

Review

Global review of the ISO 50001 standard and provision of a framework for improving energy management systems for Iran

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ARTICLE INFO

Article history:

Received 15 January 2026

Received in revised form

30 April 2026

Accepted 15 June 2026

Keywords:

ISO 50001, Energy management system, Energy efficiency, Sustainable development, Organizational barriers, Implementation framework

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DOI: 10.55670/fpll.fuen.5.3.3

ABSTRACT

Energy management has become an essential tool for addressing the challenge of sustainable development, driven by rising demand, price volatility, and concerns about global warming. ISO 50001 has emerged as an excellent methodological tool that uses the PDCA (Plan-Do-Check-Act) cycle to enhance an enterprise's energy efficiency. This article provides a systematic, methodical literature review of quantitative effects and case studies on the application of ISO 50001 in developed and developing nations from 2000 to 2025. By conducting a comprehensive literature search of Scopus, Web of Science, and IEEE Xplore, the article provides a factual description of the ISO 50001 application, which can annually decrease the energy intensity by 41-26%, support long-term efficiency over a period of 12 years, and provide significant cost savings as a byproduct of the reduction in Greenhouse Gas (GHG) emissions. The article emphasizes the critical success factors (CSFs), such as senior management support, organizational values and behavior change, the development of technical capacities, and the development of a supportive policy structure. However, a wide range of constraints still exist, including a lack of funds, technical competencies, organizational resistance, and supportive infrastructure. The article considers a special case of the Iranian nation, which has shown higher values than the global average due to lower energy consumption costs, outdated technology, a lack of management systems, and an abundance of Iranian energy resources. This article encourages the application of a methodological model that includes the PDCA tool, barrier management structured analysis, and the structured maturity development model, among others, by adapting it to the specific case of the Iranian nation.

1. Introduction

In recent decades, global energy management has become a cornerstone of sustainable development due to rising energy demand, price volatility, and environmental issues related to greenhouse gas emissions. Studies have shown that energy management systems (EMS) significantly contribute to energy savings, more efficient use, and lower energy intensity in firms [1]. Recent studies show that the appropriate use of energy management systems can decrease energy consumption by 10-30% and reduce greenhouse gas emissions in industrial and building applications [2]. Thus, the International Organization for Standardization (ISO) has developed ISO 50001 as an all-encompassing framework that enables the cost-effective establishment and implementation

of energy management systems. This initial version of the standard was revised in 2018 and adapted in 2024, with consideration of climate action changes, to provide a systematic approach based on the PDCA cycle, enabling organizations to manage and optimize their energy performance [3]. Internationally, a number of standards have been developed for energy and environmental management that assist organizations in addressing performance within defined boundaries and for varying purposes. Table 1 summarizes the standards of comparison. The reasons for selecting ISO 50001 as the focus of this research are as follows: First, unlike ISO 14001 and ISO 9001, which emphasize only improving management system effectiveness, ISO 50001 explicitly requires measurable improvements in

actual energy performance. Second, the use of the Annex SL high-level structure facilitates easy integration with other ISO standards. Third, as the only global energy management standard, ISO 50001 has been adopted by more than 90 countries. Fourth, these standard addresses not only technical aspects but also managerial, organizational, and cultural dimensions of energy management. Fifth, studies have shown that ISO 50001-certified organizations achieve an average 4.1% energy performance improvement in the first year and sustain 3.4% improvement in subsequent years, with some Canadian organizations achieving 10% cumulative improvement in the first two years [2].

Abbreviations

AI	Artificial Intelligence
CO ₂	Carbon Dioxide
CSFs	Critical Success Factors
DMAIC	Define-Measure-Analyze-Improve-Control
EB	Energy Baseline
EJ	Exajoules
EMS	Energy Management System
EPI	Energy Performance Indicator
ESG	Environmental, Social, and Governance
GHG	Greenhouse Gas
IoT	Internet of Things
ISO	International Organization for Standardization
LSS	Lean Six Sigma
MNC	Multinational Corporations
PDCA	Plan-Do-Check-Act
PSM-DID	Propensity Score Matching Difference-in-Differences
ROI	Return on Investment
SDG	Sustainable Development Goal
SEC	Specific Energy Consumption

Iran, as one of the countries with rich fossil energy reserves, faces serious challenges in energy efficiency and optimal use of energy resources. Energy intensity in Iran is significantly higher than the global average, indicating poor energy efficiency performance across various economic sectors. Energy subsidies, outdated technologies, and the absence of comprehensive energy management policies are among the main factors contributing to this situation [7]. Recent research shows that the transition process from fossil fuels to renewable energies in Iran is accompanied by multiple challenges [8]. Furthermore, the establishment of mandatory building energy consumption standards in Iran has encountered considerable obstacles [9]. These conditions underscore the urgent need to implement systematic energy management approaches, such as ISO 50001. The primary aim of this systematic review is to develop a detailed, actionable framework for applying the ISO 50001 standard in Iran's industries and organizations. This framework is established through a systematic evaluation of successful global practices, recognition of obstacles and prospects unique to Iran, and development of solutions adapted to local conditions. This research aims to address the following inquiries:

- 1) Which countries (both developed and developing) have successful experiences with ISO 50001 implementation that will be analyzed, and what common trends can be discerned?
- 2) Which aspects of energy management are emphasized in this study? Specifically, the current research examines energy consumption reductions, improvements in energy efficiency, decreases in energy intensity, reductions in greenhouse gas emissions, and savings in operational costs.
- 3) Which industrial and service sectors (manufacturing industries, commercial buildings, government sector) have seen the most significant success in implementation?

Table 1. Comparison of energy and environmental management standards [4-6]

Standard	Scope	Main Focus	Performance Improvement Requirement	Integration with Other Standards
ISO 50001:2018	Energy Management	Continuous energy performance improvement, reduction of consumption and intensity, cost reduction, and CO ₂ emissions	Yes - Explicit requirement	High - Annex SL high-level structure
ISO 14001:2015	Environmental Management	Overall environmental impact reduction, waste management, and pollution	No - Management system improvement	High - Annex SL high-level structure
ISO 9001:2015	Quality Management	Product and service quality improvement	No - Management system improvement	High - Annex SL high-level structure
EN 16001:2009 (Superseded)	Energy Management	Precursor to ISO 50001 in Europe	Yes	Medium - Replaced by ISO 50001
ENERGY STAR (United States)	Energy Performance	Certification of specific energy performance level	Yes - Based on criteria	Medium - Complementary to ISO 50001
ASHRAE Standards	Building Optimization	Technical standards for HVAC systems and building efficiency	Variable	Low - More technical approach
SEP (Superior Energy Performance)	Superior Energy Performance	Certification of demonstrated energy performance improvement	Yes - Minimum 5% improvement	High - Based on ISO 50001

4) What critical success factors (CSFs) and primary challenges in ISO 50001 implementation have been recognized across various countries?

5) How can a framework for implementation be designed that is appropriate for Iran's circumstances, considering specific challenges (financial limitations, insufficient technical knowledge, institutional deficiencies), harnessing local opportunities (energy-intensive sectors, significant energy efficiency potential), and offering prioritized steps for operational execution?

This systematic literature review searches reputable databases (Scopus, Web of Science, IEEE Xplore) for articles published from 2000 to 2025. Using specific inclusion and exclusion criteria, studies on the implementation of ISO 50001, country experiences, and sector-specific cases are selected. Content analysis extracts and categorizes data on successful implementations (in both developed and developing countries), CSFs, obstacles, and energy performance indicators (EPis). These global findings are contextualized in relation to Iran's specific conditions. The proposed framework integrates the PDCA model (the foundation of ISO 50001), SWOT analysis (assessing Iran's position), barrier analysis (technical, economic, organizational, and institutional), an energy management maturity model (evaluating organizational readiness), and an implementation roadmap with timelines.

This research presents three key innovations: First, comprehensiveness—unlike previous studies focusing on single industries or countries, it systematically examines global success and failure patterns across diverse contexts (2000-2025). Second, integration with sustainable development goals demonstrates how ISO 50001 simultaneously addresses economic (cost reduction), environmental (emissions reduction), and social objectives (energy sector job creation). Third, contextualized framework development that bridges global best practices with Iran's specific conditions. The research necessity stems from: a scientific gap in systematic ISO 50001 studies for developing countries, particularly Iran; practical urgency given Iran's high energy intensity requiring systematic management strategies for organizations and policymakers; policy alignment with Iran's energy reforms (subsidy restructuring, clean energy transition, efficiency improvement); and global responsibility as a major greenhouse gas emitter needing actionable pathways for emissions reduction.

This systematic literature review organizes the findings into distinct sections 3-9 to provide a comprehensive analysis of ISO 50001 implementation globally and its adaptation for Iran. Section 3 presents an overview of the ISO 50001 standard, including its history, evolution (2011 and 2018 versions), structure based on the PDCA cycle, and key requirements. Section 4 examines international implementation experiences through quantitative impact assessments, case studies, sector-specific applications (manufacturing, buildings, public sector), regional analyses (EU, North America, Asia, developing countries), and emerging trends such as digitalization and Environmental, Social, and Governance (ESG) integration. Section 5 identifies Critical Success Factors (CSFs) (e.g., top management commitment, organizational culture) and enablers (e.g.,

regulatory incentives, multinational knowledge transfer). Section 6 analyzes barriers categorized as technical, economic, organizational, and institutional, with a focus on developing countries like Iran. Section 7 develops an Iran-specific framework integrating PDCA, barrier management, maturity models, and a phased implementation roadmap tailored to local challenges (e.g., energy subsidies, outdated infrastructure). Section 8 discusses policy recommendations for national, organizational, and sectoral levels. And finally, Section 9 discusses the proposed framework and recommendations. This logical progression bridges global evidence to actionable Iranian strategies.

2. Methodology

This study adopts a Systematic Literature Review approach to synthesize worldwide experience with ISO 50001 implementation and to develop a customized framework for Iran. The search process identifies potential studies using systematic search techniques, a two-stage screening process, detailed consideration of study inclusion and exclusion based on quality and relevance, and data extraction. The extraction of data is conducted for five prominent dimensions, such as classifications for countries according to MDCs like developed and developing countries, sectors of use such as industry, like industrial, trading, and public sectors for ISO 50001 system implementation, energy consumption indicator and CSFs for implementation, and energy usage and efficiency gain affected by ISO 50001 system implementation. The collected data is further synthesized for both quantitative analyses, such as energy savings percentage, economic benefit, and emissions reduction, and qualitative studies, such as decision factors for implementation and the procedural processes affected by global frameworks and contexts. The findings are then scrutinized to identify broader similarities and global best-practice approaches, providing a comprehensive view and further customization to appropriate energy frameworks and economic dynamics for Iran. The process for framing this customized approach comprises four key components: the PDCA cycle, a barrier categorization system, energy management maturity, and a systematic implementation approach that culminates in recommendations. This is appropriate to its field for the following reasons: the customized framework would have intrinsic connections to research and be locally adaptive to the challenges and opportunities of its implementation.

Figure 1 presents the systematic methodology used in the research as a flow chart illustrating the sequential steps and decisions involved in the literature review process. The flowchart begins with defining the research objective and proceeds to the stages of the systematic literature review, in which three major academic databases (Scopus, Web of Science, and IEEE Xplore) are accessed simultaneously to identify relevant publications from 2000 to 2025. The procedure incorporates designated keywords related to ISO 50001, Energy Management Systems, and experiences with their implementation. Following the commencement of the research investigation, the procedure uses predefined selection criteria, categorized as inclusion and exclusion, to filter relevant research studies based on their relevance, quality, and applicability.

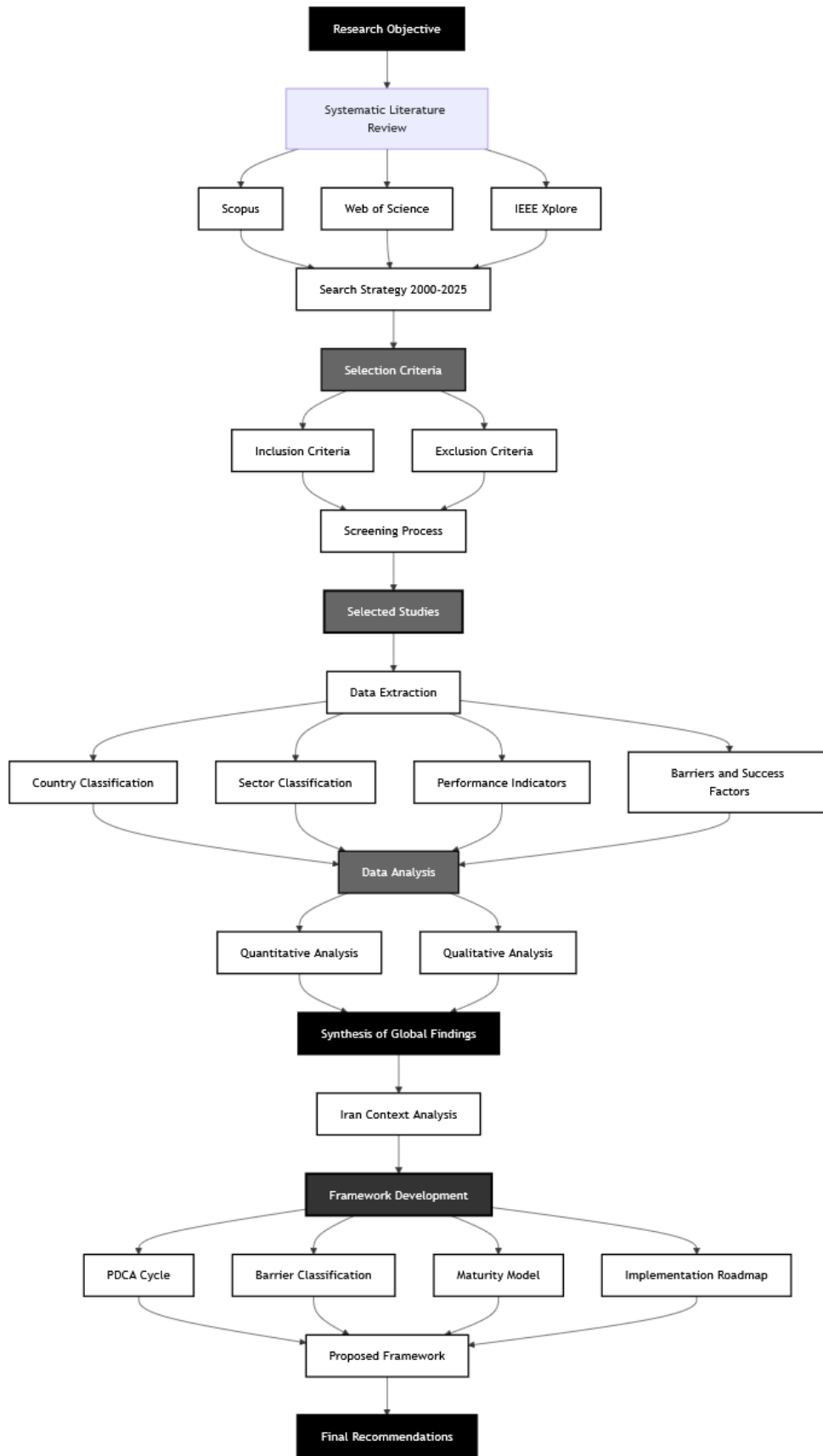


Figure 1. Systematic literature review methodology flowchart

The procedure incorporates a two-step screening method, beginning with screening selected research studies based on their titles and abstracts. Following the screening procedure, the research employs a detailed method based on the entire body of research. The selected studies from the screening procedure undergo data extraction across five categories: country classification, sector classification, Performance Indicators, Barriers, and Success Factors. The data extracted from the research procedure initiates the analysis, which utilizes both quantitative and qualitative methods. Both analysis methods lead to the synthesis stage, where the findings are identified globally by determining the pattern. The research findings commence the explanation, situating the study in the Iranian context and developing a framework specific to the findings. The research incorporates the use of a four-component procedure, which includes the PDCA cycle procedure, the classification of barriers, the Maturity model procedure, and the roadmap procedure, to develop the proposed framework. The research is based on the development of Iranian recommendations based on the findings. The research concludes its findings based on the Iranian national, organizational, and regional context. The graphical representation enhances the transparency and reusability of the methodologies used in the research.

