Next Sustainability 8 (2026) 100506

Contents lists available at ScienceDirect

Next Sustainability

journal homepage: www.sciencedirect.com/journal/next-sustainability

Review article

Energy Management Systems (ISO 50001), carbon neutrality, circular economy and the sustainable development goals: A bibliometric and systematic review

Muhammad Ikram *, Jinane Es-sadki

School of Business Administration, Al Akhawyan University in Ifrane, Avenue Hassan II, P.O. Box 104, Ifrane, 53 000, Morocco

ARTICLE INFO

Keywords:
ISO 50001
Energy Management Systems
Carbon neutrality
Circular economy
Sustainable Development Goals
Bibliometric and Systematic Literature Review

ABSTRACT

Organizations are under increasing pressure to improve energy performance while simultaneously advancing net-zero commitments and circular economy transitions. However, the existing ISO 50001 literature remains fragmented, with limited integration between Energy Management System (EnMS) practices, decarbonization pathways, resource circularity, and SDG-oriented outcomes, creating a need to clarify how ISO 50001 can function as a strategic platform for low-carbon and circular transformation. Therefore, this study investigates the global research landscape of ISO 50001, examining how EnMS activities and sub-activities drive energy performance improvement, decarbonization, and alignment with the United Nations Sustainability Goals (SDGs). A hybrid methodology was employed, combining bibliometric mapping with a systematic review governed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, analyzing Scopus-indexed literature published between 2015 and 2025. Bibliometric analysis was conducted to delineate the intellectual framework, thematic evolution, geographic distribution, and major research trends of energy management, while a qualitative synthesis of 111 articles was performed to extract key ISO 50001-based EnMS activities and implementation practices. The bibliometric results highlight the leading journals, thematic clusters, research topics, and analytical approaches in ISO 50001 literature. The systematic synthesis identifies recurring links between energy planning, performance measurement, operational control, management review, organizational capability, and low-carbon management practices. Building on these findings, this study contributes to existing body of knowledge by proposing a conceptual multilayer integrated ISO 50001, net zero and circular economy model which offers actionable strategic insights for researchers, energy practitioners, and policymakers seeking to enhance ISO 50001 implementation for energy efficiency, resource retention, climate mitigation and sustainable development.

1. Introduction

The imperative to mitigate energy consumption and expedite low-carbon transitions has elevated global energy governance to a focal point of international sustainability policy [1]. By aligning with the United Nations Sustainable Development Goals (SDGs), contemporary frameworks derive institutional legitimacy for tackling climate and energy challenges by promoting access to reliable sustainable and modern energy while supporting broader objectives related to climate action, responsible production and sustainable industrial development [2,3]. In 2015, the UN General Assembly launched 17 goals designed to comprehensively address global social, economic, and environmental challenges [4]. Among these, SDG 7 on affordable and clean energy and SDG 13 on climate change are critical drivers for organizational energy strategies as they emphasize energy efficiency improvement, greenhouse gas reduction, and systematic integration of sustainability principles into institutional and corporate decision-making [5–7]. Improving energy performance has become an important pathway for mitigating climate change, while aligning with the Paris Agreement's ambitions and the global transition towards net-zero emissions [8,9]. Energy efficiency is widely recognized as one of the most cost-effective strategies for reduced emissions, low operational costs, and strong energy security [10]. Yet, achieving long-term energy performance improvement depends on structured management practices, continuous

* Corresponding author.
E-mail address: i.muhammad@aui.ma (M. Ikram).

https://doi.org/10.1016/j.nxsust.2026.100506
Received 16 June 2026; Received in revised form 15 August 2026; Accepted 9 September 2026

monitoring, organizational commitment, and evidence-based decision-making [11]. Therefore, formal Energy Management Systems (EnMS) play a strategic role as systematic frameworks for optimizing corporate energy use.

Recent literature highlights the increasing importance of ISO 50001 and EnMS research in the context of digitalization, energy transition, and sustainable industrial transformation. Wigger et al. [12] show how artificial intelligence (AI) can support energy consumption forecasting and anomaly detection in manufacturing energy management, while Pagulayan and Calderon [13] highlight the increasing relevance of ISO 50001 in AI-driven data centers, where cooling loads and power density create new energy-governance challenges. Similarly, Iturralde Carrera et al. [14] demonstrate that computational modeling, machine learning, and intelligent algorithms can strengthen Energy Performance Indicator (EnPI) development and dynamic energy baselining. Beyond ISO 50001-specific studies, Alka et al. [15] emphasize that sustainable energy enterprises require coordinated innovation capabilities, regulatory support, market responsiveness, and long-term sustainability orientation. These recent contributions indicate that EnMS research is moving from conventional energy monitoring toward intelligent, innovation-driven, and strategy-oriented energy governance.

While energy management is often viewed primarily as a tool for operational efficiency, the current industrial transition demands a broader approach than simply reducing energy intensity. Organizations are now expected to lower absolute emissions, decarbonize purchased energy, and redesign products and processes to extend material value through reuse, repair, refurbishment, remanufacturing, and high-quality recycling [16]. Within this broader context, ISO 50001 serves not only as a standard for managing energy use but also as an organizational discipline that connects operational efficiency with lifecycle thinking, procurement decisions, and product stewardship [17]. This perspective is particularly important in sectors where resource extraction, processing, logistics, use-phase behavior, and end-of-life management contribute significantly to carbon emissions [18]. Therefore, this review positions ISO 50001 within a comprehensive transition agenda that integrates energy performance, decarbonization, and circular economy practices at both the firm and value-chain levels.

The ISO 50001 standard, developed by the International Organization for Standardization (ISO), provides a systematic framework for implementing Energy Management Systems (EnMS) across various organizational contexts. Recognized internationally as the primary standard for energy management, it offers a structured approach for organizations aiming to control and optimize their energy performance [19]. Introduced in 2011 and updated in 2018, ISO 50001 outlines requirements for establishing, implementing, maintaining, and continually improving an EnMS. Its main objective is to guide firms through a systematic process to progressively enhance energy performance, focusing on efficiency, utilization, and consumption. Like other ISO management system standards, ISO 50001 is based on the Plan-Do-Check-Act (PDCA) cycle, which helps align energy management with broader corporate strategy, operational management, and performance evaluation [20]. Additionally, ISO 50001 certification provides external validation of an organization's systematic commitment to energy efficiency, thereby enhancing its credibility regarding sustainability, cost reduction, and climate mitigation efforts [21].

Prior studies suggest that adopting ISO 50001 can support improvements in energy efficiency, energy cost savings, operational control, employees' awareness, and emissions reduction [22–24]. Recent studies have often examined the standard through particular analytical lenses rather than fully connecting its research evolution with process-level EnMS activities and broader sustainability objectives. Previous contributions have addressed implementation barriers and challenges [25,26], certification and sector specific implementation experiences [23,27], integration with broader or comprehensive management systems [28], energy management maturity models [29], and energy performance outcomes in manufacturing contexts [30]. Although existing research provides critical perspectives on distinct dimensions of ISO 5000, these findings remain dispersed across sectors, methodologies, and thematic areas. This fragmentation highlights the need for an integrated systematic and bibliometric analysis to map the field's intellectual structure, clarify the main EnMS activities, and examine the standard's contribution to broader sustainability objectives, including SDGs, decarbonization and global energy transition.

While previous studies have demonstrated that ISO 50001 enhances measurement, operational control, and continuous improvement, the literature is less explicit about how these capabilities intersect with circular-economy objectives. Much of the existing discussion focuses on energy savings or direct emissions reduction, even as organizations increasingly face pressures related to material efficiency, supplier engagement, take-back systems, product durability, and end-of-life accountability [31]. This study identifies a significant gap, suggesting decarbonization opportunities depend more on design decisions, procurement specifications, logistics configurations, and reverse-flow recovery than on in-plant efficiency measures alone. The originality of this study lies in its integrated framework, where ISO 50001 serves as the managerial foundation, net zero as the decarbonization pathway, and circular economy as the resource governance principle that extends improvement beyond immediate operations. This approach allows the review to engage more directly with current discussions on industrial transformation, resilient supply chains, and sustainability-focused operations management.

This study addresses existing research gaps by providing a comprehensive, process-oriented analysis of ISO 50001's role in enhancing energy performance, promoting decarbonization, and aligning with sustainability objectives. Employing a dual methodology that combines systematic literature and with bibliometric analysis, the study consolidates fragmented ISO 50001 literature from 2015 to 2025, identifies key thematic clusters, and examines the EnMS activities and sub-activities that facilitate effective energy management in organizations.

The distinction from prior ISO 14001 analysis is also substantive. While ISO 14001 addresses environmental management across a broad range of environmental aspects, ISO 50001 is specifically structured around continual improvement in energy performance. Accordingly, the present study focuses on the core elements of ISO 50001, such as energy review, significant energy uses, energy baselines, performance indicators, operational control, design and procurement, competence, monitoring, and management review. Components related to the CE and SDGs are subsequently mapped onto this energy-management architecture as potential extensions, rather than being treated as inherent requirements of ISO 50001. Thus, this study provides a domain-specific synthesis of energy governance and its possible interfaces with decarbonization and circularity, rather than replicating the environmental-management framework developed for ISO 14001 [32].

This study contributes by developing a multilayer integrated model that connects ISO 50001, net zero, and circular economy principles. The proposed model broadens the traditional understanding of ISO 50001 by linking EnMS activities with decarbonization pathways, circular economy strategies, resource efficiency throughout the value chain, and outcomes aligned with SDGs. ISO 50001 is positioned as a managerial framework supporting energy efficiency, emissions reduction, circular procurement, eco-design, waste minimization, recovery, recycling, and sustained value creation. This integrated model conceptually demonstrates how energy management, net-zero transition, and circular economy practices as mutually reinforcing components within a unifies sustainability framework. The study also provides a comprehensive overview of ISO 50001 research and identifies future research directions to enhance the standard's impact on global climate objectives.

2. Methodology

2.1. Study design and literature selection

This study adopts and established procedure for bibliometric analysis [33] in combination with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure transparency, replicability and quality of the data selection [26,34]. The study selection followed the standard four core PRISMA phases: Identification, screening, eligibility, and inclusion. The study selection process followed the four core PRISMA phases: identification, screening, eligibility, and inclusion and one reporting mechanism. Recent PRISMA-based reviews emphasize the importance of transparent documentation and clear justification for retaining or excluding records at each stage [35]. In line with best practices in systematic reviews of sustainable energy systems, this study reports search strings, database filters, screening thresholds, eligibility logic, and synthesis boundaries to enhance reproducibility and reduce ambiguity [36,37]. Therefore, bibliographic cleaning, topical screening, full-text eligibility assessment, and final qualitative synthesis were conducted as distinct steps, rather than treating all exclusions as a single filtering decision.

