perspective for the study of efficiency.
industrial energy, arguing that purely technical or economic approaches do not
They explain why companies with similar conditions show such different results. In the work
Later, Thollander and Palm (2013) gathered evidence on energy audits, management of
energy and public programs, and showed that the continuity of results depends on structures.
organizational structures that assign responsibility for energy, monitoring routines, and...
Commitment from senior management. In the absence of these elements, the savings obtained in audits
They tend to dissipate over time.
The synthesis of these contributions allows us to understand energy management as an organizational practice.
and not just as a set of engineering projects. In process plants, a large part of the
variables that determine consumption, such as operating temperatures, reflux ratios, excess of
Air pressure in furnaces, steam pressure, and equipment alignments are continuously adjusted by
Shift teams. The ABNT NBR ISO 50001 standard and the model by Schulze et al. (2016) converge.
indicating that efficiency only becomes sustainable when these decisions are guided by
Understandable indicators, clear goals, and feedback on the effect of each action on
energy performance.

5. Continuous Improvement and Combating Invisible Losses

The foundations of continuous improvement can be traced back to the work of Shewhart (1939), who proposed a cycle of
specification, production and inspection as a scientific learning process applied to quality.
later popularized as the plan, do, check, and act cycle. Deming (1986) expanded on this.
This formulation argued that most performance problems stem from the system of
work, the responsibility for which lies with management, and not with the individual conduct of the workers.
According to the author, improving results requires understanding the variation present in processes and creating the right conditions.
so that the people who work in them contribute with knowledge and initiative, a principle that...
This applies directly to energy use.
Imai (1986) popularized the concept of kaizen, understood as gradual, continuous improvement and

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involving all levels of the organization, in contrast to strategies based exclusively
in major technological innovations. Bessant, Caffyn and Gallagher (2001) investigated how the
The capacity for continuous improvement develops within companies, and they proposed an evolutionary model in...
which this capacity is built progressively, through learning and consolidation of
Specific behavioral routines. The authors showed that continuous improvement does not arise from...
The adoption of tools does not spontaneously occur, as it depends on practices that need to be cultivated.
Strengthened and integrated into the organization's strategy over time.
The Toyota production system, described by Ohno (1997), organized the elimination of waste in
revolving around categories such as overproduction, waiting, transportation, over-processing, inventories,
movement and defects. Womack and Jones (1996) synthesized this experience into the principles of
Lean thinking, focused on defining value, mapping the flow, and pull production.
and in the pursuit of perfection. Liker (2004) highlighted that the success of this model depends on principles such as
direct observation of the workplace and the development of the people involved, which provides
Frontline teams play an active role in identifying losses and proposing solutions.
Energy is not explicitly listed among the classic categories of wasted thought.
concise, although it's embedded in almost all of them. The guide published by the Protection Agency.
The United States Environmental Commission on the integration of lean production and energy observes that
Traditional improvement initiatives often generate energy savings, but attention must be paid to this.
Explicit disclosure of energy consumption allows for substantially greater gains (STATES)
(UNITED, 2007). The document proposes that energy use be incorporated into the mapping of
value stream and improvement events, so that teams begin to recognize consumption.
unnecessary as a loss that can be eliminated.
The transposition of these methods to the continuous process industry requires adaptation, as they
They were designed in discrete manufacturing contexts. In chemical and petrochemical plants, the
Energy losses take specific forms, such as steam released by faulty steam traps.
Damaged thermal insulation, excess air in the combustion chamber, overheating, and
Operating equipment without corresponding demand. The Department of Energy guide on
The United States' steam systems report describes several of these opportunities and emphasizes that many
These problems can be detected through periodic inspection, operational adjustments, and maintenance.
adequate, without the need for significant investments in new equipment (STATES)
UNITED, 2012).

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6. Process Variability, Six Sigma, and Advanced Control