The literature review included a search of major research databases, including Scopus, Web of Science, and IEEE Xplore, for articles related to energy systems, industrial efficiency, and engineering sustainability, conducted from 2000 to 2025. The year range included the introduction of ISO 50001 and the emergence of structured energy management methods. The three research databases were selected because they contained extensive published research on all three topics. The search attempts included various combinations and types of searches using keywords such as ISO 50001, energy management system, energy efficiency, implementation processes, obstacles, success factors, industrial applications, buildings, and developing nations. Additionally, all studies were limited to those published in English and that had passed peer review. The three research databases were selected because they contained extensive published research on all three topics. The search attempts included various combinations and types of searches using keywords such as ISO 50001, energy management system, energy efficiency, implementation processes, obstacles, success factors, industrial applications, buildings, and developing nations. Table 2 presents the five primary search keywords and their respective publication frequencies in global and Iran-specific contexts.

As illustrated in Table 2, the significant disparity between global publication volume and Iran-specific research (ranging from 100:1 to 300:1) underscores the critical research gap this manuscript addresses, where systematic ISO 50001 studies for Iran remain substantially underrepresented. Additionally, all studies were limited to those published in English and that had passed peer review. The selection of studies was based on predetermined inclusion and exclusion criteria. The selection of studies was based on predetermined inclusion and exclusion criteria. Articles were included in this review if they specifically discussed ISO 50001 or similar structured energy management systems (e.g., ISO 50002) and included

information on actual applications, results, or logical evaluations of energy management system implementations. The process for screening articles included an initial title and abstract review, followed by a full-text review to assess the article's methodological quality and relevance. Data from the list of accepted studies were compiled and categorized according to the following criteria: Country Classification (Developed vs. Developing), Sector (Industrial, Commercial & Institutional), Energy Performance Indicator Types, Barriers to Implementation, and Success Factors.

Table 2. Primary search keywords and Scopus publication volume

Key Words	Number of global articles	Number of articles related to Iran
ISO 50001	22,000+	50-70
Energy management system	1,177	100+
Energy efficiency	3,905	200+
Implementation barriers	8,500+	40-50
Policy framework	15,200+	80-100

A comparative and thematic analysis of the collected evidence was conducted to identify common trends, challenges, and outcomes by region and sector. The results were analyzed in the context of Iran's unique energy structure, institutional framework, and economic conditions. The framework presented in this report combined several sources of support, including the PDCA process as defined in ISO 50001, classification of implementation barriers (technical, economic, organizational, and institutional), energy management maturity concept, and detailed implementation guidance. This approach provides a vehicle for translating lessons learned from experience into an effective model applicable to the Iranian context, rather than relying on generic, abstract, or idealistic expectations.

This systematic literature review organizes the findings into distinct sections (3-9) to provide a comprehensive analysis of ISO 50001 implementation globally and its adaptation for Iran. Section 3 presents an overview of the ISO 50001 standard, including its history, evolution (2011 and 2018 versions), structure based on the PDCA cycle, and key requirements. Section 4 examines international implementation experiences through quantitative impact assessments, case studies, sector-specific applications (manufacturing, buildings, public sector), regional analyses (EU, North America, Asia, developing countries), and emerging trends such as digitalization and Environmental, Social, and Governance (ESG) integration. Section 5 identifies CSFs (e.g., top management commitment, organizational culture) and enablers (e.g., regulatory incentives, multinational knowledge transfer). Section 6 analyzes barriers categorized as technical, economic, organizational, and institutional, with a focus on developing countries like Iran. Section 7 develops an Iran-specific framework integrating PDCA, barrier management, maturity models, and a phased implementation roadmap tailored to local challenges (e.g., energy subsidies, outdated infrastructure). Section 8 discusses policy recommendations for national,

organizational, and sectoral levels. This logical progression bridges global evidence to actionable Iranian strategies.

3. ISO 50001: an overview

To preview the analytical emphasis derived from the reviewed corpus, Figure 2 maps the manuscript's top 10 keywords by centrality grade (1-10 scale based on frequency/contextual weight) against energy performance impacts (% quantified from primary studies). Bubble sizes scale with magnitude; colors distinguish facilitators (green) from inhibitors (red). High-centrality drivers "Efficiency" (grade 10, 39% peak savings) and "Savings" (8, 36%) dominate, validating quantitative focus. Methodological anchors "ISO 50001" (10, 4.1% annual average) and "PDCA" (9, 3.4% sustained) frame the structure. Context-specific "Iran" (9, 15% adaptation potential) and "Implementation" (9, 12%) bridge global-to-local. Barriers (7, -15% drag) signal priorities. This content-derived visualization structures the presentation of subsequent results.

3.1 History and evolution of the standard

The establishment of ISO 50001 marks an important step forward in the global effort to manage energy more effectively. This standard was put in place after the United Nations Industrial Development Organization recognized a lack of consistency among the methods companies in different countries use to address climate change and energy-use efficiency [10]. Before the development of ISO 50001, there were several different national energy management standards created by governments from various regions of the world, such as China, Denmark, Ireland, Japan, Korea, the Netherlands, Sweden, Thailand, and the U.S. This has resulted in many different types of energy management systems being used by companies around the world [5, 11].

The 2011 version: ISO 50001:2011 was published on June 17th, 2011, after many years of intensive collaboration by ISO's Project Committee PC 242, comprising experts from 44 countries and 14 additional observers [12]. The intention was to create a standard that would be usable worldwide, regardless of organization size, type, or sector, with a systematic approach to improving energy performance on an ongoing basis through enhanced energy efficiency, self-sufficiency, use, and consumption [13]. The 2011 version established the foundational framework based on the Plan-Do-Check-Act (PDCA) cycle, aligning well-established ISO management system standards such as ISO 9001 (quality management) and ISO 14001 (environmental management) [14]. A distinguishing feature of ISO 50001:2011 was its requirement that organizations demonstrate improvement in actual energy performance, not merely in the effectiveness of the management system itself, a significant advancement over other ISO standards [15]. This approach positioned energy management as a critical business function that requires measurable outcomes and continuous improvement [16]. The early adoption of the standard demonstrated market receptivity and practical applicability across diverse organizational contexts [3]. **The 2018 revised version:** On August 21, 2018, the second edition of ISO 50001:2018 was released; this edition introduced significant amendments that improve the compatibility, clarity, and accessibility of the standard for organizations of varying types [17]. The most significant amendment to the ISO 50001:2018 edition was the addition of a high-level structure based on Annex SL; consequently, ISO management systems now use the same core text and terminology across all ISO standards, enabling more effective integration of multiple management systems within the organization [1,18].

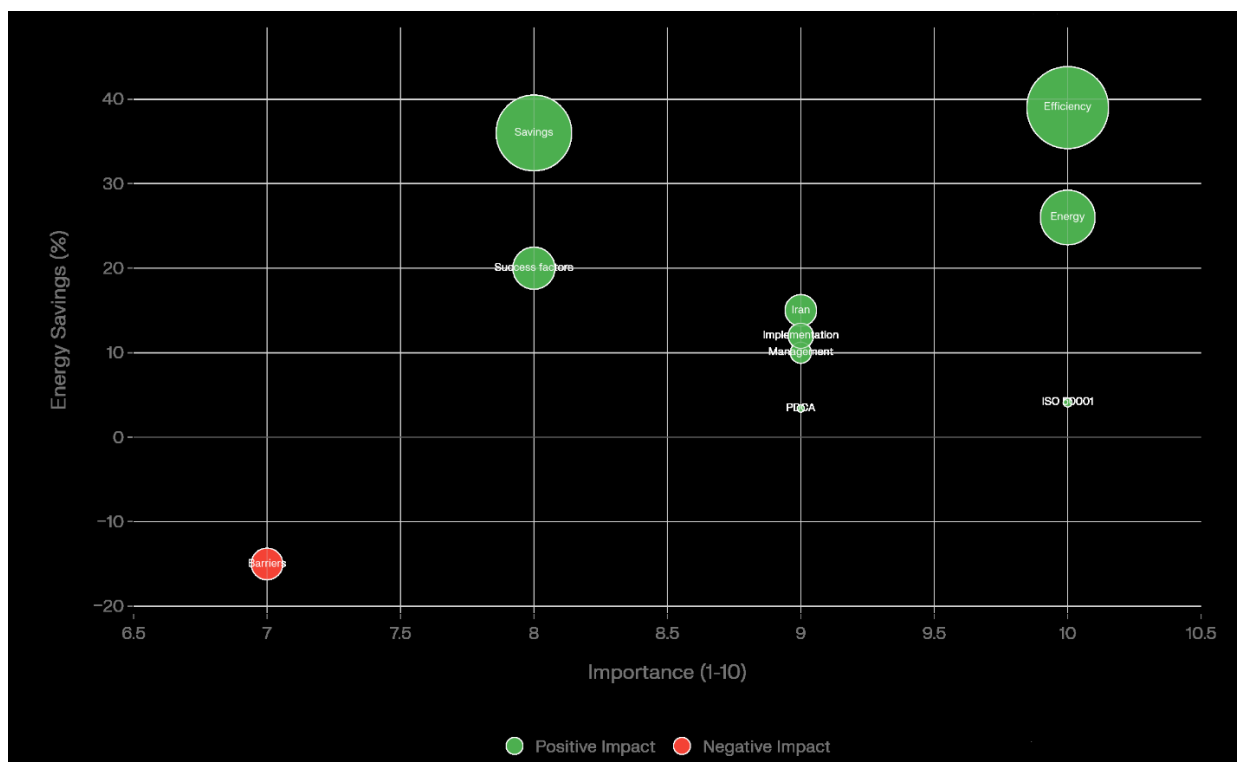


Figure 2. Keyword centrality and energy impact bubble chart

Another change with the 2018 revision was an increased focus on the importance of senior management and leadership, as it required all levels of senior management to affirm their commitment and responsibility for improving an organization’s energy performance [19]. The themes of behavioral/attitude change and societal metamorphosis have emerged as significant in ISO 50001:2018, acknowledging that, to achieve sustainable energy management, people need to get involved and participate at every level within the organization, not just through technical or physical actions. The 2018 revision of ISO 50001 has also clarified guidance on the use of EPIs and Energy Baselines (EBs) and now provides a fuller explanation of how to normalize and adjust for variables that affect EPIs [20].

3.2 Structure and requirements of the standard

As shown in Figure 3, the ISO 50001 standard establishes a methodical framework for energy management based on a holistic interpretation of the Plan-Do-Check-Act (PDCA) cycle (Deming Circle). By using this PDCA approach, ISO 50001 allows energy management practices to be viewed as an organization’s ongoing development process rather than a finite, one-time event; all four phases continually interact to create an environment conducive to improved energy performance. During the Plan phase of the PDCA cycle, organizations establish baseline measures to assess energy performance by setting targets for Total Energy Usage Associated with Production Processes, Energy Efficiency Ratio (EER), Energy Drivers, and Energy Peak Usage. During the Do phase of the PDCA cycle, the organization implements its plans, documents all decisions and actions taken, and provides regular updates through employee meetings, as well as essential records for both internal and external communication.

The Check phase includes the ongoing evaluation of established target metrics to validate the effectiveness of the actions taken in achieving set energy goals by clearly recording, analyzing, and documenting all energy-related information to enable a comprehensive assessment of performance. The Act phase ultimately aims at providing a mechanism for ongoing improvement identified from the review of the data by collecting all relevant information for energy management reviews, along with presenting the analyzed results of the review with proposed solutions that will form the basis for both management decisions and reports from external energy auditors [21].

3.3 Motivations and benefits of adopting ISO 50001

Companies will get ISO 50001 Certification for various reasons, including economic, Environmental, Compliance, and Strategic Reasons. Since its establishment, ISO 50001 has been shown to yield significant advantages across numerous areas.

Economic benefits: Implementing ISO 50001 provides organizations with the most tangible and immediate benefits. Several recent empirical studies conducted in China, examining the period from 2007 to 2016, show that companies certified under ISO 50001 have reduced energy intensity by roughly 26% due to increased investment in energy-efficient technology and greater availability of financing for energy improvements [22]. An extensive international analysis of 72 cases across many economic sectors has shown that the most reported advantages of implementing ISO 50001 were cost savings, improved productivity, and improved overall operations [7].