Observed gaps in the ISO 50001 literature, the growing importance of EnMS in supporting decarbonization and net zero strategies, and the need to evaluate how ISO 50001 practices relate to broader climate governance mechanisms and SDGS motivated the formulation of cleaner research questions a priority to define the scope of the review.

To align the analytical protocol with the integrated ISO 50001 net zero circular economy model, the scope of the review was broadened beyond energy and carbon performance to also encompass material circularity and value-chain interactions. Accordingly, the revised screening framework incorporated additional terms such as “circular economy,” “resource efficiency,” “reuse,” “repair,” “refurbishment,” “remanufacturing,” “recycling,” “reverse logistics,” “closed-loop,” “ecodesign,” and “product stewardship,” alongside the existing ISO 50001 and decarbonization terms. The coding structure was also expanded to classify evidence across four interconnected dimensions: energy outcomes, carbon outcomes, material-circularity outcomes, and governance or coordination mechanisms.

This adjustment does not redefine ISO 50001 as a circular-economy standard; instead, it allows the review to examine how EnMS routines may support broader sustainability transitions when integrated with procurement, design, logistics, and post-use recovery strategies. The research questions (RQs) were developed as follow:

RQ1. : What ISO 50001-based EnMS activities and sub-activities are reported in the literature as driver of energy efficiency, decarbonization, and CE practices?

RQ2. : How does ISO 50001 integrated with net-zero and decarbonization pathways, CE strategies to established energy management frameworks, climate governance mechanisms in the literature?

RQ3. : How effective is ISO 50001 in improving energy performance, reducing carbon emissions, circular value creation and supporting SDGs?

The screening protocol was governed by explicit inclusion and exclusion criteria to improve reproducibility. Studies were included when they were published in English between 2015 and 2025, indexed in Scopus, classified as articles or reviews, and substantively addressed ISO 50001 or EnMS implementation, outcomes, governance, or related sustainability dimensions. Studies were excluded when they were duplicates, non-English publications, conference papers, editorials, notes, book chapters, or documents that did not provide a substantive connection to ISO 50001, EnMS activities, energy performance, emissions reduction, or related organizational practices.

Scopus was selected as the exclusive primary database due to its extensive multidisciplinary scope and superior international coverage. Prior bibliometric evaluations indicate that Scopus includes approximately 27,000–28,000 active peer-reviewed journals, offering a broader journal base than databases such as the Web of Science Core Collection. Singh et al. [38] and Ikram and Es-sadki [32] reported that nearly all journals indexed in Web of Science (approximately 99.11%) are also included in Scopus. This makes Scopus particularly suitable for the present study, as research related to ISO 50001 spans multiple academic disciplines, including energy management, environmental science, operations management, industrial engineering, corporate governance, and ecological economics. The broader disciplinary scope increases the likelihood of identifying relevant studies across these interrelated domains. Additionally, Scopus provides enhanced representation of research from emerging economies, including localized studies from countries such as China and Japan. This expanded geographical scope is crucial for fostering a more comprehensive global understanding of ISO 50001 implementation.

Guided by these RQs, the Scopus search was executed on 21 January 2026, and the final export used for screening was downloaded on the same date. The search covered publications published between 1 January 2015 and 31 December 2025. The core Scopus logic was structured as follows: *TITLE-ABS-KEY (("ISO 50001" W/2 carbon*) OR ("ISO50001" W/2 carbon*) OR (CO2 W/2 "ISO 50001") OR (CO2 W/2 ISOS0001) OR ("ISO 50001" W/2 "carbon neutral*") OR ("ISO50001" W/2 "carbon neutral*") W/3 ("circular economy" OR "resource efficiency" OR reuse OR repair OR refurbish* OR remanufactur* OR recycl* OR "reverse logistics" OR "closed-loop" OR ecodesign)) OR (('ISO 50001" OR ISO50001 OR "energy management system*" OR "energy management" OR "energy efficiency") W/4 ("net zero" OR "net-zero" OR"zero-carbon" OR decarboni*))*. The complete search string utilized in Scopus is presented in Fig. 1. A wide search string was developed by merging ISO 50001 related terminology with energy management systems, energy efficiency, decarbonization, carbon emissions, net-zero, sustainability and clean energy keywords. Boolean and proximity operators were utilized to optimize the search, ensuring it was both exhaustive and highly targeted. To maintain alignment with the targeted domain, the search string limited results to publications containing “ISO 50001, ISO50001 or energy management system" alongside at least one carbon related concept such as *carbon, CO2, carbon neutral, net-zero, zero-carbon, decarbonization (including decarbonizing variants), greenhouse gas, circular economy,” “resource efficiency,” “reuse,” “repair,” “refurbishment,” “remanufacturing,” “recycling,” “reverse logistics,” “closed-loop,” “ecodesign,” and “product stewardship, sustainability, or sustainable development* within the title, abstract, or keywords. Main thematic nodes were combined using the AND operator while the OR was used for synonymous or closely related terms. The systematic workflow is illustrated in Fig. 1 alongside the search strategy and the resulting dataset.

Publications from 2026 were analyzed separately from the main review corpus (2015–2025) and were only included in the bibliometric or systematic dataset if they were indexed within the defined search period and identified by the final database search. Publications from 2026 cited in the introduction, discussion, or future-research sections serve as supplementary sources to contextualize recent developments beyond the review window, and do not affect the PRISMA counts, bibliometric networks, or qualitative coding outcomes.

To avoid ambiguity in the PRISMA flow, each reduction stage was assigned a distinct methodological purpose: the first stage involved cleaning and limiting the database output; the second stage screened for topical relevance through titles, abstracts, and keywords; the third stage assessed full-text eligibility; and the final stage retained only studies that provided extractable evidence for the systematic coding framework. The initial Scopus query yielded a total of 863 documents. All records were exported into R for cleaning, normalization, and duplicate detection using DOI matching, exact-title matching, and manual verification of near-duplicate variants. Before substantive screening, 199 records were removed: 46 duplicate records, 82 documents that did not meet the predefined article/review document-type criterion, 15 non-English

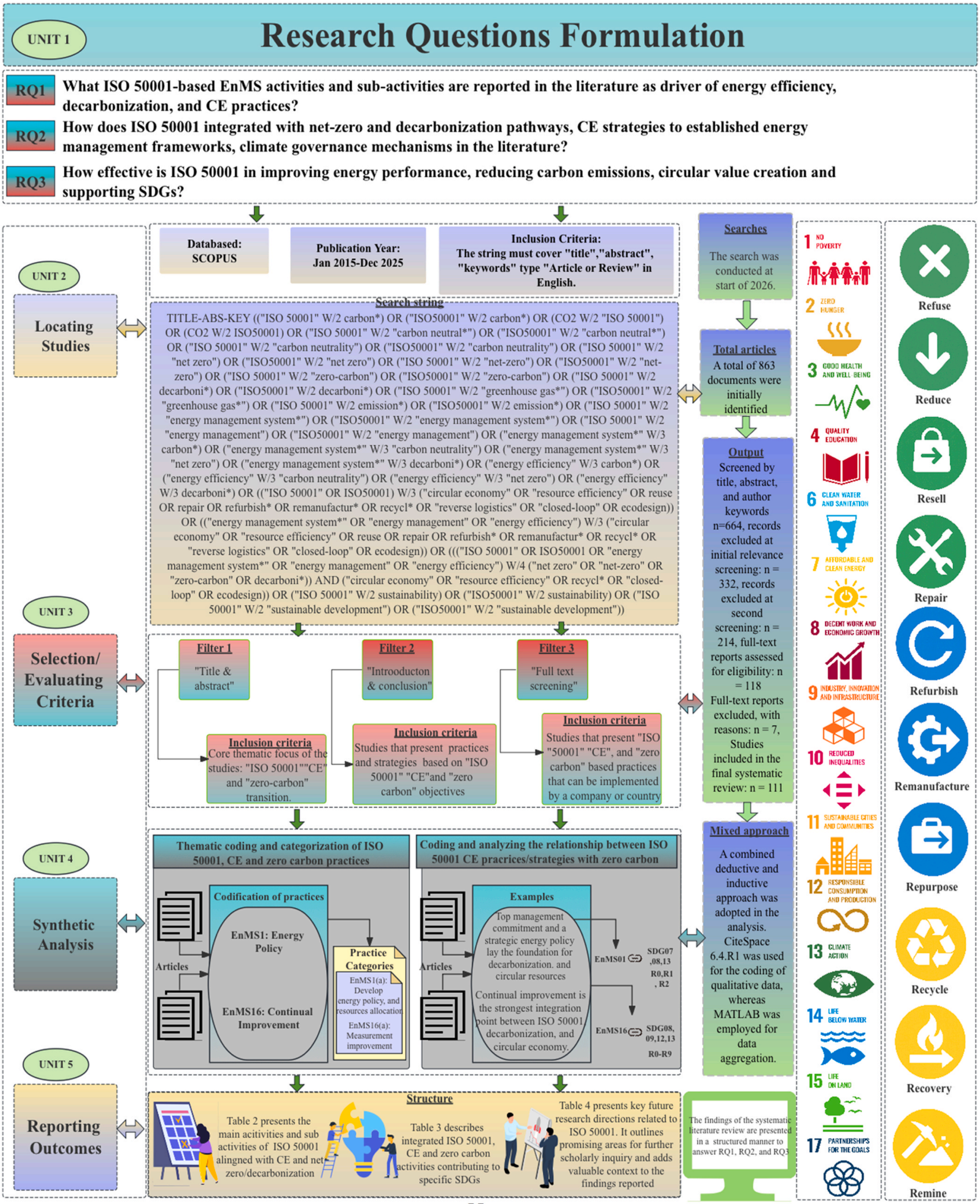

Fig. 1. PRISMA screening and methodological workflow.

publications, and 56 records that fell outside the specified publication period or scope. This left 664 records for title, abstract, and keyword screening. At this stage, 332 records were excluded because their focus did not sufficiently relate to ISO 50001 or Energy Management Systems (EnMS) in the context of energy performance, decarbonization, sustainability, resource efficiency, or the circular-economy dimensions considered in this review. As a result, 332 records remained and progressed to the second screening stage. The second screening involved a more detailed assessment of the abstracts and available article information against the eligibility criteria. A further 214 records were excluded because they did not provide sufficient substantive or analytical engagement with ISO 50001/EnMS within the scope of the review. This stage resulted in 118 reports being retained for full-text eligibility assessment. Following examination of the complete articles, 7 additional reports were excluded for documented full-text eligibility reasons: insufficient substantive focus on ISO 50001/EnMS ($n = 1$); no relevant energy-management/decarbonization evidence ($n = 2$); outside the organizational or policy scope defined for the review ($n = 3$); other prespecified eligibility reason ($n = 1$). These exclusions are reported in Fig. 1 according to the documented reason for exclusion, rather than being combined with the 214 records removed during the preceding screening stage. These 111 studies constitute the dataset used for the systematic synthesis and, where specified in the bibliometric methods, the corresponding bibliometric analyses.