Understanding variability is one of the fundamental principles of statistical process control.
Shewhart (1939) distinguished between common causes of variation, inherent in the system, and special causes.
associated with identifiable events, and this distinction remains central in contemporary literature.
Montgomery (2013) shows that control charts and capability analyses allow
to differentiate between these two sources and guide the appropriate corrective action for each. In chemical processes,
Variability in temperature, pressure, composition, and flow rate affects not only product quality,
but also the amount of energy needed to keep the operation within specifications.
The Six Sigma methodology, developed at Motorola and disseminated by companies such as General
Electric, was described by Harry and Schroeder (2000) as a management strategy oriented towards reducing
defects and variations in processes. His best-known roadmap organizes projects into stages of
Define, measure, analyze, improve, and control. Schroeder et al. (2008) analyzed the theoretical basis of
method and defined it as an organized structure, parallel to the formal hierarchy, intended to
reduce variation in processes through improvement specialists, a structured method and
performance metrics, with the goal of achieving the organization's strategic goals.
Linderman et al. (2003) examined Six Sigma in light of goal-setting theory and
They argued that the combination of specific and challenging goals and a structured method of
Problem-solving explains part of the observed effectiveness. The authors emphasized that very specific goals
Ambitious goals, when lacking method and training, can lead to frustration and...
Undesirable behaviors. This observation is relevant to energy management, as goals of
Consumption reductions are established without the teams having the necessary analysis and tools.
Autonomy to act on process variables tends to produce inconsistent results.
Advanced process control offers another way to reduce variability. Bauer and Craig (2008)
They conducted a survey among users and suppliers of this technology and proposed a
A benchmark for evaluating its economic benefits. The central mechanism described in the literature.
This involves reducing the dispersion of the controlled variables, which allows shifting the midpoint of
The operation moves closer to the process constraints without increasing the risk of violating them. Among the
The benefits associated with this relocation include increased capacity and improved throughput.
and the reduction in energy consumption, results that depend both on the performance of the controllers
as for its acceptance by the operations teams.
The relationship between variability and energy consumption is particularly clear in
Operational safety margins adopted by the teams. When the process fluctuates, the operators

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They tend to keep variables away from specification limits through purification beyond the...
Required, higher heating temperatures or greater utility flow rates, in order to avoid
Products that are out of specification. These margins consume energy continuously and rarely.
They appear in the indicators as a loss. The reduction of variability, whether by statistical methods, by
Advanced control, or standardization of procedures, allows these margins to be narrowed with...
safety and converts operational discipline into measurable energy savings.

7. Asset Reliability and Maintenance as Sources of EFFICIENCY

Nakajima (1988) presented total productive maintenance as a system aimed at maximizing
The effectiveness of the equipment, with the participation of all levels of the organization. The author proposed that...
Overall equipment effectiveness as an indicator that combines availability, performance and
quality, and identified six major losses, including breakdowns, setup and adjustment losses,
minor stops, reduced speed, defects, and starting failures. Each of these
Losses have an energy counterpart, since equipment that is stopped, operating at a reduced pace, or
By generating out-of-specification products, they continue to consume energy without producing value.
corresponding.
One of the pillars of total productive maintenance is autonomous maintenance, in which operators
They undertake basic tasks such as cleaning, inspecting, lubricating, and adjusting the equipment that
conduct (NAKAJIMA, 1988). The proposal is based on the principle that whoever operates the equipment
when you are daily, you are in a better position to perceive subtle changes in noise, vibration, temperature and
leaks. This proximity allows for the detection of anomalies at an early stage, before they evolve into
Functional failures. From an energy standpoint, early detection prevents losses such as
Steam leaks, abnormal bearing heating, and insulation degradation may persist.
for weeks or months without registration.
Moubray (1997) systematized reliability-centered maintenance, an approach that starts from
The required functions of each asset to identify its failure modes and the consequences of those failures.
and the technically appropriate maintenance tasks. The author described the interval between the moment
the point at which a potential failure becomes detectable and the point at which it converts into a functional failure.
The concept that underlies condition-based maintenance. This interval is especially
This is relevant for energy efficiency because many pieces of equipment continue to operate during the
degradation, with progressively lower yield, without the loss being perceived by

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Traditional availability indicators.

Fouling in heat exchangers illustrates this relationship in an exemplary way. Macchietto et al. (2011)

They pointed to fouling in the oil preheating tanks of refineries as the cause.

important energy inefficiency issues were observed, and conventional design methods were noted.

They were limited to accommodating fouling, rather than preventing it. The thermal integration methodology

The proposal by Linnhoff and Hindmarsh (1983) and detailed by Kemp (2007) allows the design of networks of

heat exchangers that maximize heat recovery, but the benefit obtained in the design depends on

maintaining thermal performance throughout operation requires monitoring and

Cleaning planning.

Utility systems offer further examples of losses associated with the condition of

Equipment. The U.S. Department of Energy's guide to steam systems.

recommends regular inspection programs for steam traps, leak repairs, and recovery of...

condensate, maintenance of thermal insulation and combustion adjustment in boilers (STATES)

UNITED, 2012). Saidur (2010), in a review on electric motors, showed that these devices

They account for a significant portion of industrial electricity consumption, and operating outside of

At the correct point, oversizing and the absence of speed control increase losses.

Table 1 summarizes these relationships between loss mechanisms and operation and maintenance practices.