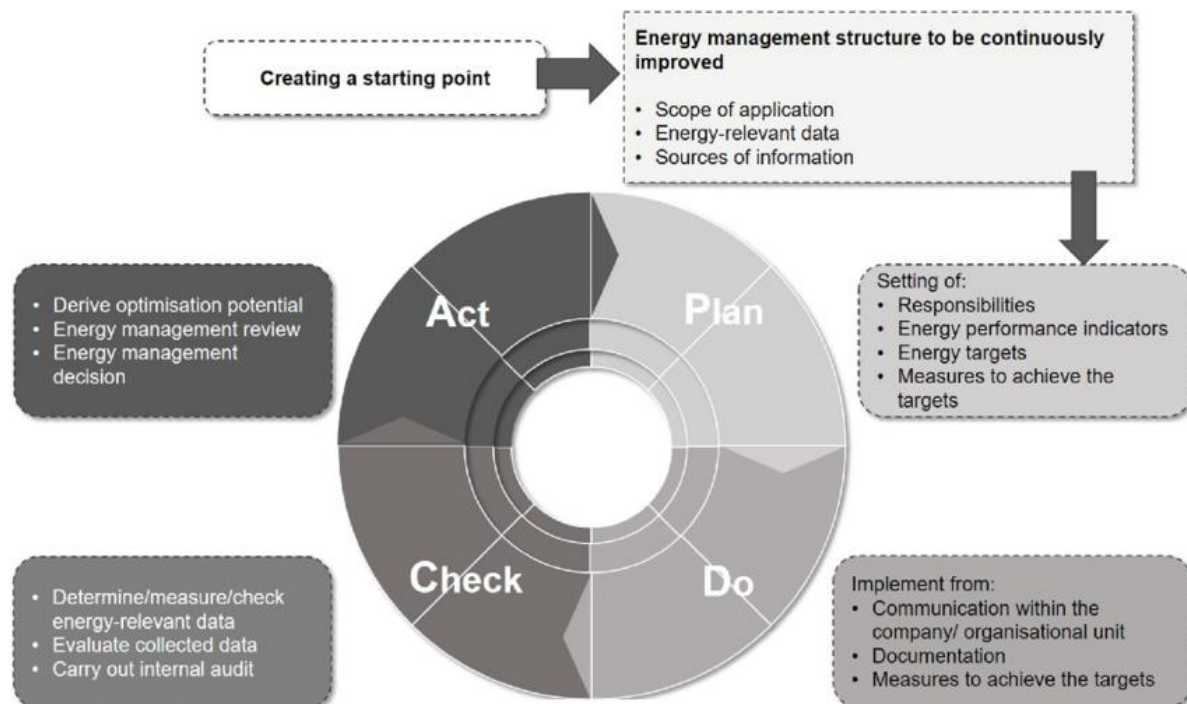


Figure 3. Based framework of the ISO 50001 energy management system

Energy-saving measures implemented under ISO 50001 create opportunities to enhance financial performance by reducing operational expenditure. In addition to energy savings, organizations find that a systematic approach to energy management identifies opportunities to optimize processes, reduce waste, and increase operating efficiency, thereby enhancing overall financial performance. Also improved financial planning and budgeting accuracy from the implementation of ISO 50001, as systematic monitoring and measurement of energy-related costs provide a clearer picture of energy spending and enable organizations to identify trends and patterns in their energy use. More accurate forecasting and better resource allocation result in improved overall financial performance.

Organizations are increasingly integrating ISO 50001 with their ESG Strategy. Organizations can enhance their ESG ratings by improving energy performance, thereby meeting Stakeholder requirements for Sustainability Leadership [7]. ISO 50001 also supports Compliance with Environmental Regulations and Voluntary commitments, such as Carbon Reduction Targets and Climate Neutrality pledges, and enhances corporate reputation and increases brand value in the minds of environmentally conscious consumers and investors [23].

4. International implementation experiences: evidence from practice

This section reviews a variety of empirical studies, cases, and research related to the adoption of ISO 50001 across geographic locations, industrial sectors, and organizational environments. The summary of these findings is based on research articles published primarily between 2000 and 2025 that discuss the various implementation approaches, the results achieved, the obstacles encountered, and the success enablers identified across these areas.

4.1 Quantitative impact studies

In the study conducted by Wang and Pan [22], the researchers evaluated the impact of adopting ISO 50001 on manufacturing energy intensity, measured as total output for the year divided by total energy consumption for the same year. To do this, using a unique panel dataset of manufacturing organizations from China for 10 years (2007-2016) and the propensity score matching difference-in-

manufacturing by ~26%. Furthermore, Wang and Pan concluded that increased investment in energy-efficient technologies and greater access to 'green credit' financing for energy-efficiency projects are the primary means of reducing the energy intensity of production processes. Fitzgerald et al. [2] used longitudinal data collected from ISO 50001-certified manufacturing facilities to investigate the extent of change in energy savings achieved by each organization over time. Results from Fitzgerald et al. showed energy savings of nearly 4.1% in the first year of ISO 50001 implementation, maintaining energy savings of ~3.4% for [up to] 12 years beyond certification. Therefore, the research by Fitzgerald et al. [2] provided further evidence that ISO 50001 enables continuous, ongoing improvement, rather than only periodic or short-term increases in efficiency, as had been assumed for other types of energy management systems. McKane et al. [24] devised an all-encompassing approach to estimating the measurable outcomes of ISO 50001's effect on reducing greenhouse gas emissions at the global, national, regional, and international levels. Their calculations reveal that achieving ISO 50001 implementation across 50% of the anticipated global industrial and service industry energy consumption by the year 2030 will yield a total of 105 exajoules (EJ) of primary energy savings, a total savings of about US\$700 billion (in today's dollars) and an estimated avoidance of 6,500 million metric tons of CO₂ emissions. It provides an open, uniform method for determining the extent to which implementing ISO 50001 programs may influence energy efficiency at the state and local levels.

Jeong and Lee [4] analyzed the comparative effects of ISO 14001 (Environmental Management Systems) and ISO 50001 (Energy Management Systems) on energy efficiency performance. Based on an analysis of ISO 9001-certified companies in Germany, the authors found that ISO 50001 certification led to greater improvements in energy efficiency than ISO 14001 alone, thereby corroborating the notion that ISO 50001 offers more specialized benefits than the general ISO 14001 certification. Table 3 presents a comprehensive overview of quantitative studies examining the measurable impacts of ISO 50001 implementation across different countries and timeframes, demonstrating significant reductions in energy intensity and greenhouse gas emissions.

Table 3. Quantitative impact assessment of ISO 50001 implementation: a multi-country analysis of energy performance outcomes

Authors	Country/Region	Methodology	Time Period	Key Findings
Wang & Pan [22]	China	PSM-DID	2007-2016	26% reduction in manufacturing energy intensity; increased investment in energy-efficient technologies and access to green credit financing
Fitzgerald et al. [2]	Longitudinal data from manufacturing facilities	Longitudinal Analysis	Up to 12 years post-certification	4.1% energy savings in first year; maintained 3.4% savings for up to 12 years; demonstrated continuous improvement
McKane et al. [24]	Global	Global Impact Assessment	Projection to 2030	With ISO 50001 in 50% of global industries: 105 EJ primary energy savings, US\$700 billion cost savings, 6,500 million metric tons CO ₂ emissions avoided
Jeong & Lee [4]	Germany	Comparative Analysis	-	ISO 50001 certification resulted in greater energy efficiency improvements than ISO 14001 alone

4.2 Case study-based investigations

Fuchs et al. [7] used an innovative content analysis methodology to code the motivating factors, support factors, challenges, benefits, and success factors for ISO 50001 implementations across 72 case studies of organizations that had received ISO 50001 certification through their participation in the Clean Energy Ministerial’s Energy Management Leadership Program. These case studies came from organizations across a variety of economic sectors, geographic locations, and types. Their analysis revealed that the most frequently mentioned drivers of ISO 50001 implementation were current organizational values and sustainability goals (65% of cases), commitments to environmental sustainability (58% of cases), and government incentives or regulatory requirements (47% of cases). Organizations also noted receiving a variety of benefits beyond energy cost savings from adopting ISO 50001, including increased productivity (54% of cases), improved operational efficiency (48% of cases), and enhanced competitiveness (31% of cases). The primary obstacle to successful implementation was the lack of a culture of energy focus within the organization (42% of organizations reported this as a barrier), followed by a lack of in-house expertise in technical matters (35% of organizations reported this as a barrier) and problems with accessing data to inform the implementation process (28% of organizations reported this as a barrier). A comprehensive case study by Alotaibi et al. [25] detailing the implementation of ISO 50001 at The Saudi Standards, Metrology and Quality Organization (SASO), a government agency in the Kingdom of Saudi Arabia. Information was gathered through several methods, including an energy audit and monitoring of the implementation of ISO and other energy-efficiency audits and procedures across the three locations: Riyadh, Jeddah, and Dammam. SASO adhered to ISO guidelines by incorporating various energy-efficient technologies and processes, resulting

in a 39% reduction in electricity use compared to 2019 (the baseline year) and savings of \$3.6 million. As a result of ISO 50001, the SASO also created a 38% reduction in CO₂ emissions. Through SASO’s experience, it was found that commitment from top management to implement ISO 50001 within the organization and to develop a company culture around this new implementation, continual monitoring of energy-efficiency measures, and the use of data to aid decision-making were the key factors for success. This research presents unique empirical evidence of the effectiveness of implementing ISO 50001 in governmental contexts, particularly in the Middle East, where energy prices have historically been subsidized. Trubetskaya et al. [26] studied the implementation of both ISO 50001 and Lean Six Sigma (LSS) methods at an Irish dairy plant, where they showed that by using the LSS framework of Define-Measure-Analyze-Improve-Control (DMAIC) in addition to the requirements of ISO 50001, the facility reduced its thermal energy consumption by 36%, decreased its CO₂ emissions by 46%, and saved 35% annually on its energy costs. This research was the first to demonstrate that employing both LSS and ISO 50001 approaches can improve energy management in the dairy industry. Pandin et al. [3] conducted a bibliometric analysis of research on ISO 50001-based energy management systems, using the Scopus database to review 1,177 published articles. As a result of their analysis, they identified important areas of study, leading contributors, contributing organizations, and contributing countries, as well as the main themes currently found in the ISO 50001 literature. They identified an increase in research interest in digitalization and Industry 4.0, which may indicate future trends in energy management. To understand the practical realities of ISO 50001 implementation, Table 4 summarizes key case study findings from diverse organizational settings, including government agencies, manufacturing facilities, and food processing plants across multiple countries.

Table 4. Organizational case study synthesis of ISO 50001 energy management systems: CSFs and implementation barriers

Authors	Organization/Sector	Country	Research Method	Key Results	Success Factors/Barriers
Fuchs et al. [7]	72 case studies from Clean Energy Ministerial Program	International	Content Analysis	Drivers: organizational values (65%), environmental sustainability (58%), government incentives (47%) Benefits: productivity (54%), operational efficiency (48%), competitiveness (31%)	Barriers: lack of energy culture (42%), technical expertise shortage (35%), data access problems (28%)
Alotaibi et al. [25]	SASO (Saudi Standards Organization)	Saudi Arabia	Government sector case study	39% electricity reduction, US\$3.6 million savings, 38% CO ₂ emissions reduction	Top management commitment, organizational culture development, continuous monitoring, data-driven decisions
Trubetskaya et al. [26]	Dairy plant	Ireland	Combined ISO 50001 & Lean Six Sigma (DMAIC)	36% thermal energy reduction, 46% CO ₂ reduction, 35% annual energy cost savings	Integration of ISO 50001 and LSS methodologies
Pandin et al. [3]	Bibliometric analysis	International	Analysis of 1,177 articles from Scopus	Identified key research areas, leading contributors, organizations, countries; emerging trend: digitalization and Industry 4.0	-

4.3 Sector-specific studies

Manufacturing industries: Gopalakrishnan et al. [12] developed a structured methodology to support the implementation of ISO 50001 in the manufacturing sector by providing an easy-to-follow framework aligned with manufacturing operations. The framework also addresses the technical, organizational, and cultural aspects of establishing an energy management system. To help realize this goal, the authors highlighted the importance of integrating EnPI into existing production monitoring systems, rather than simply treating energy management as an isolated function. In an industrial-based context, Jovanović and Filipović [5] developed and validated a maturity model for Energy Management based on ISO 50001. This maturity model provided a structured method to assess an organization's current level of energy management capability and outline clear pathways for developing the capability to advance through defined levels of maturity. Validation of the model through industrial case studies indicated that it is a useful tool for facilitating a systematic approach to Energy Management advancements. In their research, Javied et al. [15] examined how manufacturing firms implement Energy Management Systems to enhance their overall energy performance. The authors identified specific challenges associated with implementing energy management systems in manufacturing environments, including the complexity of production processes, the variability of energy consumption patterns, and the difficulty of developing suitable baseline methodologies that reflect changes in production output.

The Energy Management Maturity Model focuses on the factors that help manage energy use in buildings. Antunes et al. [27] provided research to better understand some of these factors, such as the complexities of establishing and tracking energy-use baselines due to occupant behaviors, the weather-related use patterns, and the operational scheduling of a building's normal operations. Through this research, the authors hope that building operators can use this information to understand how to create energy management maturity and continually develop their knowledge and capacity for best energy management practices. In Cotton et al. [28], the authors examined the impact of developing energy literacy in higher education by examining how implementing ISO 50001 provides both an educational opportunity and an operational benefit. The results showed that institutions implementing an EMS can both reduce energy use and enhance students' sustainability education. Additionally, Leonidou et al. [29] investigated what dynamic capabilities create eco-based advantages and eco-based performance for Global Hotel Chains. In particular, how and why systematic Energy Management implementations lead to competitive positioning opportunities within the hospitality industry. The authors found that hotels that achieved ISO 50001 EMS certification saw an increase in guest comfort satisfaction and a reduction in their operational energy consumption, thus dispelling the myth that integrating energy-efficiency measures may reduce the quality of hospitality service.

Public sector and governmental organizations: Limited research has investigated ISO 50001 in government environments. The slow rate of adoption by government entities has hindered the amount of research completed in this area [30, 31]. However, recent research shows that

energy management within public-sector organizations is a significant area for development. Rudberg et al. [32] explored a strategic view of energy management as practiced in public and semipublic organizations. The authors also identified several unique challenges that differ from those seen in other industries, namely, political decision-making processes, constrained budget availability, and diffuse accountability. Munguia et al. [33] examined how implementing energy efficiency in public buildings is a key step toward achieving the objectives outlined in the UN 2030 Agenda for Sustainable Development. This study illustrated how the introduction of ISO 50001 helps achieve Sustainable Development Goal 7: Affordable and Clean Energy, as well as other associated objectives. The authors emphasized that public-sector organizations adopting ISO 50001 serve as role models for promoting community-wide energy efficiency.