The search strategy was intentionally broad at the identification stage; studies were not required to discuss ISO 50001, circular economy, and zero-carbon transition simultaneously to be included in the review pool. Instead, records were retrieved if they contained a clear ISO 50001 or EnMS anchor along with at least one adjacent sustainability domain, such as decarbonization, carbon emissions, net zero, sustainability, SDGs, circular economy, or resource efficiency. During revision of the search protocol, circular-economy and resource-efficiency terminology was incorporated explicitly into the search expression to improve coverage of the conceptual intersection examined in this review. Following this modification, the Scopus search was rerun using the revised query on 21 January 2026. The resulting dataset of 863 records replaced the earlier exploratory retrieval and constitutes the definitive source dataset used for screening, PRISMA accounting, bibliometric mapping, and systematic synthesis. All numbers reported in the manuscript and Fig. 1 therefore refer to this regenerated dataset. This broader retrieval logic explains why a sizeable number of studies remained after screening, even though only a smaller subset explicitly discussed circularity or net-zero framing. In the second screening stage, titles, abstracts, and author keywords were reviewed for alignment with the study's focus on ISO 50001 and Energy Management System (EnMS) practices related to energy performance, decarbonization, sustainability, and, where relevant, resource efficiency or circularity themes. At this stage, 214 records were excluded because they did not demonstrate a substantive link to ISO 50001 or EnMS implementation, or because they focused on general energy policy, unrelated technical optimization, or sustainability topics without meaningful ISO 50001 content. This resulted in 111 records for eligibility assessment.

To reduce selection bias, an independent screening approach was used at both the title/abstract and full-text stages, employing a shared decision sheet based on the inclusion criteria. Disagreements were resolved through discussion, and reasons for exclusion were recorded at each stage. The final qualitative coding of the 111 included studies was supported by a calibration round in which both authors independently coded a subset of the sample against the main EnMS categories and their associated sub-activities. Inter-coder consistency for this calibration round was assessed using Cohen's kappa, yielding $\kappa = 0.86$. After refining the codebook, the remaining papers were coded and cross-checked, with contested assignments resolved through discussion. Because the review included conceptual, empirical, and review-based articles, a light-touch quality appraisal was used to assess thematic relevance, clarity of method, specificity of reported practices, and adequacy of supporting evidence. This appraisal informed interpretation, but studies were not excluded solely on the basis of methodological design differences.

In the final stage, abstracts were read in full, and full texts were consulted when abstract information was insufficient to determine fit. The final review corpus comprised 111 articles. Fig. 1 presents the PRISMA-based screening logic. A hybrid coding approach was used: deductive coding was guided by predefined energy management systems derived from the ISO 50001 standard, while inductive coding identified emerging themes, and insights that extending beyond the initial analytical framework [39]. This approach aligns with systematic reviews that use standards-based frameworks to organize and synthesize management system study [40]. To ensure direct alignment with the research's core objectives, the synthesized results were structured around the three initial research questions: (i) Organizational adoption of ISO 50001-based practices for enhanced energy management and decarbonization (RQ1); (ii) the integration of ISO 50001 within broader net-zero strategies, energy management frameworks, and climate governance systems (RQ2); and (iii) the tangible impact of ISO 50001 on energy performance, carbon reduction, and relevant Sustainable Development Goals (RQ3). This organization maintains a focused analytical approach throughout the review.

2.2. Data analysis tools

This research utilized an integrated analytical approach supported by different software tools for data processing and bibliometric mapping. Initial bibliographic data extracted from Scopus database was managed and preprocessed in R via *Rstudio* to mainly clean the dataset, remove duplicates, filter keywords, and run preliminary frequency analysis. Moreover, to map and visualize the structural and thematic landscape of the ISO 50001 literature, CiteSpace (version 12.6.4 R1) was employed to visualize complex bibliometric networks, including evaluating author collaboration patterns, articles, co-citations, as well as keywords co-occurrence maps. The networks' structural integrity was validated by key topological metrics. Network fragmentation and group distinctiveness were evaluated via *Modularity (Q)*, and internal cluster homogeneity was assessed using the *Weighted Mean Silhouette (S)*. MATLAB was employed to aggregate, quantitatively analyze and visualize the coded results from the systematic review, facilitating aligned synthesis and the generation of charts/graphs [41]. Ultimately, combining bibliometric mapping with systematic review for both macro level view of the field's evolution and micro-level qualitative assessment of ISO 50001 implementation practices.

A distinction was maintained between evidence synthesized directly from the included studies and the conceptual extensions formulated in this review. Findings related to the implementation of ISO 50001/EnMS, energy-performance practices, barriers, enabling conditions, and reported organizational outcomes were considered as evidence derived from the literature when explicitly reported in the included studies. In contrast, connections between these EnMS practices and CE strategies or specific SDGs were regarded as analytical mappings unless the foundational study empirically investigated that relationship. The CE mapping was established by evaluating the extent to which a recognized practice is likely to support resource reduction, reuse, recovery, lifecycle extension, or associated circular principles. In contrast, the SDG mapping was based on alignment with official target descriptions and relevant literature. These mappings indicate conceptual alignment and potential contribution, rather than established causal effects on circularity or the achievement of SDGs.

3. Results

3.1. Bibliometric analysis results

The bibliometric findings were interpreted using both visual patterns and network indicators. The final network contained 443 nodes and 1848 links, with a density of 0.0189. The cluster solution yielded Modularity Q = 0.7204, Weighted Mean Silhouette S = 0.7937, and Link Retaining Factor (LRF) = 2.5, indicating that ISO 50001, carbon neutrality, SDGs, and CE practices exhibit excellent structural separation and internal coherence. These metrics demonstrate that the mapped clusters represent meaningful thematic groupings rather than being merely descriptive visualizations. The largest clusters were #0 Energy management system, #1 Production control, #2 Significant energy users, and #3 ISO 14001. Nodes with the highest betweenness centrality included, *Journal of Cleaner Production* (centrality=337), *Energy Management Systems* (centrality=415), and Carbon emissions reduction target (centrality=291), suggesting that these nodes bridge otherwise separated strands of ISO 50001 research.

3.1.1. Leading Journals in ISO 50001 research

The analysis of the top ten academic journals publishing research on ISO 50001 and carbon management topics between 2015 and 2025 reveals a highly centralized citation structure (see Fig. 2). *The Renewable and Sustainable Energy Review, Journal of Cleaner Production, Energy Policy, Applied Energy, Sustainability* emerge as the most influential journals, confirming its central role as the leading outlet for high-impact publications related to integrated energy management systems, decarbonization and net-zero studies. Collectively, these top energy-oriented journals account for the majority of academic impact, indicating that ISO 50001 research is strongly concentrated around the theme of energy transition. Other technical engineering outlets, including *Sustainable Energy Technologies and Assessments, IEEE Access, Energy Building, Energy Procedia, Applied System Innovation*, and *Journal of Engineering, Design and Technology* show the interdisciplinary nature of the topic demonstrating that ISO 50001 and decarbonization research spans energy management, corporate sustainability strategy and management frameworks.

The journal co-citation network shown in Fig. 2 indicates a concentrated publication structure around a small set of high-impact energy and sustainability outlets. *Renewable and Sustainable Energy Reviews, Journal of Cleaner Production, Energy Policy, Applied Energy, and Sustainability* occupy the most influential positions in the map, as indicated by large node size and, where applicable, high betweenness centrality. Specifically, *Journal of Cleaner Production* received 743 citations, *Renewable and Sustainable Energy Reviews* 618, *Sustainability* 318, *Energy Policy* 260, *Energies* 197, and *Sustainable Energy Technologies and Assessments* 59 citations. This quantitative reporting strengthens the interpretation that ISO 50001 research is still anchored primarily in energy-transition and industrial-sustainability journals, even as it becomes more interdisciplinary.

3.1.2. Top leading research areas in ISO 50001

The bibliometric analysis mapped several primary thematic clusters within the ISO 50001 literature. A total 12 distinct thematic domains were identified through keyword network science mapping, underscoring the interdisciplinary nature of ISO 50001 scholarship. The most critical clusters are synthesized below and presented in Fig. 3:

3.1.2.1. Energy Management System (Cluster #0). This is the largest and conceptually central hub of the network, indicating that ISO 50001is primarily studied as a structed organizational framework for deploying, sustaining, and optimizing energy management systems. This core cluster focuses heavily on the structural lifecycle of the standard, including institutionalizing energy policies, conducting formal energy reviews, establishing robust performance monitoring systems, and continual improvement loops. Because of its central positioning, this cluster acts as the theoretical foundation upon which other specialized research streams, such as production control, energy efficiency and sustainable energy, are build.