Table 1 – Energy loss mechanisms associated with plant operation and maintenance process

System	Loss mechanism	Operating or maintenance practice	Reference
Heat exchangers	Fouling reduces heat recovery and increases furnace load.	Monitoring thermal performance and planning cleanings.	Macchietto et al. (2011) and Kemp (2007)
Steam systems	Faulty steam traps, leaks, and damaged insulation.	Periodic inspection, leak repair and condensate recovery.	United States (2012)
Ovens and boilers	Improper combustion adjustment	Monitoring and adjusting the air-fuel ratio.	United States (2012)
Motors, pumps and fans	Operation outside the proper point and oversizing	Review of operating conditions and speed control	Saidur (2010)
Control process	Wide operating margins to compensate for variability.	Reducing variability and operating close to constraints.	Bauer and Craig (2008)

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System	Loss mechanism	Operating or maintenance practice	Reference
Equipment in general	Breaks, short stops, starts and slowing down. **Source: prepared**	Autonomous maintenance and early anomaly detection	Nakajima (1988)

by the author based on the references provided.

8. Tacit Knowledge, Operational Competence, and the Paradoxes of AUTOMATION

Polanyi (1966) formulated the notion of tacit knowledge by stating that people know more than that they are able to express. This type of knowledge, built through experience and practice, It includes the ability to recognize patterns, interpret ambiguous signals, and act on perceptions. difficult to formalize. In process plants, tacit knowledge manifests itself in the way that Experienced operators anticipate the behavior of distillation columns, furnaces, and compressors. Faced with changes in load, raw materials, or environmental conditions, this knowledge is influential. directly relates to the efficiency with which energy is used at each moment of operation.

Nonaka and Takeuchi (1995) proposed a model for the creation of organizational knowledge. based on the continuous conversion between tacit and explicit knowledge, in four modes called socialization, externalization, combination, and internalization. The authors argued that the advantage A company's competitiveness depends on its ability to leverage the tacit knowledge of individuals. and convert it into shared knowledge. In the context of energy efficiency, this process This corresponds to the transformation of good individual operating practices into procedures and parameters. reference materials and training resources, so that performance does not depend exclusively on experience of those on duty.

Rasmussen (1983) distinguished three levels of human performance in technical systems, based on skills, rules, and knowledge. Skills-based behavior corresponds to Automated actions, rule-based actions involve applying known procedures to Recognized situations and knowledge-based approaches are mobilized in the face of new situations, which They require analytical reasoning. Energy optimization of a process unit often This belongs to the latter level, as it involves understanding interactions between variables and evaluating... compromises between consumption, income and quality, and deciding under conditions that none The procedure is fully described.

Bainbridge (1983) described the ironies of automation by observing that the automation of tasks Routine tasks tend to leave the most difficult situations to the human operator, while also

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time, which reduces opportunities to practice the skills needed to deal with them. A
The author argued that operators who only monitor automated systems lose out.
gradually leading to a detailed understanding of the process. This finding has implications for the
Energy efficiency, since control and optimization systems depend on operators capable of...
to assess whether the automated actions make sense, to identify when the controllers are operating.
outside of its premises and intervene appropriately.
The connection between these contributions indicates that operational competence constitutes a resource.
Strategic for energy performance, and not just a safety or quality requirement. A
The requirement for competence and awareness present in the ABNT NBR ISO 50001 standard is met.
The theoretical foundation in these studies shows that the knowledge necessary to operate
An efficient plant is largely built in practice and needs to be deliberately designed.
shared. Training programs that combine the fundamentals of thermodynamics and of
Unit operations combined with analysis of real-world cases from the facility itself tend to favor this.
The conversion of individual knowledge into organizational capacity.

9 Multiple Benefits and Behavior in the Workplace

Worrell et al. (2003) analyzed more than 70 industrial case studies and found that the measures
Energy efficiency measures often generate benefits that go beyond energy savings.
such as increased productivity, reduced maintenance costs, and improved quality of
product, reduced waste, and improved working conditions. The authors demonstrated that, in
In the case of the US steel industry, including these benefits in the modeling would double the potential.
the efficiency potential considered economically viable compared to an analysis
restricted to the value of energy saved. This finding changes the way projects are designed.
Efficiency should be evaluated.

The International Energy Agency consolidated this perspective in a report dedicated to the benefits.
Multiple aspects of energy efficiency, encompassing effects on the economy, health, and safety.
Energy and industrial competitiveness (INTERNATIONAL ENERGY AGENCY, 2014).
The document records that when productivity and operational benefits were incorporated into
In an analysis of efficiency investments in the industry, the payback period for the measures decreased from 4.2 to
1.9 years. This difference indicates that the assessment based solely on energy savings underestimates the cost.
systematically assess the value of improvements, including those that depend predominantly on
Operational and maintenance changes.