4.4 Regional and national implementation studies

European Union: Thollander and Palm [34] have provided an extensive review of energy management in the European Union's industrial sector, examining the policy instruments, voluntary agreements, and regulatory frameworks that facilitate improvements in energy efficiency. They found that the EU Energy Efficiency Directive's provision allowing ISO 50001 certification as an acceptable alternative to mandatory energy audits created significant incentives for implementation, particularly in industries with high energy consumption. Fleiter et al. [35] explored the characteristics associated with the adoption of energy efficiency measures in the German industrial sector, including factors that positively influence the decision to adopt, as well as those associated with the successful implementation of energy efficiency technologies. They concluded that when regulatory compliance is paired with financial incentives (e.g., tax relief provisions that provide for the certification of energy management systems), there are particularly strong incentives for implementation. Brunke et al. [23] conducted an empirical study to evaluate barriers and facilitators to implementing energy conservation measures and energy management practices in the Swedish iron and steel sector. Their investigation found that a number of barriers unique to the iron and steel sector inhibit the adoption of energy conservation measures, including technical barriers related to complex process integration and capital-intensive improvements, as well as organizational barriers related to competing investment priorities and the need for rapid return on investment.

North America: Boyd et al. [36] highlighted the evolution of ENERGY STAR EPI used to benchmark Industrial Plant Manufacturing Energy (MIE) in the United States. This research was conducted prior to the development of ISO 50001, but provided an initial basis for the systematic measurement of Energy Performance by improving methods for identifying and developing measurements that would inform future Energy Management Systems. Lawrence et al. [37] approached a specific energy consumption (SEC) concept, used in the Energy Management System to improve the efficiency of Industrial Energy Usage by providing an understanding of the measurements used in developing a Performance Indicator, and clearing up the confusion and inconsistency caused by these energy performance metrics

that have made it difficult to use ENERGY STAR EPIs to create meaningful benchmarking.

Asia: Zhang et al. [38] assessed the mediating role of managers' environmental concern in the relationship between external pressures and firms' energy conservation practices in China. Results revealed that external pressures mediated the relationship between managers' environmental concerns and firms' energy conservation activities, given the positive relationships between external pressures (regulations, customer expectations, and competition) and both managers' environmental awareness and commitment. Tanaka [39] analyzed Japan's policies and practices that encouraged energy efficiency in the manufacturing sector, examining a combination of regulatory and voluntary measures to increase Japanese industry's energy efficiency. Findings indicate that mandatory energy management regulations for identified energy-intensive factories have played a vital role in laying the foundation for the subsequent implementation of the ISO 50001 standard in Japan. An international comparison of CO₂ emissions in the iron and steel industry by Kim and Worrell [40] has provided a sector-based view of the potential for energy efficiency and the hurdles to achieving energy-efficiency savings in this sector. Results highlighted distinct technological adoption patterns and the relative ease with which efficiencies can be improved across national contexts.

Developing countries and emerging economies: Hasan et al. [1] conducted a detailed investigation of energy management methods used in energy-intensive businesses in Bangladesh. The investigation examined barriers, drivers, and experiences in implementing energy management practices among energy-intensive enterprises in a developing country (Bangladesh) in South Asia. The results of this study indicate that some of the main obstacles faced by small and medium-sized enterprises in adopting ISO 50001 are the lack of a sufficient number of competent energy auditors and consultants, the lack of sufficient capital resources for financing certification and/or improvements to existing energy-intensive processes, and the lack of knowledge of the benefits associated with ISO 50001 Certification.

Pereira et al. [41] studied rural electric power/energy access and energy poverty in Brazil as a means of developing a better understanding of the issues related to energy access and energy efficiency in developing countries (Brazil) economies. The authors identified the need to combine approaches related to basic energy access with improved energy efficiency in emerging economic contexts. The regional comparison presented in Table 5 illustrates stark contrasts between developed economies, where ISO 50001 is supported by established policy frameworks and financial incentives, and developing nations that struggle with infrastructure gaps, workforce shortages, and awareness deficits.

Table 5. Cross-national study of ISO 50001 adoption: regulatory frameworks and institutional support mechanisms in global contexts

Region/Country	Authors	Study Focus	Key Findings	Policies/Incentives
European Union	Thollander & Palm [34]	Industrial sector in EU	Review of policy instruments, voluntary agreements, regulatory frameworks	EU Energy Efficiency Directive: ISO 50001 certification as alternative to mandatory energy audits
Germany	Fleiter et al. [35]	Energy efficiency adoption in industry	Regulatory compliance + financial incentives (tax relief) = strong implementation incentives	Tax relief provisions for EnMS certification
Sweden	Brunke et al. [23]	Iron and steel sector	Technical barriers: complex process integration, capital-intensive improvements Organizational barriers: competing investment priorities, rapid Return on Investment (ROI) requirements	Sector-specific barriers
United States	Boyd et al. [36] Lawrence et al. [37]	ENERGY STAR EPI Benchmarking	Evolution of systematic energy performance measurement; SEC concept	Foundation for future EnMS
China	Zhang et al. [38]	Mediating role of managers' environmental concern	External pressures (regulations, customer expectations, competition) → managers' awareness → energy conservation practices	Regulatory and market pressures
Japan	Tanaka [39]	Energy efficiency policies and practices	Mandatory energy management regulations for energy-intensive factories → basis for ISO 50001 implementation	Regulatory requirements
Bangladesh	Hasan et al. [1]	Energy-intensive enterprises	Barriers: lack of competent auditors/consultants, insufficient capital, lack of awareness of benefits	Developing country challenges
Brazil	Pereira et al. [41]	Rural electricity access and energy poverty	Need to combine basic energy access + energy efficiency improvements	Emerging economies

4.5 Sectoral deep-dives

Hasanbeigi et al. [42] developed conservation supply curves for the cement industry in Thailand. Their research provided a detailed technical and economic assessment of the opportunities for the cement industry to improve its efficiency through achieving compliance with the ISO 50001 requirements. The methodology developed by Hasanbeigi and colleagues allowed organizations to systematically assess, assess and prioritize energy efficiency investments consistent with the planning requirements of ISO 50001. Trianni et al. [43] performed a study that contrasted barriers to industrial energy efficiency in Europe. In their comparison study, they identify technical barriers that are inherent to the foundry sector, and generic barriers that were organizational and financial. The authors found that the success of energy management efforts will depend heavily on tailoring your strategy to your specific operations. Apeaning and Thollander [44] studied Ghana's largest industrial zone and determined what inhibited the implementation and what facilitated the implementation of energy-efficient industrial improvement programs (through consideration of economic conditions). Based on their work, it was possible to gain insight into the barriers to implementing energy-efficient industrial operations in Africa by identifying shortfalls in supporting infrastructure, human resource shortages, and financing challenges. These barriers are especially prevalent in a developing economic industrial environment. Paramonova et al. [45] found that Swedish energy-intensive industries have a large, untapped potential for economically efficient utility savings, despite the presence of strong energy-efficiency legislation in Sweden, suggesting that the energy-efficiency gap may be attributable to complex systemic issues that extend beyond the economics of energy-efficient industrial operations. Prashar [46] describes how SMEs in the food industry implemented Energy Management systems with virtually no funding. Prashar also discusses the challenges associated with adopting these practices and how SMEs overcame them. Table 6 synthesizes sector-specific implementation studies, revealing that while all industries benefit from ISO 50001 certification, each sector faces distinct technical, organizational, and operational barriers that require tailored implementation strategies.

4.6 Organizational behavior and culture

Lo et al. [47] examined multiple factors and the effectiveness of different strategies for enhancing pro-environmental behavior within the organization. They found that if organizations want to manage energy efficiently, they must implement changes at all levels, from the shop floor to the executive suite, and they provided multiple ways organizations can help build and maintain an energy-aware culture. Latan et al. [48] examined how enterprise-level environmental strategy and management commitment affect corporate environmental performance and explored how environmental management accounting can serve as a link between the two. They concluded that an organization's environmental improvement is more likely to occur when formal mechanisms, such as ISO 50001 certification, exist to support management's implementation of energy efficiency goals, and that these mechanisms serve as a pathway for creating a direct correlation between management's intentions and actions through systematized means of

measuring, tracking, and holding accountable for an organization's performance. Paillé et al. [49] assessed the effect of an organization's HRM practices at the employee level on the organization's environmental performance. Through his studies, he found that an organization's HRM practices, including employee training, performance evaluations that incorporate environmental criteria, and rewards/recognition systems aligned with sustainability objectives, had a significant impact on pro-environmental behaviors related to conserving energy in the organization's workplace.

4.7 Emerging trends and future directions

Using large-scale data to develop new business models for unlocking the circular economy, Jabbour et al. [50] examined the relationships among energy management, resource efficiency, and circular economy principles. Their findings indicate that future implementations of ISO 50001 will increasingly align with broader circular economic strategies.

Digital transformation: Medojevic et al. [51] investigated how Industry 4.0 concepts are transforming energy and environmental management systems, drawing on evidence from Serbian manufacturing companies. Their study indicated that digital technologies such as the Internet of Things (IoT), Big Data Analytics, and Artificial Intelligence (AI) can increase the effectiveness of energy management systems. Tymoshenko et al. [52] studied the impact of Industry 4.0 concepts on the modeling of energy scenarios in developing economies. Their research suggests that through digital transformation, developing countries can leapfrog traditional energy management approaches; however, there is still a need for large-scale capacity building and infrastructure development.

ESG and Sustainability Integration: Research by Berg et al. [53] documented confusion stemming from divergence among ESG Rating Agencies and highlighted the extent to which organizations struggled to demonstrate consistent sustainability performance. While they did not specifically address ISO 50001, they provided insight into how standardized frameworks, such as ISO 50001, can furnish organizations with more consistent and verifiable assessments than the multitude of proprietary ESG Assessment Models. Gillan et al. [54] reviewed one area of ESG and CSR research within Corporate Finance. Their findings illustrated a greater integration of environmental performance, in general, and energy efficiency, in particular, into traditional Corporate Governance and Corporate Financial Decision-Making. They concluded that as the pressures associated with the Business Case to adopt ISO 50001 continue to grow, so too will the adoption of ISO 50001. Ronalter et al. [55] described how Quality Management and Environmental Management Systems can serve as a business selection tool to assist organizations with improving their ESG performance. Their results indicate that organizations that have achieved ISO Certification, including ISO 50001, have generally higher ESG Scores and Ratings than organizations that are not ISO Certified; conversely, having an ISO Certification provides organizations with a greater market incentive to pursue ISO Certification, independent of energy cost savings.

Table 6. Industry-specific energy management system implementation: sectoral challenges and performance outcomes of ISO 50001 certification

Industrial Sector	Authors	Study Focus	Key Findings	Sector-Specific Challenges
Manufacturing	Gopalakrishnan et al. [12]	Structured methodology for manufacturing	Integration of EnPI into production monitoring systems; technical, organizational, and cultural aspects	Complexity of production processes, variability of energy consumption patterns
Manufacturing	Jovanović & Filipović [5]	Energy Management Maturity Model	Assessment of current capability levels and pathways for advancement	-
Manufacturing	Javied et al. [15]	EnMS implementation in manufacturing	Challenges: process complexity, consumption variability, baseline methodology difficulties	Production output changes
Commercial Buildings	Antunes et al. [27]	Energy Management Maturity Model for buildings	Complexities: occupant behaviors, weather-related patterns, operational scheduling	Occupant behavior
Higher Education	Cotton et al. [28]	Energy literacy impact	Energy use reduction + enhanced student sustainability education	Educational and operational opportunity
Hospitality (Hotels)	Leonidou et al. [29]	Dynamic capabilities for eco-advantage	Increased guest satisfaction + reduced energy consumption	Dispelling myth of reduced service quality
Public Sector	Rudberg et al. [32]	Energy management in public organizations	Challenges: political decision-making processes, constrained budgets, diffuse accountability	Slow adoption rate in government
Public Sector	Munguia et al. [33]	Energy efficiency in public buildings	Connection to Sustainable Development Goal (SDG) 7 and sustainability objectives; role modeling for community-wide efficiency	Social responsibility
Process Industries - Cement	Hasanbeigi et al. [42]	Conservation supply curves for cement industry	Technical and economic assessment of efficiency opportunities	Thailand
Foundry	Trianni et al. [43]	Barriers to industrial energy efficiency	Technical barriers inherent to sector + generic organizational and financial barriers	Need for operation-specific tailoring
Energy-Intensive Manufacturing	Apeaning & Thollander [44]	Ghana's largest industrial zone	Infrastructure shortfalls, human resource shortages, financing challenges	African developing economy barriers
Swedish Energy-Intensive Industries	Paramonova et al. [45]	Untapped efficiency potential	Energy efficiency gap despite good legislation = complex systemic issues	Beyond economics
Food & Beverage (SMEs)	Prashar [46]	EnMS implementation with minimal funding	Practical implementation in resource-constrained SMEs	SME challenges and solutions

4.8 Comparative and meta-analyses

Marimon et al. [11] conducted a comparative analysis of the diffusion of the ISO 14001 standard across sectors of activity. The research primarily focused on environmental management; however, the research provided several methods for developing analytical approaches to ISO 14001 management system standard adoption patterns, which were subsequently used by authors studying ISO 50001. Fonseca et al. [10] developed a map of the relationship between ISO management system standards and the Sustainable Development Goals. Their research identified numerous connections between ISO 50001 and many sustainable development goals beyond SDG 7 (Affordable and Clean Energy), including SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Singh and Lalk [56] studied the barriers to improving energy efficiency in the medium to large-sized manufacturing businesses operating in South Africa. The comparative evaluations of the various scales of the manufacturing facilities allowed researchers to see how the size of the organization affects the success factors and challenges of energy management system implementation

4.9 Critical perspectives and limitations

Sardianou and Genoudi [57] studied the factors influencing consumers' willingness to adopt renewable forms of energy. These findings provide a foundation for understanding the underlying motivations and barriers to changing energy consumption behaviors. Their research indicates that similar economic and psychological factors affect the energy decisions of individuals and organizations. Sola and de Paula Xavier [58] found that organizational human factors pose barriers to energy efficiency in industrial electrical motors. Their study highlighted the behavioral and organizational dimensions often overlooked in purely technical studies and emphasized the importance of integrating organizational and technical aspects within ISO 50001's systematic approach. Rohdin and Thollander [59] documented both barriers to energy efficiency and driving forces behind it in non-energy-intensive manufacturing in Sweden. Their work showed that energy management issues are not confined to large energy consumers but will require different solutions for factories in which energy costs are a small percentage of total costs.