3.1.2.2. Production Control (Cluster #1). The second major theme represents the operational execution of ISO 50001. Rather than treating the standard purely as an administrative or managerial framework, research focuses on how energy management practices are translated into production processes, emphasizing energy conservation tactics, process optimization and operational monitoring. The prominence of this cluster

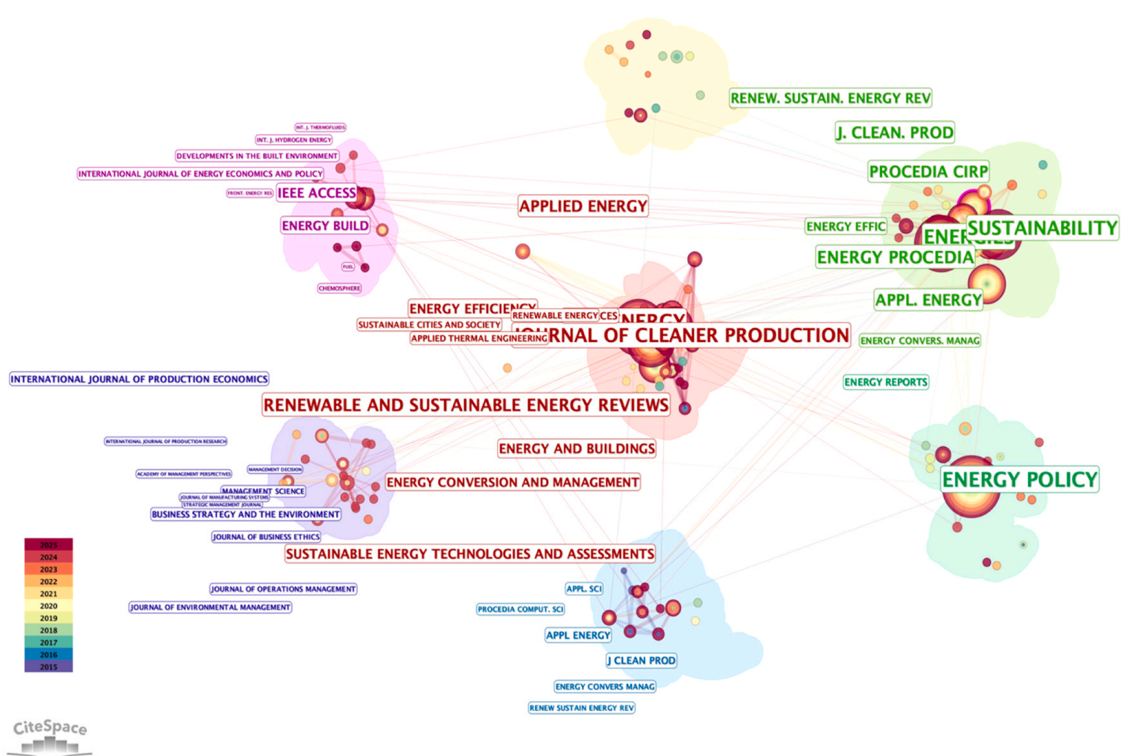

Fig. 2. Top scientific journals in the ISO 50001, net zero and circular economy.

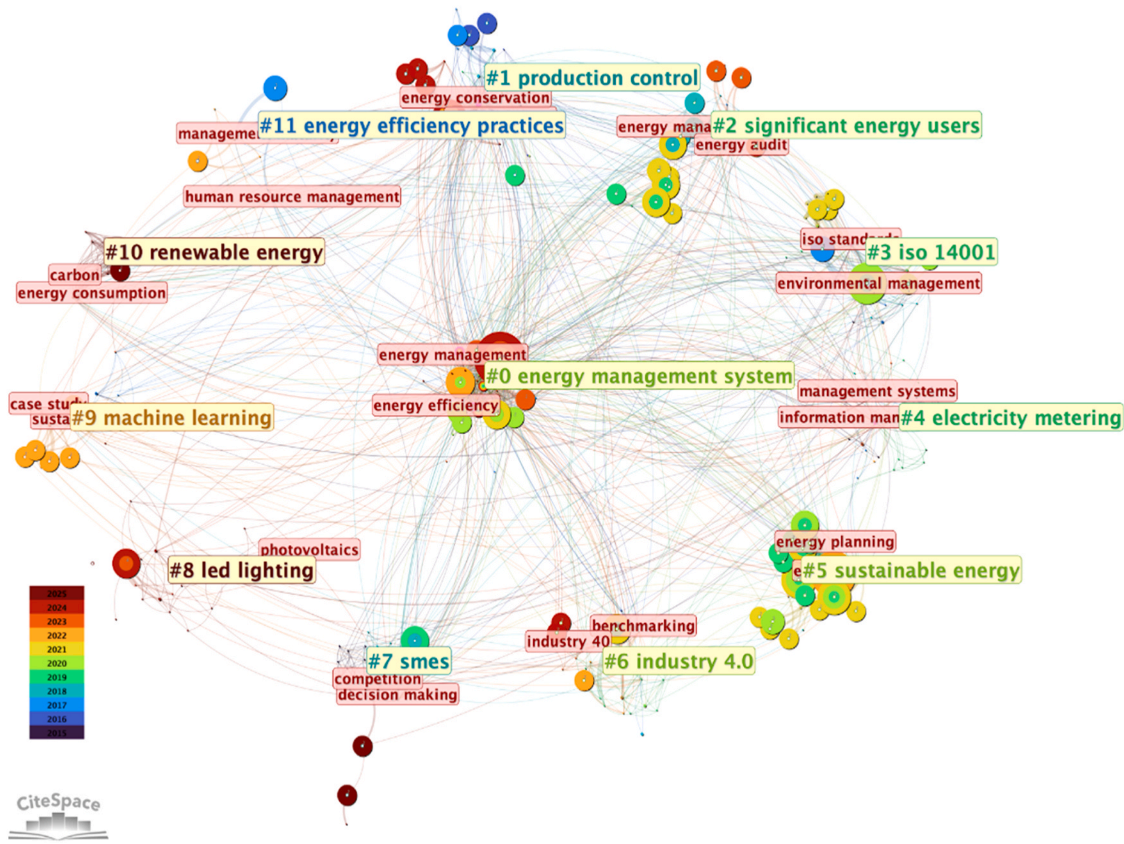

Fig. 3. Leading thematic clusters in ISO 50001 research.

highlights the standard's deep integration with industrial operations, where real time production control is crucial for reducing energy consumption and improving efficiency.

3.1.2.3. Significant Energy Users (Cluster #2). Focusing on one of the core technical mandates of ISO 50001, this cluster captures how organizations systematically isolate, analyze and govern areas of substantial energy consumption. The co-occurrence of related terms such as energy audit and energy management indicates that studies in this field explores how firms leverage data, audits and energy reviews to isolate primary consumption sources and develop targeted improvement actions. This cluster underscores the performance-driven nature of ISO 50001, where energy savings directly depend on the precise management of high-impact equipment and processes.

3.1.2.4. ISO 14001 (Cluster #3). This fourth major thematic area explores the convergence of ISO 50001 with ISO 14001 environmental management standards and broader corporate sustainability strategies. The emergence of this cluster indicates that ISO 50001 is often studied in relation to environmental management systems and cohesive sustainability strategies. This alignment reflects the structural compatibility between energy and environmental management standards, notably for firms aiming to harmonize energy efficiency, carbon footprint mitigation and overall environmental performance. The cluster also indicates a macro-level perspective, positioning ISO 50001 as a component of a broader integrated management framework and not as an isolated energy standard.

Beyond these top clusters, the bibliometric landscape also revealed several specialized clusters, including machine learning, energy conservation and energy planning. These themes indicate that ISO 50001 literature has diversified across various organizational contexts, technologies, and analytical approaches. This diversification demonstrates that ISO 50001 scholarship has matured, evolving from a focus on the implementation of formal energy management systems to a comprehensive research agenda that addresses operational control, digitalization and sustainable transitions.

3.1.3. Thematic Approaches in ISO 50001 Research

To complement the identification of the main thematic areas, the cluster map illustrated in Fig. 4 provides a deeper interpretive perspective of the approaches through which ISO 50001 has been examined in the literature. While the thematic areas highlight what subject dominates the field, these distinct clusters reveal the underlying conceptual, methodological and practical lenses applied by researchers. By shifting the focus from subjects to approaches, this visualization uncovers how the academic community frames and implements ISO 50001 across different contexts.

The largest and most central cluster is *Carbon emissions reduction target (Cluster #0)*. Its central position underscores that ISO 50001 research is strongly connected to the macro-level energy-related emissions mandates. This indicates that the standard is frequently examined as a pragmatic governance framework rather than a tool for improving energy performance. The dominance of this cluster reflects the increasing relevance of ISO 50001 in the context of climate action, energy transition policies, and organizational mandates to align energy efficiency improvement with emissions reduction targets. A second important approach is represented by *Resource-based view (Cluster #1)* which evaluates ISO 50001 through a strategic and organizational lens. This perspective shifts the focus from purely technical energy-savings measures to the development of internal resources such as energy knowledge, managerial commitment, employee awareness, and continual improvement routines. As a result, ISO 50001 can be

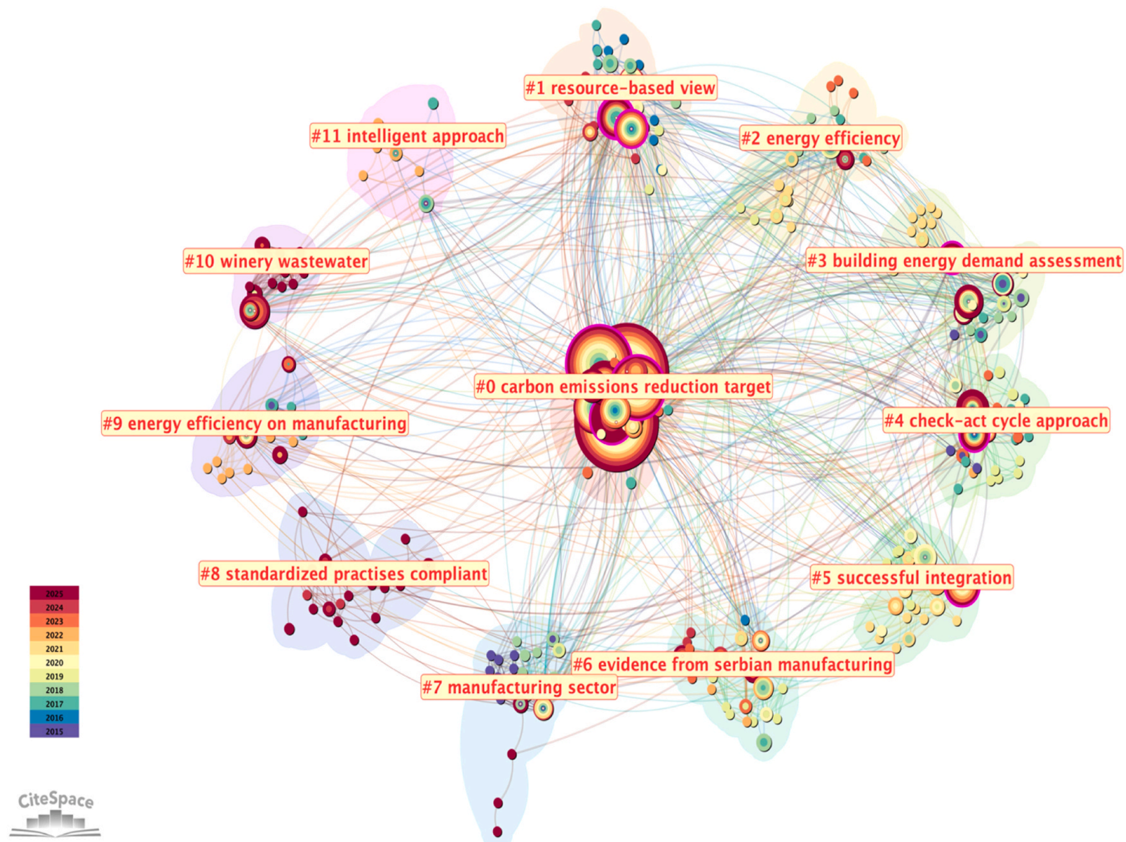

Fig. 4. Leading thematic approaches in the ISO 50001 research.

understood as a framework that strengthens organizational capabilities and may contribute to long-term competitiveness through improved energy management.