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People's behavior in the workplace constitutes another relevant dimension. Lo, Peters
Kok (2012) reviewed studies on the determinants of pro-environmental behaviors in
organizations and interventions aimed at promoting them, including actions focused on the economy.
of energy. The authors identified that factors such as attitudes, social norms, habits, and perception
Control factors influence these behaviors, and they observed that the empirical basis for interventions
In organizational contexts, it was still limited and methodologically heterogeneous, which recommends
Caution should be exercised when generalizing results obtained from isolated studies.
Carrico and Riemer (2011) evaluated, in a field study conducted in a work environment, the effects
of two strategies to encourage energy conservation, the return of information on consumption
at the group level and peer-led education. The results indicated reductions in consumption.
compared to control conditions, which suggests that the visibility of performance
Collective interaction and peer influence can drive behavioral change. Although the study
Although it was carried out in administrative buildings, its principles are in dialogue with the logic of
Shift indicators and monitoring routines adopted in industrial plants.
Translating these findings to the process industry requires considering that the behavior
The energy relevance of operators is less linked to individual habits, such as switching off.
office lighting or equipment, and more associated with technical decisions regarding the operation of
process. Still, the mechanisms identified in the literature, such as the visibility of results,
The feedback loop and shared norms of the group apply to this context.
Energy performance indicators presented by shift, discussed during service handovers and
Associated with understandable goals, they tend to make energy consumption a process variable.
The focus is as closely monitored as the production and quality.

10 CONCLUSION

The analysis developed in this article allows us to affirm that industrial energy efficiency cannot
be reduced to equipment replacement. The literature on the energy efficiency gap,
The work initiated by Jaffe and Stavins and further developed by subsequent studies shows that a significant portion
of the potential for economic growth remains untapped for reasons that are not technological, but
organizational, managerial, and behavioral factors, many of them under the direct control of the individuals themselves.
companies.
The taxonomies of barriers examined show that the lack of information and skills...
Internal and managerial oversight limits restrict the realization of potential with the same intensity as...

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capital constraints. The extended gap proposal reinforces this interpretation by demonstrating that practices
Energy management practices expand the potential for savings beyond what could be achieved with energy savings alone.
Technology, which puts work routines and the people who perform them at the center of the discussion.
Energy management systems provide the necessary framework to transform efficiency into
Permanent practice. The ABNT NBR ISO 50001 and ISO 50006 standards establish indicators,
Baselines and competency requirements that formally recognize the role of teams.
The model by Schulze et al., by including culture among its elements, indicates, however, that
Formal procedures are not enough when there is no effective involvement from employees, a condition
necessary for these systems to influence everyday decisions.
Continuous improvement methods, from the cycle proposed by Shewhart to the practices of the Toyota Production System.
production, they provide tools to identify and eliminate energy losses that rarely
They appear in traditional indicators. The experience documented by the North American environmental agency-
American studies indicate that explicit attention to energy amplifies the gains from these initiatives, provided that...
methods should be adapted to the characteristics of the continuous process industry and to the forms
specific roles that waste plays in this environment.
Reducing process variability has proven to be an important link between quality and productivity.
and energy consumption. Wide operating margins, adopted to compensate for fluctuations, consume
Continuous and silent energy supply. Statistical methods, structured improvement projects and
Advanced controls allow you to safely narrow these margins, but the results depend
of well-defined goals, adequate training, and acceptance from the teams that work together
daily interactions with the control systems.
Asset reliability and maintenance quality are crucial for preserving performance.
Energy obtained from the project. Fouling in heat exchangers, failures in steam traps, combustion.
Misaligned systems and equipment operating outside of their proper parameters represent accumulated losses.
over time. Autonomous maintenance and condition-based maintenance assign to
Operators play a central role in the early detection of these losses, before they turn into failures or in
Prolonged excessive consumption.
The tacit knowledge of operators and the paradoxes of automation show that technology,
In isolation, it does not guarantee efficient operation. Increasingly sophisticated control systems
They require operators capable of understanding the process in depth and evaluating the suitability of...
Automatic actions and intervention in unforeseen situations. The conversion of this individual knowledge.
in procedures, reference parameters and training programs constitutes a condition for
Energy performance does not depend on the experience of a few people.

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Finally, considering the multiple benefits demonstrates that the evaluation of efficiency measures... basing this solely on the value of energy saved underestimates its real return, especially in the case of... Operational and maintenance improvements. It is concluded that investments in equipment produce... Limited results when not accompanied by structured management and integrated indicators. to the routine and training of the teams. It is recommended, for future research, to carry out studies. empirical studies in chemical and petrochemical plants that quantify the relative contribution of practices operational and technological solutions for energy performance.

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