5. Success factors and enablers

For the successful implementation of energy management, an essential element is the commitment of the highest levels of management. Such leadership commitment should include not only verbal support but also a variety of physical actions (e.g., allocating dedicated resources, systematically incorporating energy considerations into capital budgeting processes, and developing an organizational infrastructure that trains employees at all levels of the organization in energy management) [60]. Without support from leadership, energy initiatives may remain peripheral opportunities rather than a core part of business operations. An organization's structure has a significant influence on its effectiveness in Energy Management Practices. Multinational Corporations (MNCs) appear to be more successful than the average domestic

corporation in adopting and implementing EMSs. This advantage comes from MNCs having access to international knowledge networks, establishing best practices in their operations worldwide, and having increased financial capacity to invest in more advanced and energy-efficient technologies. These cross-border knowledge transfer mechanisms, such as the sharing of expertise, the diffusion of management practices, and the allocation of financial resources, significantly affect the speed at which a subsidiary reaches full maturity in its Energy Management Practices [61].

Discussing how environmental regulations affect companies, especially in energy management, continues to support what is sometimes referred to as the "Porter hypothesis." That is, rather than being a source of net cost, strict environmental regulations may encourage company innovation and competitive advantage [62]. A meta-analysis of studies done across several countries has shown that flexible environmental regulations can help companies to create green innovation, and that, in particular, the narrow version of the Porter hypothesis is true when regulatory frameworks both (1) provide companies with clear expectations on performance (via environmental targets) and (2) allow for flexibility in how companies meet their performance expectations [63]. When environmental regulations set targets without specifying exactly which technologies to use to achieve them, they can encourage both operational efficiency and technological innovation [63, 64]. The recognition of ISO 50001 certification as an acceptable means for companies to comply with environmental regulations demonstrates the effectiveness of this design for environmental regulation compliance [64]. ISO 50001 reduces administrative burden for companies that have received the certification and simultaneously creates positive incentives for all companies that manage their energy systematically. Therefore, if appropriately structured, regulations can promote rather than inhibit company performance.

Even at the most basic level, energy management should not be viewed solely as reducing energy costs; industrial energy efficiency provides many benefits in the form of improvements in maintenance requirements, product quality, process reliability, and production capacity, and these operational improvements contribute positively to the financial performance of a company through many avenues beyond direct energy cost reduction [65]. Longitudinal studies of organizations that use systematic methods for managing emissions, such as establishing energy management systems, show improvements in financial performance over time [66]. These findings highlight that the traditional viewpoint that there is a trade-off between financial and environmental objectives is incorrect. The findings of the study illustrate the opportunity for organizations to maximize their financial and environmental objectives through systematic management practices. Voluntary agreements for energy efficiency have been found to be successful when established with clear performance commitments, credible monitoring and verification processes, and significant consequences for organizations that do not comply with their commitment [67]. In addition, these programs are more effective when combined with

technical assistance and financial incentives to help organizations overcome many of the challenges they face in improving energy performance on their own [68]. For small and medium enterprises, technical assistance programs paired with financial incentives are of significant importance because of the limited technical expertise and capital that these organizations possess, which limits the extent to which they can engage outside specialists.

Carbon pricing mechanisms, when combined with the adoption of voluntary management systems, increase organizational efficiency [69]. Price signals provide financial incentives to reduce emissions, while management systems, such as ISO 50001, enable organizations to identify and implement opportunities for improvement. Therefore, combining market-based mechanisms with voluntary standards creates opportunities for synergy in policy frameworks and initiatives. With advances in understanding occupant behavior patterns, energy management can become increasingly sophisticated, especially in commercial building environments [70]. Understanding that technical systems have behavioral contexts has influenced a new generation of energy management approaches that optimize technical systems and engage users in the process. The emergence of digital transformation offers new opportunities for implementing energy management systems [71]. The use of IoT sensors allows for a more granular and immediate view of energy consumption across multiple systems and locations. AI applications can create pattern recognition, anomaly detection, and predictive maintenance. Advanced analytics offer improved baseline modeling and performance measurement [72], thereby resolving many of the technical issues that have limited the effectiveness of traditional approaches to energy management.

While the above technologies support systematic management approaches such as ISO 50001, ISO is a framework for effectively using digital tools, allowing organizations to develop coherent strategies that maximize the value of technology investments and provide actionable insights, rather than creating data without the ability to act on it. The creation of net-zero and zero-energy building concepts sets an aspirational performance target for many energy management systems [73]. The performance targets defined within these frameworks also link operational energy management systems to broader decarbonization objectives, demonstrating how implementing ISO 50001 enables organizations to make transformational changes rather than merely incremental improvements.

6. Barriers and challenges

There are multiple resource availability constraints that organizations encounter when implementing energy management systems, as well as five major categories of barriers, as observed in the analyzed implementation experiences. The first barrier is related to limitations for resources, which include a lack of skilled workers with energy expertise, insufficient capital to purchase required hardware or software for initial implementation or monthly operation, as well as time restraints due to competing priorities of other functions within the organization and a lack of sufficient, robust technology to accurately monitor, measure, and analyze energy use. The second barrier concerns the

knowledge gap. The majority of organizations lack personnel with the knowledge needed to understand energy systems, energy measurement techniques, and energy performance optimization methods. The knowledge gap includes not only technical personnel but also managers making investment decisions and operations personnel who directly impact daily energy usage at the organizational level [74].

The third barrier to organizations appears to result from organizational resistance. Organizational resistance includes cultural barriers as well as competing priorities. To effectively manage energy through a comprehensive energy management system, employees must adopt behavior changes and new work practices. This often encounters resistance from employees who are comfortable with the current routine. In an organization where a culture does not support energy performance improvement, technical solutions alone will be inadequate [14]. Lastly, the technical complexity of the energy management system poses significant challenges for organizations, particularly smaller ones without the resources to develop in-house expertise in energy management. This means all aspects of energy systems are complex because they require integrated interactions among different equipment types, manufacturing processes, and building systems; thus, the organization needs sophisticated analytical equipment and processes to identify optimization opportunities and verify the resulting improvements.

There are a number of external factors, such as regulatory uncertainties, volatile energy prices, and a limited number of qualified service providers, that add to the hurdles faced by small- to medium-sized enterprises with limited resources [68]. A management system that is already established typically raises the question of whether ISO 50001 provides value beyond what is already present in environmental management systems (e.g., ISO 14001) and/or duplicates what they can already do. Studies show distinct benefits to implementing ISO 50001, even for organizations already ISO 14001-certified [75]. The energy management system provides not only a specific focus on measurable performance improvement but also a number of other capabilities based on energy-specific metrics that are not part of today's more general environmental management systems. Achieving synergies among multiple management systems will require intentional, direct efforts [76]. Organizations need a coherent, integrated framework to leverage similarities across documentation, audit processes, and management reviews while maintaining each standard's unique focus. Once multiple management systems have been successfully integrated, they each provide additional support to the others; for example, ISO 50001 and ISO 14001 certifications are associated with better performance in building sustainability assessments, such as LEED and BREEAM [6].

When you add the operational management component on how to effectively implement and integrate energy management with lean manufacturing principles, there are additional opportunities for synergy that produce benefits beyond what a standalone ISO 50001 usually provides [77]. This supports the concept of integrating energy into your existing operational improvement processes (not treating energy management as a separate process) [78].

Energy efficiency measures often face significant bias in the corporate capital budgeting process [79]. As a result of this bias, many energy investments outperform other types of investments in terms of the financial returns they generate for the company but face a more rigid evaluation process and a shorter (i.e., more difficult-to-achieve) payback period than other types of investments. This creates an inherent tension for companies that invest in improving their energy efficiency: Energy efficiency projects are seen as a way to reduce operating costs rather than as a strategic investment, resulting in their systematic undervaluation within corporate capital budgeting decision-making frameworks.

7. Energy situation in Iran

Iran has significant energy resources, but it does not use them efficiently. Iran uses energy wastefully. Iran lacks a system to manage its energy resources effectively. Iran's energy consumption is much higher than that of other OECD member countries. These countries are members of the OECD. The OECD is a group of developed nations. Iran's high energy consumption makes it difficult to understand how energy is used across the country. Iran's energy usage is unclear due to this. Iran needs to make better use of its energy resources, especially given its abundant energy reserves. Thus, there is a complication in effectively managing and utilizing its abundant, diverse renewable resources due to poor decision-making [80]. It has been found that the increasing Iranian energy demand is the result of interrelated processes, including the increasing Iranian population and urbanization rates, government-set low energy prices, and a lack of enforcement mechanisms for efficient-use regulations [81, 82]. While the Iranian demographic and urbanization processes create unprecedented demand, the structures fail to perfectly align demand with efficient-use incentives [81, 83]. It is worth noting that Iranian energy subsidies contribute to inefficient use patterns and practices across industrial and other sectors [82, 84]. The Iranian energy subsidies, although highly popular politically and intended to ensure proper energy use in Iran, are characterized by deeply entrenched practices that are difficult to change [82, 85].

The residential sector accounts for a large share of final energy use, mainly due to extensive use of natural gas for space heating and a poorly insulated building stock [86]. The building stock in Iran is highly inadequate in thermal performance, mainly due to the lack of basic insulation, glazing, and passive design [87, 88]. Geographical analysis has shown substantial variation in energy use and carbon emissions, mainly due to climatic, economic, and urban factors [83]. Over the years, electricity demand has steadily increased, mainly due to the rise in household appliances and industrial growth [89]. The increase in the number of air conditioners, refrigerators, washing machines, and consumer electronics has significantly altered the dynamics of residential electricity demand, while industrial growth has substantially increased base loads [90, 91]. Scenario analyses demonstrate that until efficient interventions are implemented, electricity demand in Iran is expected to increase exponentially, and demand for fuel and carbon emissions are likely to accelerate [84, 89]. This scenario makes the traditional supply-side approach, which involves constructing new capacity, both financially challenging and

environmentally unsustainable. Environmentally speaking, Iran ranks among the top 12 countries in CO₂ emissions, and the increase in emissions is primarily driven by growing energy demand [83]. The carbon intensity of Iranian emissions is illustrative not only of the considerable reliance on and dependence on fossil fuels but also of their inefficient consumption throughout the entire supply chain. Decomposition analysis has shown that improvements in energy consumption efficiency have mitigated increases in emissions during periods of sustained economic growth [92]. The industrial sector presents both obstacles and opportunities in Iran's energy context. The energy demand of industries such as petrochemical, steel, cement, and aluminum is high in both fuel oil and electricity, and they often employ obsolete technologies and processes [93]. The lack of energy management in many of these industries indicates that even simple energy-saving measures remain untouched. The lack of a comprehensive energy auditing and benchmarking process hampers industries' ability to identify opportunities for improvement [94].

Transportation is one of the challenges that Iran faces regarding energy. The country consumes a large amount of fuel for transportation, thereby increasing overall energy demand. This increases the overall energy demand. In addition, it leads to a dirty environment due to the air that is produced by the fuel. Most of Iran's cars consume a lot of fuel and, in addition, affect the country's surroundings. Public transportation is also not good in most cities [93]. The government now helps citizens cover fuel costs, leading most citizens to prefer driving personal cars to using public transportation. Therefore, this affects the country's environment and leads it to consume more energy than it needs [85]. Transportation in Iran is a problem that should be addressed. The overwhelming academic view clearly indicates one conclusion: Iran's basic energy problem does not lie in the lack of energy resources, but rather in the inadequacies of managing its demand, as well as its failure to adopt effective management approaches for its energy [83,95]. Addressing these systemic deficiencies requires transformative policy reforms, institutional strengthening, capacity development, and the adoption of internationally proven management frameworks that can drive continuous improvement across all energy-consuming sectors [94, 95]. Prior to framework development, Iran's baseline requires precise benchmarking. Figure 4 provides a comprehensive Our World in Data-style multi-panel analysis covering trends from 2000 to 2025.

The four-panel visualization reveals critical insights across key metrics. Panel 1 tracks energy intensity, measured in koe/GDP, where Iran follows a thick red trajectory, declining slowly from 250 to 220, while the World black line drops sharply from 130 to 95, with a widening shaded gap contrasting with the EU's efficient purple decline from 120 to 70. Panel 2 compares 2024 per capita consumption in GJ/person, positioning Iran grey at 110 mid-pack between Saudi Arabia's high gold outlier at 250 and India's low lime at 25. Panel 3 displays Iran's stacked energy mix dominated by 71% maroon gas share. Panel 4 presents GDP-Intensity-EJ bubbles, where Iran registers as a large red bubble (12.8 EJ total, \$14k/capita, 220 intensity) versus a massive World grey aggregate [96-100].

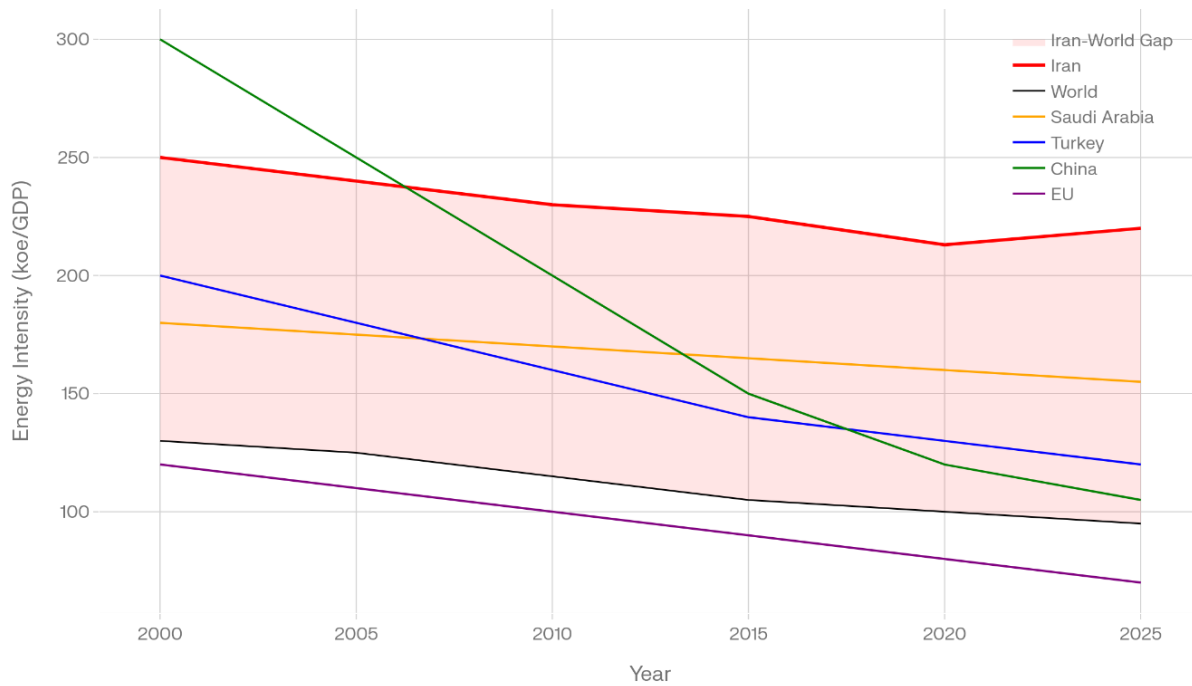


Figure 4. Iran Energy Profile vs Global Benchmarks (2000-2025)

8. ISO 50001 adoption in Iran: current status and prospects

ISO 50001 is a much more effective international tool and approach that helps increase energy performance by planning, doing, monitoring, and evaluating, and even evaluation can be defined. ISO 50001 also offers the Plan-Do-Check-Act approach, which is considered a successful method for energy management that helps define energy references and goals and monitor improvements [24]. In Iran, academic analysis of ISO 50001 is mostly focused on the case, design, and evaluation, rather than on the adoption process [101]. The reason is that the adoption process is just beginning, and academic studies also recognize that information and knowledge gathered in the early stages will facilitate improvements in later stages [101, 102]. Energy management maturity models are full of information and help organizations interpret their progress towards excellence and assess their energy performance. Notable research was conducted by Antunes et al., who developed a maturity model demonstrating how organizations progress from ad-hoc and reactive approaches to highly advanced and proactive approaches for complete integration with business, as well as strategic approaches to energy management. Organizations utilizing ISO 50001 begin their implementation process with a maturity model that identifies low levels characterized by limited data collection and management engagement [103]. Studies on international comparisons have shown that the rate of implementation of ISO 50001 in developing countries, and Iran in particular, is lower than in developed countries due to differences in financial and technical capabilities [104]. The "energy efficiency gap" hypothesis, which highlights the phenomenon of underinvestment in energy-efficiency opportunities, is apparent in developing countries because the distinct barriers they face converge in an overwhelming manner and reinforce one another [105].