The *Energy efficiency (Cluster #2)* represents of the most direct approaches within the mapped literature. Studies in this node appear to examine the standard through its ability to reduce energy consumption, improve energy performance indicators (EnPIs), and identify opportunities for efficiency improvement. Its tight structural connection with the central carbon emissions- reduction cluster confirms that energy efficiency is treated as a primary operational pathway through which ISO 50001 contributes to environmental and climate-related objectives. The inclusion of *Building energy demand assessment (Cluster #3)* underscores a significant shift in the literature, demonstrating that ISO 50001 research has expanded far beyond traditional industrial and manufacturing sectors. The presence of this approach underscores that the standard is applied in contexts where energy consumption patterns must be measured, benchmarked, and controlled. It also shows that ISO 50001 provides a structured basis to assess energy demand and improve performance in built environments.

The *Check-act cycle approach (Cluster #4)* highlights the importance of the Plan-Do-Check-Act logic integrated into ISO 50001. This cluster suggests that exiting literature pays particular attention to the evaluative and corrective phases of the standard, specifically performance monitoring, internal auditing, management review and continual improvement. The presence of this approach empirically confirms that ISO 50001 is studied as a dynamic, evolving management system rather than as a one-time certification exercise, reinforcing the idea that sustained energy performance improvement depends on systematic checking, learning, and adjustment.

In addition to these leading clusters, the bibliometric mapping highlights several specialized approaches related to implementation cycles, system integration, standardized practices, manufacturing applications, and intelligent energy management. These approaches underscore that the ISO 50001 literature has moved well past generic discussions of energy efficiency and emissions mitigation to investigate how the standard functions in practice.

3.1.4. Geographical Distribution of Research

The global footprint of ISO 50001 literature and its cross-border collaborative networks between 2015 and 2025 are illustrated in Fig. 5. The visualization reveals that while academic inquiry into ISO 50001 is internationalized, productivity remains concentrated within specific cluster. Germany, the United States, Brazil, Italy, Spain, the United Kingdom, Japan, France, and the Russian Federation account for a large number of publications within the network. These countries appear as central node, functioning as critical hubs for academic publication, citation influence and transnational knowledge exchange on energy management systems. The prominence of European countries reflects the significance of regulatory and industrial relevance of ISO 50001 standard, driven by regional mandates for energy efficiency and decarbonization. Correspondingly, the presence of the United States and Japan indicates that ISO 50001 research is also strongly connected to technologically advanced economies with established energy performance policies.

Furthermore, the map highlights a rising contribution of emerging and transitional economies. Countries such as Pakistan, Morocco, South Africa, Malaysia, Turkey, Saudi Arabia and Uzbekistan appear within the broader collaboration structure, indicating that ISO 50001 is capturing academic interest well beyond traditional industrialized economies. Their presence reflects the growing relevance of EnMS in regions facing rising energy demand and sustainability pressures. Many of these countries have limited publications output and international collaboration intensity compared to the leading research hubs and thus remain positioned on the periphery of the network.

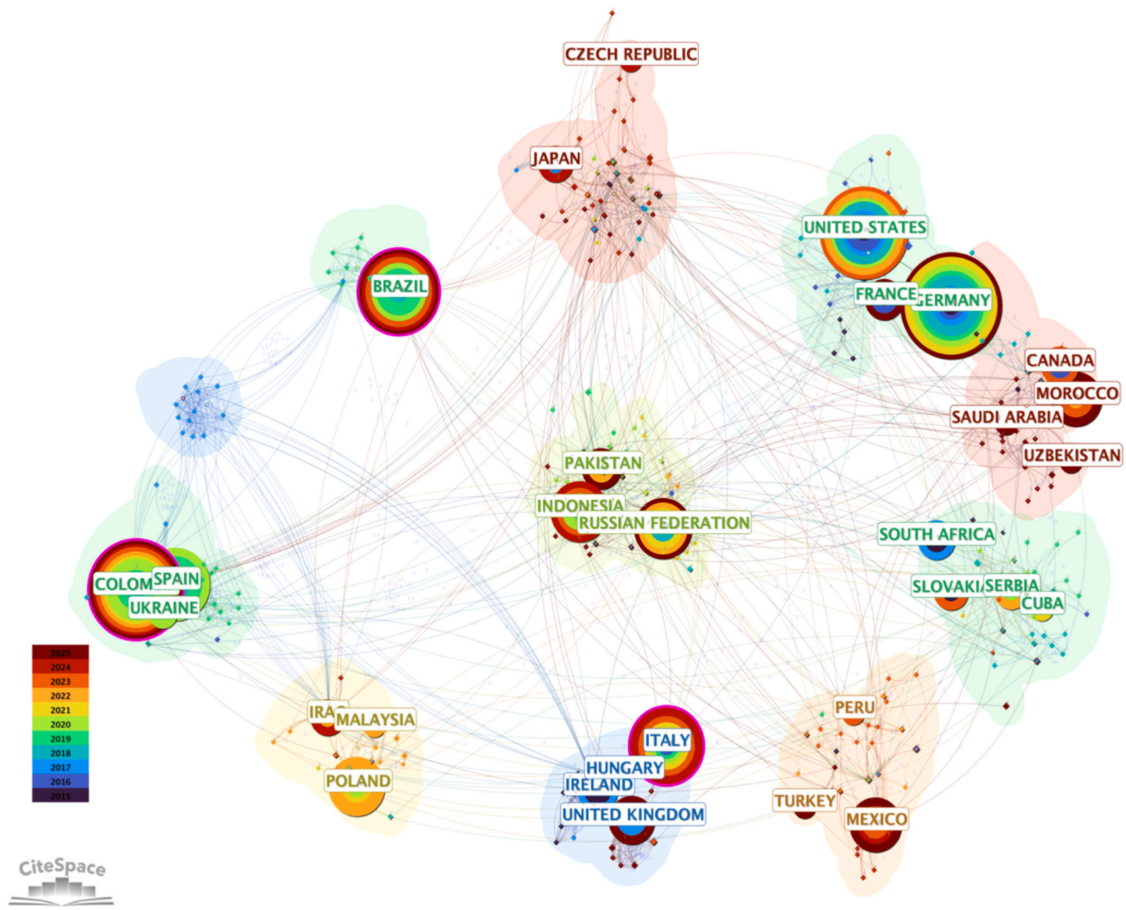

Fig. 5. Geographical distribution of ISO 50001 research.

The network analysis illustrates an increasingly internationalized research domain for ISO 50001, with collaborative links bridging Europe, America, Asia, Africa and the Middle East. Nevertheless, the network architecture remains noticeably clustered, with collaborative ties often aligning along regional, institutional or thematic boundaries, indicating that while ISO 50001 has achieved broad global relevance, academic development across regions remains uneven. Fostering deeper collaborative partnerships between established research hubs and emerging economies could further diversify the academic literature. This integration is crucial given that ISO 50001 is closely linked to global energy efficiency, carbon reduction, and sustainability transition agenda.

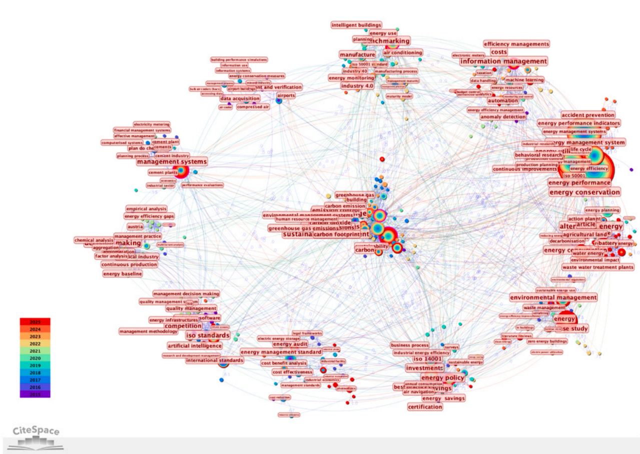

Fig. 6. The keyword co-occurrence network.

3.1.5. Keyword co-occurrence network

Fig. 6 illustrates the keyword co-occurrence landscape maps the thematic framework of ISO 50001 literature by evaluating the frequency by which key terms intersect across publications. At the network's epicenter lie foundational terms such as *"Energy Management System", "Energy Management Standard", "Energy Performance", Energy Efficiency" and "ISO 50001"*. The central positioning and high density of these nodes demonstrate that the wider body of literature remains firmly anchored in the deployment and performance outcomes of structured energy management practices.

Branching outward from the central nexus, several clusters highlight the operational and managerial dimensions of ISO 50001. Keywords such as "*management system*", "*energy audit", "energy policy","-certification","energy savings", "energy baseline*" suggest a substantial research focus on the structural requirements of ISO 50001 implementation. The presence of terms such as "cost *benefit analysis*", "cost effectiveness" and "*Investment"* indicates the studies' evaluation of ISO 50001 not only as a technical standard, but also as a managerial tool leveraged to optimize operational efficiency and reduce energy related costs.

A major paradigm shift within the network is the explicit convergence of energy management with macro-level environmental goals. Keywords such as *"sustainability"," sustainable carbon footprint", "greenhouse gas emissions", "carbon emissions", "carbon" and "environmental management"* indicate that contemporary research links energy management systems with climate change mitigation and zero-carbon objectives. Additionally, the prominence of *"ISO 14001"* within the network further suggests that ISO 50001 is frequently examined in relation to other management system standards, especially environmental management systems, reflecting the significance of integrated management approaches.

The network also reveals a clear technological and digitalization-oriented cluster. Terms such as *"industry 4.0"," information management", "data acquisition", "benchmarking", "energy monitoring", "machine learning"* and *"automation"* shows that recent ISO 50001 studies are connected to smart energy management and data driven decision making. This suggests a shift from traditional compliance-based implementation toward dynamic and automated energy analytics.

Furthermore, the keyword co-occurrence network suggests that ISO 50001 research is a multidisciplinary and evolving field. Previous studies centered mainly on energy management systems, certification, energy audits have expanded into broader debates on sustainability, greenhouse gas reduction and digital transformation. The co-occurrence patterns suggest that ISO 50001 standard is examined as part of a wider framework linking energy efficiency, environmental management and carbon reduction, which reflects the growing relevance of the standard as both practical for organizational energy management and strategic instrument to improve global sustainability transitions.

3.2. Systematic literature review results

3.2.1. ISO 50001 implementation and alignment with SDGs

To examine the contribution of ISO 50001 to broader sustainability outcomes, the systematic review assessed how the main EnMS activities identified in the literature align with the SDGs and CE principles. However, the evidence base is not uniform across these dimensions. Direct evidence in the reviewed articles is strongest for energy efficiency, performance monitoring, operational control, waste prevention, resource efficiency, procurement, and recovery-oriented practices such as residual heat or process-energy recovery. By contrast, explicit evidence connecting ISO 50001 to refurbishment, remanufacturing, repurposing, product-service systems, or reverse-logistics design was limited in the reviewed set. The circular-economy mapping in Table 1 is therefore interpreted as an evidence-informed analytical extension built around EnMS routines, rather than as proof that ISO 50001 by itself delivers the full 10 R hierarchy.

The results indicate that ISO 50001 aligns most strongly with SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). These goals reflect the core operational logic of the standard: improving energy performance, strengthening organizational capability, supporting technological upgrading, reducing inefficient consumption, and contributing to climate mitigation. The integration of circular economy principles further strengthens this alignment, particularly with SDG 12, by extending the focus from energy use alone toward resource efficiency, procurement decisions, material flows, waste reduction, recycling, and recovery.

At the strategic level, EnMS1 (Energy Policy), EnMS2 (Energy Planning), EnMS4 (Objectives and Targets), and EnMS5 (Action Plans) create the governance foundation for energy and circularity integration. Energy policy establishes formal commitment to efficiency, emissions reduction, and responsible resource use, while energy planning identifies significant energy uses, consumption patterns, improvement opportunities, and potential recovery streams. Objectives, targets, and action plans then translate these commitments into measurable programs. From a circular economy perspective, these activities are mainly linked to R0 (Refuse), R1 (Rethink), R2 (Reduce), R8 (Recycle), and R9 (Recover), as they encourage organizations to avoid unnecessary energy and material use, redesign inefficient practices, reduce waste, and identify opportunities for recycling and recovery.

A second group of activities relates to measurement, documentation, communication, and verification. EnMS3 (Performance Metrics), EnMS8 (Communication), EnMS9 (Documentation), and EnMS13 (Internal Audit) provide the information infrastructure required to evaluate energy, carbon, and circularity performance. Energy performance indicators, baselines, metering systems, documented records, and audit procedures allow organizations to verify whether improvement actions produce measurable results. When extended to include circular economy indicators, these mechanisms can also capture material intensity, recycled inputs, waste generation, recovered energy, and resource productivity. This shows that ISO 50001 can support not only energy accountability but also traceability and transparency in circular resource management.

The operational activities of ISO 50001 provide the most direct connection between energy performance and circular economy implementation. EnMS10 (Operational Control), EnMS11 (Energy-Efficient Design), and EnMS12 (Sustainable Procurement) influence how organizations design, operate, maintain, and acquire energy-related assets. Operational control reduces unnecessary consumption and prevents avoidable energy and material losses. Energy-efficient design can be expanded into eco-design by incorporating durability, modularity, repairability, refurbishment potential, remanufacturing feasibility, and recyclability. Sustainable procurement supports circularity by prioritizing energy-efficient equipment, recycled or secondary materials, refurbished assets, remanufactured components, and suppliers with credible lifecycle documentation. These activities connect strongly with R2 (Reduce), R3 (Reuse), R4 (Repair), R5 (Refurbish), R6 (Remanufacture), and R8 (Recycle).

Human and organizational capabilities are also essential to this integration. EnMS6 (Roles and Competency) and EnMS7 (Training and Awareness) demonstrate that energy and circularity performance depend not only on technologies, but also on employees' ability to identify inefficiencies, apply efficient operating practices, maintain equipment properly, reduce waste, and participate in improvement initiatives. These activities support SDG 8 by strengthening workforce capability and SDG 12 by encouraging responsible consumption and production behavior within the organization. Training and awareness are particularly important for embedding circular economy principles into daily practices, including reuse, repair-oriented thinking, proper material handling, and recycling discipline.

EnMS14 (Nonconformity), EnMS15 (Management Review), and EnMS16 (Continual Improvement) represent the corrective and learning mechanisms of the ISO 50001 system. These activities ensure that the EnMS remains adaptive rather than static. Nonconformity management identifies deviations that lead to unnecessary energy use, weak process control, or avoidable waste. Management review enables senior leadership to evaluate whether energy, carbon, and circularity objectives remain aligned with organizational strategy. Continual improvement provides the strongest integration point because it allows organizations to progressively reduce energy and material intensity, redesign inefficient processes, reuse resources, repair and refurbish assets, remanufacture components, repurpose by-products, recycle materials, and recover energy or value from residual streams.

The expanded mapping in Table 1 indicates that ISO 50001 can support selected circular-economy outcomes when firms extend EnMS routines toward material efficiency, procurement reform, design improvement, waste reduction, recycling, and recovery. The strongest evidence remains concentrated on energy-related and process-governance functions. Accordingly, the contribution of ISO 50001 to circularity is framed as enabling and conditional, rather than automatic or comprehensive. Where direct evidence was not found consistently in the reviewed set, the circular interpretation is presented as a conceptual implication of EnMS logic rather than as a recurring empirical finding.

3.2.2. ISO 50001 EnMS activities framework and carbon mitigation

To comprehensively address RQ1, the systematic literature review synthesized a comprehensive framework of EnMS activities and sub-activities demonstrating how ISO 50001 implantation drives

Table 1
Mapping of ISO 50001 Activities, Circularity Economy and UN Sustainable Development Goals[a].

Main Activity	Aligned SDGs	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	Description
Energy Policy – EnMS1	7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 13 CLIMATE ACTION	✓	✓	✓								An effective energy policy strengthens access to clean and efficient energy use by embedding energy performance, cost reduction, and emissions mitigation into strategic priorities. It also supports circular economy principles by refusing avoidable energy and material waste, rethinking operational priorities, and reducing inefficient resource consumption. In this sense, EnMS1 establishes the strategic commitment required to connect energy governance with decarbonization and circular resource stewardship.
Energy Planning – EnMS2	7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 13 CLIMATE ACTION		✓	✓							✓	Energy planning contributes to SDG 7 and SDG 13 by identifying significant energy uses, efficiency opportunities, and carbon-reduction potential. It also supports SDG 9 by encouraging systematic planning tools and process innovation. From a circular economy perspective, planning enables organizations to rethink energy and material flows, reduce avoidable losses, and identify opportunities for recovering waste heat, process energy, or other residual resources.
Performance Metrics – EnMS3	7 AFFORDABLE AND CLEAN ENERGY; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 13 CLIMATE ACTION			✓						✓	✓	Energy performance indicators, baselines, and metering systems make energy efficiency and emissions reduction measurable, thereby supporting SDG 7, SDG 9, and SDG 13. When these metrics are expanded to include material intensity, waste generation, recycled inputs, recovered energy, or resource productivity, they also support circular economy implementation. EnMS3 therefore provides the measurement infrastructure for tracking reductions in both energy demand and resource leakage.
Objectives & Targets – EnMS4	7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 13 CLIMATE ACTION		✓	✓						✓	✓	Objectives and targets translate energy policy into measurable energy, carbon, and performance commitments. They support SDG 7 by improving energy efficiency, SDG 8 by reducing operational costs, SDG 9 by stimulating process innovation, and SDG 13 by linking energy savings to emissions reduction. They also support circularity when organizations set targets for lower material intensity, reduced waste, recycled-content use, energy recovery, and improved lifecycle efficiency.
Action Plan – EnMS5	7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 13 CLIMATE ACTION		✓	✓						✓	✓	Energy action plans convert energy objectives into concrete projects, responsibilities, timelines, and verification methods. These plans advance SDG 7 and SDG 13 through efficiency upgrades and emissions reduction, while also contributing to SDG 8 and SDG 9 through cost savings and operational innovation. Circular economy alignment occurs when action plans include waste reduction, scrap recycling, recovery of residual heat, improved resource productivity, and circular procurement initiatives.
Roles & Competency – EnMS6	8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE		✓	✓								Defining roles and competencies supports SDG 8 by strengthening workforce capability and SDG 9 by improving organizational capacity for technical and process innovation. Circular economy integration depends on assigning clear responsibilities for resource productivity, supplier engagement, waste minimization, and lifecycle-oriented decision-

(continued on next page)

Table 1 (*continued*)