The barriers to energy efficiency can be classified under the headings of economic barriers, such as lack of access to finance and investment; information barriers, such as lack of data and awareness of energy performance; and technical knowledge barriers and resistance to change in organizations. However, rising energy costs and environmental issues are increasingly prompting organizations to adopt a formalized energy management system [44]. The cut in energy subsidies in Iran, a politically contentious move, has altered the paradigm regarding the cost-effectiveness of investing in energy efficiency for industry and business [84]. In addition, growing awareness of climate change and local air quality is gradually serving as an intangible driver encouraging organizations to adopt environmental responsibility as a factor in their reputation within formalized management systems [104].

Evidence from existing organizational implementations confirms that the full implementation of ISO 50001 within organizational decision-making structures can yield savings of 3%-20% across industry and public institutions [24, 106]. Strategies for savings and opportunities lie in several fruitful sources, such as reducing non-value-added activities, exploiting equipment capabilities, improving maintenance activities, advancing technology in implementing ISO 50001, and a paradigm shift toward reducing energy consumption in organizations [106]. Beyond direct energy savings, ISO 50001 implementation generates important co-benefits that extend organizational value. These include enhanced data availability and quality, which enable better operational decision-making across multiple domains; improved employee awareness and engagement with resource efficiency; strengthened organizational discipline through systematic procedures and documentation; and enhanced credibility with external stakeholders, including customers, regulators, and financial institutions. For organizations

pursuing broader sustainability objectives or quality certifications, ISO 50001 integrates naturally with complementary management systems, including ISO 9001 for quality and ISO 14001 for environmental management. Where an organization is established based on generic goals for sustainable projects and certification in an organization pursuing certification based on general quality and environment, ISO 50001 is found to naturally support certification on overall quality ISO 9001 and environment ISO 14001 certification [103].

Although the adoption of ISO 50001 is beneficial, its adoption in Iran is voluntary; however, this has significant implications for integration and the promotion of policies aimed at ensuring nationwide adoption. This indicates that the adoption of ISO 50001 is driven solely by individual organizations' interests, as there are no financial or competitive forces serving as stimuli [104]. One significant lesson from other nations is the rapid adoption of energy management systems in response to compelling policy imperatives [107]. The development status of ISO 50001 in Iran may be in its embryonic stage, but it is highly promising [104]. A few trailblazing organizations demonstrated the capability and effectiveness of establishing ISO 50001, thereby setting the momentum for large-scale adoption [101, 102]. However, an odd number of innovative organizations may not generate sufficient momentum for the large-scale adoption of ISO 50001, a requirement that requires careful intervention [44, 107].

9. Proposed framework and recommendations

Based on the synthesis of the peer-reviewed literature, it is clear that an optimal way to improve energy efficiency in Iran requires an overarching, comprehensive, and multi-layered approach that combines policy transformation, the establishment of management systems based on ISO 50001, and technological development. All of this must be accomplished at different levels: national policy design, organizational management practices, and individual practices, taking into account that an optimal transformation requires consistency at all levels [108]. Based on a synthesis of peer-reviewed literature, Iran's energy efficiency requires a multi-layered approach across policy, organizational, urban, and transition levels. Figure 5 establishes Section 9's graphical centerpiece, systematically cascading recommendations from national policy instruments through organizational execution to urban adaptation, culminating in sustainable transition outcomes. Each level addresses specific Iranian challenges while leveraging ISO 50001's proven methodology.

9.1 National policy level: strategic reorientation

In terms of national policy, energy studies have consistently emphasized the need to shift from a supply-side approach to demand management and efficiency. Iran's energy policy has focused on expanding generation and distribution networks to meet rising demand and has paid little heed to managing demand through efficiency improvements. Such a mindset can be associated with institutional settings and the country's political economy, which favor large projects and have the requisite skills and expertise [108]. However, scenario studies have shown that efficiency measures have better economic and environmental

payoffs than infrastructure projects [109]. A policy shift in this matter needs to integrate many important elements. One of those important elements is energy pricing reform. This can itself serve as a starting point for any country, given its impact on energy demand driven by subsidized prices. It can become challenging for policymakers to redesign their subsidies, but segmented support for disadvantaged groups can help. International best practice shows that effective reforms have been successful in many countries in environments with ingrained subsidized schemes [110].

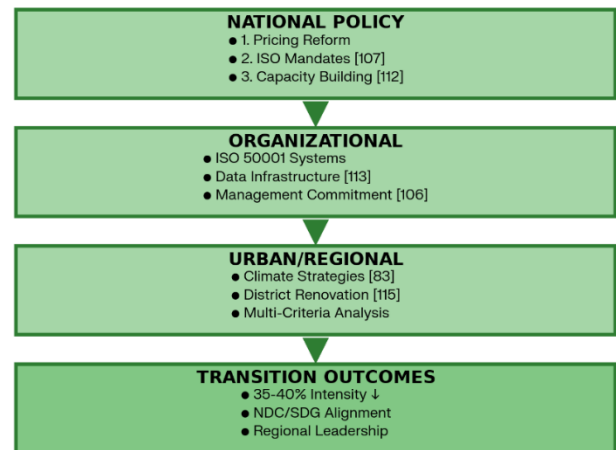


Figure 5. Iran's multi-level energy management framework

Second, the development of regulatory frameworks for energy efficiency establishes a baseline for expected performance. This includes building requirements that meet a basic standard for a building's thermal efficiency, the prohibition of the least efficient appliances, and basic requirements for industry efficiency as a condition for operating licenses [111]. These policies work best when a strong enforcement system and a corresponding series of updates are implemented. Third, making ISO 50001 part of the national policy instruments in the form of mandates for big energy users, fiscal rewards for voluntary adoption, or use preferences by government agencies when purchasing from certified companies can go a long way in hastening the spread of energy management systems. Already, some nations have made a success of such policies, starting with mandates for energy management systems in large industrial complexes, supplemented by tax holidays, energy audits, and easier loans with special interest rates offered to small- and medium-scale companies. Iran can adopt such strategies, beginning with public companies and followed by mandates in the country's industrial sectors [107]. Fourth, to enhance national capabilities in efficient energy use, there is a need to invest in education, training, and knowledge dissemination. The development of national certificates for training energy managers and auditors, and learning demonstrations that highlight best practices in energy management, can help fill the capability gap that has been a constraint in the past. Technical and learning institutions, such as higher education institutions, play an important role in training future generations of energy experts with the knowledge and skills required to implement the solutions [112].

9.2 Organizational level: systematic energy management

At an organizational level, ISO 50001 can and should become the primary working tool for continuous improvement [106]. This has been vindicated by the structured implementation of an energy management system in industry, which has increased energy visibility [106, 113]. The development of a comprehensive system for collecting and analyzing energy data is the starting point of successful energy management. To that end, detailed data on energy use and behavioral patterns regarding the firm's energy consumption across its various facilities, processes, and activities are needed. This would require investment in the necessary infrastructure, such as metering, data, and analysis systems that can translate energy consumption into intelligence. The development of technologies such as smart meters and energy analytics systems has reduced the costs of advanced energy management systems [113]. Integrating ISO 50001 into national industrial and construction standards and regulations, through financial incentives and reporting, would go a long way toward accelerating its implementation. The mandatory reporting of energy performance standards, as in other countries, brings greater transparency, enabling benchmarking and the identification of laggards, thereby promoting change on their own turf. A comparison of performance with industry rivals fosters healthy competition that also contributes to compliance with standards and regulations in this area [107].

Effective ISO 50001 implementation needs to address typical organizational hurdles that hinder efficient energy management [44]. Top management commitment has been identified as the single most important factor in successful energy management, as it reflects priority, resource allocation, and attention, despite the inherent turbulence of the process [44, 106]. Specific organizational structures need to be put in place to address energy management duties, review energy performance, and integrate energy goals into organizational strategy and business planning [113]. Cross-functional integration is another critical dimension that affects energy performance, as energy issues cannot be addressed and optimized from a facilities and engineering perspective alone. The purchasing approach affects equipment energy efficiency, the production process affects operational patterns, and maintenance and people's behavior affect overall consumption [114]. The energy management system approach encourages organizations to examine energy implications from a cross-functional perspective, with a view to creating coordination mechanisms that integrate diverse activities with energy-efficiency objectives [113]. The continuous improvement procedures integrated into the ISO 50001 framework ensure that initial success is maintained and further developed over time [24]. Energy audits are conducted periodically to identify new opportunities in the technology domain as well as changes in organizational settings [44]. Management reviews are conducted to assess performance trends resulting from implemented actions. Internal audits are conducted within the organization to ensure that procedures are implemented and that areas are identified for further process development [24].

9.3 Urban and regional level: context-sensitive strategies

The urban and regional multi-criteria planning methods emphasize that energy solutions need to be tailored to local climatic and socioeconomic conditions. Iran's varied geography and climate, ranging from arid to semi-arid to humid subtropics and cold mountainous areas, pose entirely different demands on energy services and the technology mix [83]. The demand for heating and cooling energy is primarily driven by Iran's cold and hot regions, respectively, which require entirely different architectural and efficiency strategies for their buildings and equipment [112]. Urban structure and development patterns significantly affect energy consumption through several indirect pathways. Evidence suggests that compact, mixed land use with a prominent public transport network will require much less transport-related energy than a spread-out, car-dependent development pattern or land use type [115]. Density affects a building's climatic efficiency, and attached buildings will have lower heat loss than separate ones. Vegetation and surface materials affect the urban microclimate and cooling loads through processes such as evapotranspiration and albedo [112]. Research involving district-scale renovation has shown that integrating energy management, building renovation, and renewable energy can significantly reduce energy use in urban settings. A district-scale strategy can provide economies of scale, rather than dealing with buildings one by one, which is inefficient. Upgrades across the entire district can lead to energy savings of over 50% relative to the original energy use [115].

Multi-criteria decision methods offer a systematic means of comparing alternative approaches in the energy sector with respect to criteria such as cost, emissions, reliability, and acceptability. For hot, dry climates in particular, multi-criteria decision analysis methods have highlighted the relevance of passive cooling techniques, solar energy applications, and the water-energy connection [83]. Regional energy policies should also address socioeconomic aspects, income levels, work patterns, and development rates. Lower-income communities may need special support to implement energy-efficiency measures, whereas industrial areas must address larger energy users. A tourist region has varying demand levels across seasons and therefore requires flexible supply and storage solutions [94].

9.4 National energy transition: toward sustainable development

The analysis of national energy transitions for resource-dependent economies indicates that the institutionalization of energy management practices is a crucial factor in achieving sustainable development goals [116]. In this context, ISO 50001 provides a practical link between strategic aims and operational outcomes [106]. Studies that modeled comprehensive energy transition scenarios in Iran, exploring the shift from the present fossil fuel-based energy system to more sustainable ones, identified energy efficiency improvements as an important enabling factor in these transitions [109, 117]. The results showed that, in addition to renewable energy, fuel switching, and energy efficiency improvements, Iran can reduce carbon emissions while ensuring the energy services needed for economic

development. The Iranian case of economic growth and environmental quality warrants critical consideration of strategies to decouple economic performance from environmental degradation. Research evidence on Iran's emissions trend confirms that energy demand is a key driver of rising CO₂ emissions, with fossil fuels constituting a major source of greenhouse gas emissions [92]. It is not a fixed relationship, as strategic efforts can target energy efficiency and the proper management of energy demand to increase economic growth and reduce negative environmental impacts [92, 106]. Scenario analysis of Iran's future electricity supply and demand has particularly emphasized the need to adopt holistic approaches to increase energy efficiency. Indeed, if appropriate actions are not taken, electricity demand in Iran is likely to escalate over the next few decades due to economic expansion and rising living standards [109]. Indeed, addressing this demand with traditional approaches would likely be expensive and have adverse environmental impacts [109, 117].

The issue of energy policy analysis in the Iranian context shows the need for overall modifications in the following areas: The evaluation found that sector-level approaches have insufficient effect in driving positive change. A structured policy approach should be developed, in which the frameworks for cost structures, governance, and investment are reoriented toward efficiency and sustainability [108]. The use of optimization modeling techniques in sustainable future energy systems has been well chronicled. Such modeling methods assist in analyzing various options and can determine the optimal solution that would work well in a future scenario, even with uncertain parameters. For Iran, the application of optimization showed that energy saving ranks among the top priorities across all models and yields good returns under varying growth rates and fuel or technological costs [117]. Multi-criteria energy models become especially important for scenarios that involve many criteria to be satisfied simultaneously, such as the Iranian energy context, which aims to cover several criteria related to energy security, economic growth, and development. However, conventional energy models and decision-making focus only on optimizing energy use to meet future demand at the lowest cost. Nonetheless, current energy models account for the need for energy systems to meet certain societal criteria [83].