Main Activity	Aligned SDGs	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	Description
												making. Competent personnel are essential for translating energy, carbon, and circularity objectives into daily operational routines.
Training & Awareness – EnMS7	8 DECENT WORK AND ECONOMIC GROWTH; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	✓	✓	✓	✓	✓				✓		Training and awareness programs enhance workforce capability and support SDG 8 by preparing employees to participate in energy and sustainability improvements. They also support SDG 12 by encouraging responsible energy and material consumption. From a circular economy perspective, training can promote refusal of unnecessary resource use, rethinking of work practices, waste reduction, reuse of materials, repair-oriented behavior, proper segregation, and recycling awareness.
Communication – EnMS8	7 AFFORDABLE AND CLEAN ENERGY; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION		✓	✓	✓					✓		Communication strengthens SDG 7, SDG 12, and SDG 13 by making energy performance, responsible resource use, and climate-related progress visible to internal and external stakeholders. It also supports circular economy implementation by communicating resource-efficiency goals, reuse practices, recycling outcomes, product stewardship information, and credible circularity claims. Transparent communication helps prevent vague sustainability claims and reinforces accountability for energy, carbon, and material performance.
Documentation – EnMS9	7 AFFORDABLE AND CLEAN ENERGY; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION			✓						✓	✓	Documentation supports SDG 7 by maintaining evidence of energy performance and SDG 12 by strengthening accountability for responsible resource use. Accurate records of energy consumption, baselines, audits, and improvement actions can be extended to include material flows, recycled inputs, waste streams, recovered resources, and circularity outcomes. EnMS9 therefore provides the traceability needed to verify both energy improvements and circular economy performance.
Operational Control – EnMS10	7 AFFORDABLE AND CLEAN ENERGY; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 13 CLIMATE ACTION	✓		✓	✓	✓					✓	Operational control contributes to SDG 7 and SDG 13 by reducing unnecessary energy use and related emissions through standardized procedures, optimized settings, and preventive maintenance. It also supports SDG 9 through improved industrial process control. Circular economy alignment occurs when operational controls reduce material losses, reuse suitable resources within the process, maintain equipment to extend asset life, avoid unnecessary waste, and recover residual energy or process outputs where feasible.
Energy-Efficient Design – EnMS11	7 AFFORDABLE AND CLEAN ENERGY; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 13 CLIMATE ACTION	✓	✓	✓	✓	✓	✓	✓		✓		Energy-efficient design supports SDG 7 and SDG 13 by embedding lower energy demand and emissions reduction into facilities, equipment, and processes from the outset. It also contributes to SDG 9 by promoting innovation in industrial systems. Its circular economy relevance is particularly strong because design choices determine durability, modularity, repairability, reuse potential, refurbishment options, remanufacturing feasibility, and recyclability. EnMS11 therefore connects energy efficiency with eco-design and lifecycle responsibility.

(*continued on next page*)

Table 1 (*continued*)

Main Activity	Aligned SDGs	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	Description
Sustainable Procurement – EnMS12	7 AFFORDABLE AND CLEAN ENERGY; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION	✓	✓	✓	✓		✓	✓		✓		Sustainable procurement supports SDG 7 by prioritizing energy-efficient equipment, SDG 12 by promoting responsible purchasing, and SDG 13 by reducing emissions linked to purchased goods and services. It also advances circular economy principles when procurement criteria favor durable products, recycled or secondary materials, refurbished equipment, remanufactured components, repairable assets, supplier documentation, and lifecycle-based purchasing decisions.
Internal Audit – EnMS13	12 RESPONSIBLE CONSUMPTION AND PRODUCTION			✓						✓	✓	Internal audits reinforce SDG 12 by verifying whether energy and resource-management practices are implemented effectively. They can also assess whether circular economy procedures, such as waste reduction, recycling, energy recovery, procurement compliance, and resource-efficiency controls, are properly followed. By identifying gaps between planned and actual performance, EnMS13 supports corrective action and strengthens the reliability of energy, carbon, and circularity claims.
Nonconformity – EnMS14	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	✓		✓		✓				✓		Nonconformity management supports SDG 12 by identifying and correcting deviations that lead to inefficient energy use, unnecessary waste, or weak resource control. Corrective and preventive actions help eliminate root causes of energy loss, equipment inefficiency, poor recycling performance, or process waste. CE integration is reflected in refusing repeated inefficiencies, reducing recurring losses, repairing faulty processes or assets, and improving recycling-related controls.
Management Review – EnMS15	8 DECENT WORK AND ECONOMIC GROWTH; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION		✓	✓						✓	✓	Management review links energy performance with governance, business performance, and responsible production, thereby supporting SDG 8 and SDG 12. It allows senior leadership to evaluate whether energy, carbon, and circularity objectives remain suitable, measurable, and aligned with organizational strategy. Circular economy relevance emerges when management reviews include resource efficiency, recycling performance, recovered energy, waste reduction, supplier performance, and lifecycle improvement priorities.
Continual Improvement – EnMS16	8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Continual improvement is the strongest integration point between ISO 50001, decarbonization, and circular economy. It supports SDG 8 through cost savings and productivity gains, SDG 9 through innovation, SDG 12 through responsible resource use, and SDG 13 through progressive emissions reduction. Under a circular economy lens, EnMS16 enables organizations to refuse inefficient practices, rethink processes, reduce energy and material intensity, reuse resources, repair assets, refurbish equipment, remanufacture components, repurpose by-products, recycle materials, and recover energy or value from residual streams.

[a] Evidence concerning ISO 50001/EnMS practices and reported energy-performance outcomes is synthesized from the included literature. CE and SDGs associations shown in this table represent literature-informed conceptual mappings. Accordingly, the CE and SDGs links interpret as proposed pathways for integration rather than empirically established effects of ISO 50001.

decarbonization. Table 2 categorizes these activities across the typical EnMS implementation cycle, moving from strategic governance and data-driven planning to operational execution, monitoring, performance evaluation, and continual improvement. The EnMS activities are presented in a logical implementation sequence which broadly reflects the ISO 50001 Plan-Do-Check-Act cycle. These activities and sub-activities are interconnected processes, where planning *(EnMS1-EnMS5)*, implementation *(EnMS6-EnMS12)*, monitoring *(EnMS13-EnMS15)* and improvement *(EnMS16)* continuously reinforce one another. This framework translates the high-level clauses of ISO 50001 into

Table 2
ISO 50001 EnMS activities and sub-activities framework aligned with decarbonization objectives.

Author(s)	Main Activity	Sub-Activity	Description
Alotaibi et al., [22, 42–50]	Energy Policy (EnMS1)	Develop Energy Policy EnMS1 (a)	Top management commitment and a strategic energy policy lay the foundation for decarbonization. The formulation of an energy policy signifies the commitment of top management to enhance energy performance and achieve decarbonization. The policy articulates the organization's dedication to energy efficiency and the reduction of greenhouse gas emissions, directing all future energy management choices and indicating sustainability priorities throughout the company.
		Allocate Resources EnMS1(b)	Obtaining management support requires the allocation of adequate resources, including budget, personnel, and time, to the EnMS. The allocation of dedicated resources facilitates the execution of energy-saving initiatives and the integration of low-carbon technologies, thus advancing decarbonization objectives.
		Communicate Policy EnMS1(c)	Documenting and disseminating the energy policy to all employees promotes organizational awareness and engagement. Effective communication of policy promotes a culture of energy efficiency and stimulates employee engagement in achieving decarbonization goals.
Andersson et al., [51–56]	Energy Planning. (EnMS2)	Identify Significant Energy Uses – EnMS2(a)	In this "Plan" phase, the organization evaluates its energy use and carbon footprint to identify improvement opportunities. Conducting an energy review to identify major energy uses is essential for focusing on efficiency enhancements. Concentrating on SEUs enables organizations to prioritize initiatives, such as process enhancements and equipment optimization, that result in significant reductions in energy consumption and carbon emissions.
		Establish Energy Baseline EnMS2(b)	Establishing an energy consumption baseline serves as a reference point for evaluating performance longitudinally. A strong baseline facilitates the monitoring of consumption reductions, connecting energy management to greenhouse gas mitigation through the quantification of carbon savings resulting from efficiency enhancements.
Fichera et al., [12, 49,57–61]	Performance Metrics (EnMS3)	Define EnPIs EnMS3(a)	Perform a comprehensive energy review to analyze current energy consumption patterns and related GHG emissions. Defining EnPIs, such as energy per unit of output, offers quantitative metrics for assessing efficiency improvements. EnPIs facilitate progress in decarbonization by linking energy consumption to production or service levels, thereby enhancing the tracking and verification of emissions reductions.
		Implement Metering EnMS3(b)	The implementation of metering and a measurement system guarantees precise documentation of energy consumption within primary systems. The collection of real-time data via meters, sensors, and similar devices is essential for identifying inefficiencies and verifying carbon reductions resulting from energy savings.
		Analyze Energy Data EnMS3(c)	Consistent evaluation of energy consumption data relative to EnPIs and baselines facilitates the identification of inefficiencies and the monitoring of improvement trends. This data-driven monitoring may provide evidence that the implemented measures lead to verified reductions in energy consumption and emissions.
Ford, Hardy [62–65]	Objectives & Targets (EnMS4)	Set Energy Objectives (SMART) EnMS4(a)	Based on the energy review, set energy objectives and targets that support the organization's decarbonization goals. Establishing specific and measurable energy objectives and targets converts the energy policy into tangible results. Aligning these targets with efficiency improvements guarantees that the EnMS facilitates measurable carbon reduction, as each objective is directly associated with performance metrics.
		Align Targets with Strategy EnMS4(b)	Aligning energy targets with overarching business objectives integrates efficiency into strategic planning. This integration directs innovation and investment towards solutions, such as process changes and new technology, that reduce energy consumption while promoting long-term economic growth and sustainability.
Coelho et al., [66–72]	Action Planning (EnMS5)	Develop Energy Action Plan EnMS5(a)	This phase corresponds to the "Do" part of the cycle – executing the action plans and embedding energy management into day-to-day operations. Developing a comprehensive energy action plan requires enumerating activities, designating responsibilities, and distributing resources necessary to achieve objectives. An explicit action plan facilitates the execution of decarbonization initiatives, such as retrofits and efficiency upgrades, detailing the methods of implementation and evaluation.
		Allocate Tasks & Schedule EnMS5(b)	Prioritizing and scheduling energy efficiency projects directs resources toward initiatives that yield the most significant impact. This methodical approach facilitates decarbonization by systematically implementing high-impact measures, such as process optimizations and equipment upgrades.
		Verify Implementation – EnMS5 (c)	Incorporating methods for result verification within the action plan enhances accountability. By delineating the metrics for outcome assessment, organizations can ascertain whether their actions produce the anticipated energy and carbon reductions, thereby ensuring ongoing commitment to decarbonization objectives.
Bevan et al., [73–78]	Roles & Competency (EnMS6)	Define Roles & Responsibilities EnMS6(a)	Assigning roles and responsibilities for energy management tasks is crucial for an effective EnMS. Explicit responsibilities, such as leadership of energy teams, enhance organizational coordination of efficiency initiatives and sustain emphasis on emission reduction results.
		Identify Required Competencies EnMS6(b)	Defining the necessary skills for each major energy use can help align energy management activities with the appropriate technical and managerial expertise. Competency mapping and gap analysis facilitate targeted training, allowing personnel to effectively implement complex decarbonization solutions, such as renewable technologies and control systems.
		Provide Energy Training EnMS6 (c)	Developing training programs to enhance essential skills, such as data analysis and operational efficiency, facilitates ongoing improvement. Effective training enables personnel to recognize and implement carbon-reduction opportunities, such as optimizing system settings, thereby reinforcing the objectives of the EnMS.
Fernando et al., [79,80]	Training & Awareness (EnMS7)	Conduct Training Programs – EnMS7(a)	Develop competence and awareness at all levels of the organization. Provide training programs for employees and operators on energy-efficient practices, equipment use, and maintenance. Providing specialized training in energy management and efficiency enhances the workforce's ability to identify savings. Employees with adequate training are more