The following are required in implementing this integrated approach: energy pricing reform to factor in their correct costs, enforcement of binding energy efficiency standards, technical assistance to facilitate the implementation of ISO 50001, and the establishment of industry-based energy performance indicators necessary to facilitate the observation of improvement [94, 106, 110, 111]. Reforming subsidies in the energy sector has been considered one of the most imperative yet highly political aspects of Iran's ongoing transition [84, 110]. Case studies on the effects of subsidy reform show that, although price escalation can lead to short-term economic and political turmoil, the benefits of the reform measures include long-term efficiency gains, reduced budgetary pressures, and the competitiveness of renewable resources and efficiency technologies. For the reform to be considered successful, the design of the reform measures needs to be systematic, and these measures should include step-by-step implementation, compensation for the

vulnerable population, and communication about the reform's goals [110]. Energy performance indicators play several important roles in broader energy management systems [94]. They enable the creation of baselines and targets, as well as the assessment of progress and the measurement of relative performance. In the Iranian case, the development of sectoral energy performance indicators that account for the structural characteristics of the sector, such as climate, product mix, and technology mix, would increase the relevance and usefulness of the measurement systems [94, 118]. The use of renewable energy in Iran's energy infrastructure is also an important addition to energy efficiency, but it is also crucial that the policy frameworks supporting such use be appropriately formulated. Best practices based on international experience indicate that it is essential to provide supportive and stable policy environments, simplify the permitting regime, invest in grid infrastructure, and support technologies that mitigate the intermittency of solar and wind energy resources [119]. In Iran's case, with such highly favorable solar and wind resources, renewable energy can potentially meet a substantial share of the country's total electricity demand, especially following energy efficiency efforts that reduce aggregate demand [117].

Barriers to more effective use of energy in industrial plants remain significant and need to be addressed from an appropriate policy perspective [44, 94]. Barriers can be defined as the result of financial constraints, lack of capital, low payback periods, informational issues, insufficient energy audit, lack of knowledge about opportunities, organizational factors, lack of technical personnel, organizational goals, behavioral aspects, risk aversion, and organizational behavior affected by limited rationality of organizational decisions. Removal of barriers should involve an overall policy approach that combines various policy instruments targeting different types of barriers, none of which can alone achieve barrier reduction or desirable policy-level outcomes [44]. With such an approach, Iran can move from an energy paradox to an energy opportunity for sustainable, modernized development [108, 109]. With an abundance of resources, levels of inefficiency, mounting environmental concerns, and available management techniques, the optimum time for an energy shift has arrived [106, 108]. With sustained political support, capacity building, and learning experience, success in this area can be achieved [116]. The knowledge presented in this presentation provides an effective means for success, drawing on international success techniques and studies on Iranian energy systems reported in peer-reviewed articles [108, 109, 117].

10. Conclusion

This systematic literature review provides a comprehensive synthesis of global evidence on ISO 50001 Energy Management System implementation spanning 2000-2025, unequivocally confirming its proven efficacy across diverse sectors, organizational scales, and geographical contexts. Rigorous quantitative analyses consistently demonstrate first-year energy intensity reductions averaging 4.1%, with sustained improvements of 3.4% maintained over 12 years post-certification. Sector-specific peaks reach 26% reductions in Chinese manufacturing and 36-39% electricity

savings in governmental case studies in the Middle East (Saudi Arabia, SASO). Strategic projections underscore transformative potential: 50% global industrial adoption by 2030 could deliver 105 EJ primary energy savings, \$700 billion in operational cost reductions, and avoidance of 6,500 million metric tons of CO₂ emissions. Critical success factors emerge consistently across 72 international case studies. Top management commitment ranks paramount (65% prevalence), followed by organizational culture transformation toward energy consciousness, systematic technical capacity development, and enabling policy frameworks such as EU tax relief provisions and Energy Efficiency Directive alternatives to mandatory audits. Strategic system integrations amplify outcomes: ISO 50001 synergizes powerfully with ISO 9001/14001 quality and environmental frameworks and Lean Six Sigma methodologies, yielding collateral benefits, including 54% productivity enhancement, 48% operational efficiency gains, and measurable improvements in ESG ratings that are attractive to institutional investors. Implementation barriers remain formidable, particularly in developing economies. Financial constraints, technical skill deficiencies, data access limitations (42% prevalence), and entrenched cultural resistance impede progress. Iran exemplifies these challenges acutely, exhibiting energy intensity 2-3 times the global average due to subsidized pricing structures, aging industrial infrastructure, fragmented data systems, and institutional inertia despite abundant hydrocarbon reserves. The proposed Iran-specific framework strategically adapts core PDCA cycles through contextually relevant progression. Initial policy reforms target the restructuring of subsidies and the introduction of mandatory EnMS certification for large energy consumers. Subsequent organizational pilots establish baseline EnMS infrastructure and real-time energy monitoring systems. Parallel capacity-building initiatives develop certified energy auditor networks and integrate EnMS curricula within engineering programs. Final scaling phases deploy district-level building retrofits coupled with hybrid renewable integration, creating scalable replication models. This comprehensive roadmap delivers triple-bottom-line alignment with SDGs 7, 9, 12, and 13 while generating green employment and enhancing industrial competitiveness. This research delivers three substantive scholarly and practical contributions of enduring value. First, it establishes the most comprehensive global SLR to date, systematically bridging methodological gaps between developed-economy implementations and emerging-market adaptations. Second, it pioneers Iran-contextualized modeling that addresses critical gaps in the literature specific to subsidized energy economies. Third, it furnishes an immediately actionable implementation architecture, including detailed maturity assessment protocols, barrier mitigation matrices, and phased organizational roadmaps, ready for direct deployment by policymakers, industrial managers, and certification bodies. Iran faces a defining energy policy inflection point, where resource abundance paradoxically coexists with systemic inefficiency. ISO 50001 offers not merely technical compliance but strategic transformation, a proven architecture converting energy waste into sustainable competitive advantage. Realization demands unprecedented cross-sectoral alignment: presidential commitment must

cascade through ministerial reform, organizational leadership, and technical capacity at every level of implementation. The window for such systemic leapfrogging narrows as global decarbonization pressures intensify and domestic fiscal constraints tighten. Strategic action today positions Iran not only as an energy exporter but also as a regional sustainability leader.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the corresponding author.

Conflict of interest

The authors declare no potential conflict of interest.

References

- [1] Hasan, A.M., et al., A comprehensive investigation of energy management practices within energy intensive industries in Bangladesh. *Energy*, 2021. 232: p. 120932.
- [2] Fitzgerald, P., et al., Deeper and persistent energy savings and carbon dioxide reductions achieved through ISO 50001 in the manufacturing sector. *Sustainable Energy Technologies and Assessments*, 2023. 57: p. 103280.
- [3] Pandin, M., et al., ISO 50001 based energy management system: a bibliometric perspective. *International Journal of Energy Sector Management*, 2024. 18(6): p. 1938-1963.
- [4] Jeong, S. and J. Lee, Environment and energy? The impact of environmental management systems on energy efficiency. *Manufacturing & Service Operations Management*, 2022. 24(3): p. 1311-1328.
- [5] Jovanović, B. and J. Filipović, ISO 50001 standard-based energy management maturity model-proposal and validation in industry. *Journal of cleaner production*, 2016. 112: p. 2744-2755.
- [6] Brem, A., et al., How do companies certified to ISO 50001 and ISO 14001 perform in LEED and BREEAM assessments? *Energy efficiency*, 2020. 13(4): p. 751-766.
- [7] Fuchs, H., A. Aghajanzadeh, and P. Therkelsen, Identification of drivers, benefits, and challenges of ISO 50001 through case study content analysis. *Energy policy*, 2020. 142: p. 111443.
- [8] Sadabadi, A.A., N. Shahi, and F. Borhani, Change management in Iran's energy policies: analyzing the transition process from fossil fuels to renewable energies. *Energy Conversion and Management: X*, 2025: p. 101269.
- [9] Zarezadeh, M., Investigation of the challenges of establishing mandatory standards of building energy consumption criteria Labeling in Iran. *Advances in*

- the Standards & Applied Sciences, 2024. 2(4): p. 172-185.
- [10] Fonseca, L.M., J.P. Domingues, and A.M. Dima, Mapping the sustainable development goals relationships. *Sustainability*, 2020. 12(8): p. 3359.
- [11] Marimon, F., J. Llach, and M. Bernardo, Comparative analysis of diffusion of the ISO 14001 standard by sector of activity. *Journal of Cleaner Production*, 2011. 19(15): p. 1734-1744.
- [12] Gopalakrishnan, B., et al., A structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector. *Sustainable Energy Technologies and Assessments*, 2014. 7: p. 154-165.
- [13] Li, Y., X. Shi, and B. Su, Economic, social and environmental impacts of fuel subsidies: A revisit of Malaysia. *Energy Policy*, 2017. 110: p. 51-61.
- [14] Vikhorev, K., R. Greenough, and N. Brown, An advanced energy management framework to promote energy awareness. *Journal of cleaner production*, 2013. 43: p. 103-112.
- [15] Javied, T., T. Rackow, and J. Franke, Implementing energy management system to increase energy efficiency in manufacturing companies. *Procedia Cirp*, 2015. 26: p. 156-161.
- [16] Jabbour, C.J.C., et al., Unlocking the circular economy through new business models based on large-scale data: an integrative framework and research agenda. *Technological Forecasting and Social Change*, 2019. 144: p. 546-552.
- [17] Brucal, A., B. Javorcik, and I. Love, Good for the environment, good for business: Foreign acquisitions and energy intensity. *Journal of International Economics*, 2019. 121: p. 103247.
- [18] Atif, M., B. Liu, and A. Huang, Does board gender diversity affect corporate cash holdings? *Journal of Business Finance & Accounting*, 2019. 46(7-8): p. 1003-1029.
- [19] Liu, Y., A. Wang, and Y. Wu, Environmental regulation and green innovation: Evidence from China's new environmental protection law. *Journal of Cleaner Production*, 2021. 297: p. 126698.
- [20] Liu, J. and M. Zhao, Does environmental regulation promote green technology innovation in Chinese manufacturing? *Open Access Library Journal*, 2020. 7(7): p. 1-16.
- [21] Rautenstrauch, A., L. Markov, and V. Kräusel. Method for Evaluating and Identifying Energy-Efficient Process Chains for the Manufacturing of Press Hardening Tools Based on the Deming Circle. in *Global Conference on Sustainable Manufacturing*. 2022. Springer.
- [22] Wang, E.-Z. and T. Pan, Does ISO 50001 adoption reduce manufacturing energy intensity? Micro-evidence from China. *Economic Analysis and Policy*, 2025. 86: p. 653-672.
- [23] Brunke, J.-C., M. Johansson, and P. Thollander, Empirical investigation of barriers and drivers to the adoption of energy conservation measures, energy management practices and energy services in the Swedish iron and steel industry. *Journal of cleaner production*, 2014. 84: p. 509-525.
- [24] McKane, A., et al., Predicting the quantifiable impacts of ISO 50001 on climate change mitigation. *Energy policy*, 2017. 107: p. 278-288.
- [25] Alotaibi, S., et al., 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). *Sustainability*, 2025. 17(11): p. 5131.
- [26] Trubetskaya, A., O. McDermott, and S. McGovern, 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): p. 1-24.
- [27] Antunes, P., P. Carreira, and M.M. da Silva, Towards an energy management maturity model. *Energy policy*, 2014. 73: p. 803-814.
- [28] Cotton, D.R., et al., Developing students' energy literacy in higher education. *International Journal of Sustainability in Higher Education*, 2015. 16(4): p. 456-473.
- [29] Leonidou, L.C., et al., Dynamic capabilities driving an eco-based advantage and performance in global hotel chains: The moderating effect of international strategy. *Tourism Management*, 2015. 50: p. 268-280.
- [30] Bulkeley, H., et al., *Cities and low carbon transitions*. 2013: Routledge London. <https://doi.org/10.1080/08111146.2013.845133>
- [31] Liedtke, C., J. Buhl, and N. Ameli, Microfoundations for sustainable growth with eco-intelligent product service-arrangements. *Sustainability*, 2013. 5(3): p. 1141-1160.
- [32] Rudberg, M., M. Waldemarsson, and H. Lidestam, Strategic perspectives on energy management: A case study in the process industry. *Applied Energy*, 2013. 104: p. 487-496.
- [33] Munguia, N., et al., Energy efficiency in public buildings: A step toward the UN 2030 Agenda for Sustainable Development. *Sustainability*, 2020. 12(3): p. 1212.
- [34] Thollander, P. and J. Palm, Improving energy efficiency in industrial energy systems: An interdisciplinary perspective on barriers, energy audits, energy management, policies, and programs. 2012: Springer Science & Business Media.
- [35] Fleiter, T., S. Hirzel, and E. Worrell, The characteristics of energy-efficiency measures—a neglected dimension. *Energy policy*, 2012. 51: p. 502-513.
- [36] Boyd, G., E. Dutrow, and W. Tunnessen, The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use. *Journal of cleaner production*, 2008. 16(6): p. 709-715.
- [37] Lawrence, A., et al., Specific energy consumption/use (SEC) in energy management for improving energy efficiency in industry: Meaning, usage and differences. *Energies*, 2019. 12(2): p. 247.
- [38] Zhang, B., Z. Wang, and K.-h. Lai, Mediating effect of managers' environmental concern: Bridge between external pressures and firms' practices of energy

- conservation in China. *Journal of Environmental Psychology*, 2015. 43: p. 203-215.
- [39] Tanaka, K., Review of policies and measures for energy efficiency in industry sector. *Energy policy*, 2011. 39(10): p. 6532-6550.
- [40] Kim, Y. and E. Worrell, International comparison of CO2 emission trends in the iron and steel industry. *Energy policy*, 2002. 30(10): p. 827-838.
- [41] Pereira, M.G., M.A.V. Freitas, and N.F. da Silva, Rural electrification and energy poverty: Empirical evidences from Brazil. *Renewable and sustainable energy reviews*, 2010. 14(4): p. 1229-1240.
- [42] Hasanbeigi, A., C. Menke, and A. Therdyothin, The use of conservation supply curves in energy policy and economic analysis: the case study of Thai cement industry. *Energy policy*, 2010. 38(1): p. 392-405.
- [43] Trianni, A., et al., Barriers to industrial energy efficiency in foundries: a European comparison. *Journal of Cleaner Production*, 2013. 40: p. 161-176.
- [44] Apeaning, R.W. and P. Thollander, Barriers to and driving forces for industrial energy efficiency improvements in African industries—a case study of Ghana's largest industrial area. *Journal of Cleaner Production*, 2013. 53: p. 204-213.
- [45] Paramonova, S., P. Thollander, and M. Ottosson, Quantifying the extended energy efficiency gap—evidence from Swedish electricity-intensive industries. *Renewable and Sustainable Energy Reviews*, 2015. 51: p. 472-483.
- [46] Prashar, A., Towards sustainable development in industrial small and Medium-sized Enterprises: An energy sustainability approach. *Journal of Cleaner Production*, 2019. 235: p. 977-996.
- [47] Lo, S.H., G.J.Y. Peters, and G. Kok, A review of determinants of and interventions for proenvironmental behaviors in organizations. *Journal of Applied Social Psychology*, 2012. 42(12): p. 2933-2967.
- [48] Latan, H., et al., Effects of environmental strategy, environmental uncertainty and top management's commitment on corporate environmental performance: The role of environmental management accounting. *Journal of cleaner production*, 2018. 180: p. 297-306.
- [49] Paillé, P., et al., The impact of human resource management on environmental performance: An employee-level study. *Journal of Business ethics*, 2014. 121(3): p. 451-466.
- [50] Jabbour, C.J.C., et al., Digitally-enabled sustainable supply chains in the 21st century: A review and a research agenda. *Science of the total environment*, 2020. 725: p. 138177.
- [51] Malenović-Nikolić, J., Energy and Environmental Management System. *eNergetics 2023*, 2023: p. 41.
- [52] Tymoshenko, M., et al., The impact of industry 4.0 on modelling energy scenarios of the developing economies. *Journal on innovation and sustainability risus*, 2022. 13(4).
- [53] Berg, F., J.F. Kölbel, and R. Rigobon, Aggregate confusion: The divergence of ESG ratings. *Review of Finance*, 2022. 26(6): p. 1315-1344.
- [54] Gillan, S.L., A. Koch, and L.T. Starks, Firms and social responsibility: A review of ESG and CSR research in corporate finance. *Journal of Corporate Finance*, 2021. 66: p. 101889.
- [55] Ronalter, L.M., M. Bernardo, and J.M. Romani, Quality and environmental management systems as business tools to enhance ESG performance: a cross-regional empirical study. *Environment, Development and Sustainability*, 2023. 25(9): p. 9067-9109.
- [56] Singh, R. and J. Lalk, An investigation into the barriers to energy efficiency within medium to large manufacturing firms operating within the eThekweni municipal area. *South African journal of industrial engineering*, 2016. 27(3): p. 287-302.
- [57] Sardanou, E. and P. Genoudi, Which factors affect the willingness of consumers to adopt renewable energies? *Renewable energy*, 2013. 57: p. 1-4.
- [58] Sola, A.V.H. and A.A. de Paula Xavier, Organizational human factors as barriers to energy efficiency in electrical motors systems in industry. *Energy policy*, 2007. 35(11): p. 5784-5794.
- [59] Rohdin, P. and P. Thollander, Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden. *Energy*, 2006. 31(12): p. 1836-1844.
- [60] Böttcher, C. and M. Müller, Insights on the impact of energy management systems on carbon and corporate performance. An empirical analysis with data from German automotive suppliers. *Journal of cleaner production*, 2016. 137: p. 1449-1457.
- [61] Minbaeva, D., et al. MNC knowledge transfer, subsidiary absorptive capacity and HRM. in *Academy of management proceedings*. 2002. Academy of Management Briarcliff Manor, NY 10510.
- [62] Ramanathan, R., et al., Environmental regulations, innovation and firm performance: A revisit of the Porter hypothesis. *Journal of Cleaner Production*, 2017. 155: p. 79-92.
- [63] Zhang, W., et al., Revisiting the Porter hypothesis: a multi-country meta-analysis of the relationship between environmental regulation and green innovation. *Humanities and Social Sciences Communications*, 2024. 11(1): p. 1-15.
- [64] Sönnichsen, S.D. and J. Clement, Review of green and sustainable public procurement: Towards circular public procurement. *Journal of cleaner production*, 2020. 245: p. 118901.
- [65] Worrell, E., et al., Productivity benefits of industrial energy efficiency measures. *Energy*, 2003. 28(11): p. 1081-1098.
- [66] Delmas, M.A., N. Nairn-Birch, and J. Lim, Dynamics of environmental and financial performance: The case of greenhouse gas emissions. *Organization & Environment*, 2015. 28(4): p. 374-393.
- [67] Rezessy, S. and P. Bertoldi, Voluntary agreements in the field of energy efficiency and emission reduction: Review and analysis of experiences in the European Union. *Energy Policy*, 2011. 39(11): p. 7121-7129.
- [68] Thollander, P., M. Danestig, and P. Rohdin, Energy policies for increased industrial energy efficiency: Evaluation of a local energy programme for

- manufacturing SMEs. *Energy policy*, 2007. 35(11): p. 5774-5783.
- [69] Lilliestam, J., A. Patt, and G. Bersalli, The effect of carbon pricing on technological change for full energy decarbonization: A review of empirical ex-post evidence. *Wiley Interdisciplinary Reviews: Climate Change*, 2021. 12(1): p. e681.
- [70] Hong, T., et al., Advances in research and applications of energy-related occupant behavior in buildings. *Energy and buildings*, 2016. 116: p. 694-702.
- [71] Hossain, J., et al., A review on optimal energy management in commercial buildings. *Energies*, 2023. 16(4): p. 1609.
- [72] Zhao, H.-x. and F. Magoulès, A review on the prediction of building energy consumption. *Renewable and Sustainable Energy Reviews*, 2012. 16(6): p. 3586-3592.
- [73] Hernandez, P. and P. Kenny, From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). *Energy and Buildings*, 2010. 42(6): p. 815-821.
- [74] Rampasso, I.S., et al., Challenges presented in the implementation of sustainable energy management via ISO 50001: 2011. *Sustainability*, 2019. 11(22): p. 6321.
- [75] Laskurain, I., et al., Contribution to energy management of the main standards for environmental management systems: The case of ISO 14001 and EMAS. *Energies*, 2017. 10(11): p. 1758.
- [76] Uriarte-Romero, R., et al., Methodology for the successful integration of an Energy Management System to an Operational Environmental System. *Sustainability*, 2017. 9(8): p. 1304.
- [77] Pampanelli, A.B., P. Found, and A.M. Bernardes, A Lean & Green Model for a production cell. *Journal of cleaner production*, 2014. 85: p. 19-30.
- [78] May, G., et al., Energy management in manufacturing: From literature review to a conceptual framework. *Journal of cleaner production*, 2017. 167: p. 1464-1489.
- [79] Cooremans, C., Investment in energy efficiency: do the characteristics of investments matter? *Energy Efficiency*, 2012. 5(4): p. 497-518.
- [80] Hessari, F., Sectoral energy consumption in Iran. *Renewable and Sustainable Energy Reviews*, 2005. 9(2): p. 203-214.
- [81] Solaymani, S., A review on energy and renewable energy policies in Iran. *Sustainability*, 2021. 13(13): p. 7328.
- [82] Moshiri, S. Energy price reform and energy efficiency in Iran. in *IAEE Energy Forum*. 2013. <https://ssrn.com/abstract=2335755>
- [83] Ata, B., P. Pakrooh, and J. Péntzes, Driving factors of energy related CO₂ emissions at a regional level in the residential sector of Iran. *Scientific Reports*, 2023. 13(1): p. 17598.
- [84] Aryanpur, V., et al., How energy subsidy reform can drive the Iranian power sector towards a low-carbon future. *Energy Policy*, 2022. 169: p. 113190.
- [85] Breton, M. and H. Mirzapour, Welfare implication of reforming energy consumption subsidies. *Energy policy*, 2016. 98: p. 232-240.
- [86] Alayi, R., et al. Optimizing the thermal energy consumption in heating systems of residential buildings: A case study. in *AIP Conference Proceedings*. 2023. AIP Publishing LLC.
- [87] Fereidani, N.A., E. Rodrigues, and A.R. Gaspar, The effectiveness of the Iranian building code in mitigating climate change in Bandar Abbas. *Energy for Sustainable Development*, 2023. 76: p. 101266.
- [88] Ghouchani, M., et al., Thermal Performance Evaluation of TIM Combined with Residential Windows in Different Climatic Regions in Iran. *ICONARP International Journal of Architecture and Planning*, 2023. 11(2): p. 734-753.
- [89] Kari, B.M. and R. FAYAZ, Evaluation of the Iranian thermal building code. 2006. *Asian journal of Civil Engineering (Building and Housing)* Vol. 7, No. 6 (2006), Pages 675-684
- [90] Abbaspour, M., et al., Energy Demand Model of the Household Sector and Its Application in Developing Metropolitan Cities (Case Study: Tehran). *Polish Journal of Environmental Studies*, 2013. 22(2).
- [91] Rahmani, O., et al., An overview of household energy consumption and carbon dioxide emissions in Iran. *Processes*, 2020. 8(8): p. 994.
- [92] Mousavi, B., et al., Driving forces of Iran's CO₂ emissions from energy consumption: an LMDI decomposition approach. *Applied energy*, 2017. 206: p. 804-814.
- [93] Hosseini Nasab, E., et al., An analysis of energy consumption in transportation and industrial sectors—a multiplicative LMDI approach with application to Iran. *Iranian Economic Review*, 2012. 16(32): p. 1-17.
- [94] Fleiter, T., E. Worrell, and W. Eichhammer, Barriers to energy efficiency in industrial bottom-up energy demand models—A review. *Renewable and sustainable energy reviews*, 2011. 15(6): p. 3099-3111.
- [95] Karbassi, A., M. Abdulji, and E.M. Abdollahzadeh, Sustainability of energy production and use in Iran. *Energy Policy*, 2007. 35(10): p. 5171-5180.
- [96] Iran Energy Information. 2025 [cited 2026; Available from: <https://www.enerdata.net/estore/energy-market/iran/>.
- [97] Ritchie, H.R., Pablo. *Energy*. 2025 [cited 2026; Available from: <https://ourworldindata.org/profile/energy/iran>.
- [98] Iran: Primary energy consumption. 2023 [cited 2026; Available from: https://www.theglobaleconomy.com/Iran/prime_energy_consumption/.
- [99] Energy intensity level of primary energy (MJ)/\$2021 PPP GDP) - Iran, Islamic Rep. [cited 2026; Available from: <https://data.worldbank.org/indicator/EG.EGY.PRIM.PP.KD?locations=IR>.
- [100] eia. Country analysis brief: Iran. [cited 2026; Available from:

- https://www.eia.gov/international/content/analysis/countries_long/Iran/.
- [101] Ferrari, S., E. Bruni, and L. Bramonti, Effective implementation of ISO 50001: A case study on energy management for heating load reduction for a social building stock in Northern Italy. *Energy and Buildings*, 2020. 219: p. 110029.
- [102] Fuchs, H., et al., ISO 50001-based energy management systems as a practical path for decarbonization: initial findings from a survey of technical assistance cohort participants. *Energies*, 2023. 16(14): p. 5441.
- [103] Finnerty, N., et al., An energy management maturity model for multi-site industrial organisations with a global presence. *Journal of Cleaner Production*, 2017. 167: p. 1232-1250.
- [104] Lira, J.M.S., E.G. Salgado, and L.A. Beijo, Which factors does the diffusion of ISO 50001 in different regions of the world is influenced? *Journal of cleaner production*, 2019. 226: p. 759-767.
- [105] Gerarden, T.D., R.G. Newell, and R.N. Stavins, Assessing the energy-efficiency gap. *Journal of economic literature*, 2017. 55(4): p. 1486-1525.
- [106] Nelson, D.L., Initial Assessment of ISO 50001 Efficiency Improvements in Energy and Carbon Intensive Industrial Subsectors. *Clemson University*.
- [107] Johansson, M.T. and P. Thollander, A review of barriers to and driving forces for improved energy efficiency in Swedish industry—Recommendations for successful in-house energy management. *Renewable and Sustainable Energy Reviews*, 2018. 82: p. 618-628.
- [108] MOHAMMAD, K.B., S. HEIDARI, and M. ABRAVESH, Thermal performance evaluation of low-E coated building glazing systems. 2016.
- [109] Rüstemoğlu, H. and S. Uğural, CO2 emissions in Iran for 1990-2010: A decomposition analysis. *Applied Ecology and Environmental Research*, 2017. 15(4): p. 1833-1846.
- [110] Pourmoosavi, M.-A. and T. Amraee, Stochastic approaches to sustainable energy in Iran: Enhancing power system flexibility and renewable integration. *Sustainable Energy Technologies and Assessments*, 2025. 74: p. 104145.
- [111] 5 Things You Need to Know about ISO 50001 Energy Management. Available from: <https://blog.ifma.org/5-things-you-need-to-know-about-energy-management-with-iso-50001>.
- [112] Bazmi, A.A. and G. Zahedi, Sustainable energy systems: Role of optimization modeling techniques in power generation and supply—A review. *Renewable and sustainable energy reviews*, 2011. 15(8): p. 3480-3500.
- [113] Antunes, P., A maturity model for energy management. *Instituto Superior Técnico*, 2014. https://scholar.tecnico.ulisboa.pt/records/n8Q_-3HGo7LtEAAUQZLdrA0cbkt8D56avQoz
- [114] Rodrigues, E., et al., Climate change and ideal thermal transmittance of residential buildings in Iran. *Journal of Building Engineering*, 2023. 74: p. 106919.
- [115] Shahbaz, M., et al., The spatial distribution dynamic and convergence of CO2 emissions in Iran's provinces. *Environmental Science and Pollution Research*, 2022. 29(46): p. 69573-69587.
- [116] Trianni, A., E. Cagno, and S. Farné, Barriers, drivers and decision-making process for industrial energy efficiency: A broad study among manufacturing small and medium-sized enterprises. *Applied energy*, 2016. 162: p. 1537-1551.
- [117] Cagno, E. and A. Trianni, Exploring drivers for energy efficiency within small-and medium-sized enterprises: First evidences from Italian manufacturing enterprises. *Applied Energy*, 2013. 104: p. 276-285.
- [118] Trianni, A. and E. Cagno, Energy efficiency barriers in industrial operations: evidence from the Italian SMEs manufacturing industry. *Energy Productivity in Industry: Partners and Opportunities*, 2011. 12: p. 189-200.
- [119] Mohamad Taghvaei, V., et al., Economic growth and renewable energy in Iran. *Iranian Economic Review*, 2017. 21(4): p. 789-808.



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