(*continued on next page*)

Table 2 (*continued*)

Author(s)	Main Activity	Sub-Activity	Description
			inclined to engage in decarbonization initiatives by, for illustration, proposing process enhancements or following energy conservation protocols.
		Launch Awareness Campaigns EnMS7(b)	Internal communication, including newsletters, meetings, and signage, regarding energy goals and achievements, reinforces the cultural transformation necessary for achieving savings. Awareness campaigns emphasize the significance of each staff member's contribution to minimizing energy consumption and emissions, thereby fostering greater involvement in decarbonization efforts.
Sutton, Le Roux [81,82]	Communication (EnMS8)	Internal Energy Communication EnMS8(a)	Establish internal and external communication processes regarding energy performance. Internally, communicate policies, goals, and progress to all departments via dashboards or team meetings to keep energy and carbon goals visible. Creating a communication plan for EnMS activities keep organizational levels informed about energy performance and related initiatives. Transparent internal reporting, such as posters and dashboards, enhances employee engagement and emphasizes advancements in achieving emissions reduction targets.
		External Reporting EnMS8(b)	Communicating energy performance and initiatives to external stakeholders, such as customers and investors, fosters accountability and trust. The public disclosure of energy targets and outcomes strengthens the commitment to SDGs and can enhance community and customer support for decarbonization efforts.
Daroon et al., [83–86]	Documentation (EnMS9)	Maintain Documentation EnMS9(a)	Documented procedures, manuals, and guidelines are essential for ensuring consistency in energy management practices. Systematic documentation facilitates clear monitoring of energy-related activities, essential for ensuring compliance and assessing carbon savings over time.
		Control Energy Records EnMS9 (b)	Implementing document control for energy data, including bills, logs, and reports, guarantees the availability of accurate and current information. Accurate documentation of consumption and savings is crucial for substantiating emission reduction claims and facilitating ongoing enhancement.
		Use Records for Verification EnMS9(c)	The effective use of maintained records of energy consumption and enhancements facilitates the monitoring of progress relative to established targets. The evidence base is essential for illustrating the efficacy of decarbonization measures, such as quantifying avoided CO_2 through documented energy savings.
Benedetti et al., [87–89]	Operational Control (EnMS10)	Implement Operational Controls EnMS10(a)	Establishing operational procedures and control setpoints, such as optimal temperature settings and scheduling, is essential for ensuring the efficient operation of SEUs. The consistent application of these controls minimizes energy waste and directly contributes to emission reductions through the optimization of equipment performance.
		Preventive Maintenance EnMS10(b)	Regular maintenance of energy-intensive equipment, such as HVAC systems and motors, is essential for sustaining system efficiency. Proper maintenance of equipment mitigates degradation, such as motor wear, thereby preventing declines in energy performance and unintended increases in CO_2 emissions.
		Standardize Efficient Operations EnMS10(c)	Establishing standard operating procedures (SOPs) for processes characterized by high energy consumption promotes consistent efficiency. Well-defined standard operating procedures for equipment start-up, shutdown, and cycling minimize variability caused by operators, thereby reducing energy waste and limiting excess emissions.
Fitzgerald et al., [53,90]	Energy-Efficient Design EnMS11	Integrate Energy in Design EnMS11(a)	The integration of energy performance criteria into the design of facilities and equipment enhances efficiency from the foundational level. Designing systems such as HVAC or process lines for energy efficiency and flexibility, including the incorporation of automatic controls, results in reduced energy consumption and lower greenhouse gas emissions throughout their operational lifespan.
		Include Energy Specs in Procurement EnMS11(b)	Incorporating energy performance outcomes from design evaluations into procurement specifications facilitates the acquisition of efficient equipment. Specifying high-efficiency chillers or lighting fixtures based on prior evaluation helps align procured assets with long-term decarbonization objectives.
Ikram [16,91,92]	Sustainable Procurement – (EnMS12)	Green Procurement Criteria EnMS12(a)	Integrating energy efficiency and sustainability standards into procurement policies, such as energy labels and lifecycle costs, facilitates the procurement of low-carbon products. Prioritizing high-efficiency products and services enables the organization to minimize embedded energy and advance Sustainable Development Goal 12 concerning responsible consumption.
		Engage Suppliers on Energy EnMS12(b)	Engaging with suppliers and contractors to enhance their energy practices promotes efficiency across the supply chain. This enhances the decarbonization effect upstream, as suppliers implement more sustainable processes and provide products with reduced carbon footprints.
		Assess Lifecycle Impact EnMS12 (c)	Assessing the energy and carbon implications of prospective acquisitions via lifecycle assessment facilitates informed decision-making. Considering total energy use, including production and disposal, procurement choices align with decarbonization by circumventing high-emission options.
Boharb et al., [93–95]	Internal Audit (EnMS13)	Plan Internal Audit – EnMS13 (a)	Implementing a regular internal audit schedule, typically on an annual basis, guarantees that the EnMS processes are assessed for their effectiveness. Audits facilitate the early detection of non-conformities and performance deficiencies, enabling timely corrective actions that ensure the effectiveness of decarbonization initiatives.
		Conduct EnMS Audits EnMS13 (b)	Audits entail the verification of adherence to documented energy procedures and the assessment of target achievement. Audits verify the effectiveness of energy and emissions reduction measures through interviews, observations, and data analysis.
		Audit Follow-up EnMS13(c)	Documenting audit findings and ensuring follow-up actions through corrective plans completes the process in the EnMS. This feedback guarantees the rectification of any inefficiencies or unforeseen energy consumption, thereby strengthening the system's contribution to ongoing decarbonization efforts.

(*continued on next page*)

Table 2 (*continued*)

Author(s)	Main Activity	Sub-Activity	Description
Iribar et al., [96–98]	Nonconformity (EnMS14)	Identify Nonconformities EnMS14(a)	Establishing procedures for detecting deviations, such as through monitoring or audits, guarantees the identification of failures to comply with EnMS requirements. Identifying nonconformities in processes or performance constitutes the initial step in mitigating energy waste and related emissions.
		Corrective Actions EnMS14(b)	Implementing corrective measures to address the root causes of identified nonconformities effectively mitigates the risk of recurring inefficiencies. An effective corrective action process addresses underlying issues, thereby minimizing energy losses and consistently reducing carbon emissions.
		Preventive Actions EnMS14(c)	Implementing preventive measures addresses potential nonconformities prior to their occurrence. Proactively addressing conditions that may result in energy overruns, such as equipment drift, enhances the reliability of decarbonization outcomes through preventive actions.
Gahm et al., [99–102]	Management Review (EnMS15)	Schedule Review Meetings – EnMS15(a)	Regular management review sessions, such as quarterly or annual meetings, facilitate the assessment of EnMS performance by senior leadership. The review of energy outcomes and plans by top management strengthens accountability for emissions targets and incorporates energy considerations into strategic decision-making.
		Evaluate Performance – EnMS15(b)	Management reviews that analyze overall energy performance data reveal both successes and shortcomings in meeting objectives. This systematic evaluation enables leadership to assess progress in decarbonization and make informed adjustments to maintain alignment with objectives.
		Update Policy/Plan – EnMS15 (c)	Management ought to revise the energy policy, objectives, and resources in accordance with the findings of the review. Through the revision of plans based on performance evaluation, the organization maintains ongoing alignment with its decarbonization objectives and adjusts to emerging challenges.
(S. [103–106])	Continual Improvement (EnMS16)	Identify Improvement Opportunities – EnMS16(a)	Continuous assessment of performance relative to targets identifies additional opportunities for enhancement. Continuous analysis, such as benchmarking and audits, identifies opportunities for further reductions in energy consumption and emissions, thereby contributing to a cycle of ongoing optimization.
		Implement Improvement Projects – EnMS16(b)	Establishing a culture of continuous improvement requires the planning and execution of projects, such as upgrades and efficiency measures, aimed at enhancing performance beyond the existing baseline. Each improvement initiative contributes to decarbonization by progressively reducing the organization's carbon footprint.
		Measure Improvement Outcomes – EnMS16(c)	Monitoring and evaluating the outcomes of enhancement initiatives verifies that reductions in energy consumption and emissions are realized. Transparent reporting of these results guarantees that improvements are recorded and utilized to establish more ambitious future objectives.

operational components explicitly geared toward enhancing energy performance, reducing energy consumption, and contributing to the reduction of corporate carbon footprints.

The EnMS activities identified in this review can be interpreted as supporting circularity through at least five connected mechanisms. First, strategic commitment, policy setting, and planning create the managerial conditions under which resource-efficiency and circularity priorities can be formalized rather than treated as ad hoc sustainability claims. Second, energy review, baseline development, and performance indicators can be expanded to identify not only significant energy uses, but also material-intensive stages, loss points, and recovery opportunities across production and logistics. Third, operational control, competence development, and communication enable the practical coordination needed for leaner process design, waste prevention, maintenance, reuse, and more efficient handling of returns and secondary materials. Fourth, procurement and supplier engagement can extend ISO 50001 beyond direct operations by linking energy performance with upstream material choices and embodied-carbon considerations. Fifth, audit, management review, and continual improvement provide the feedback structure required to institutionalize closed-loop learning over time. ISO 50001 does not itself prescribe circularity; instead, it may provide the governance architecture through which circular objectives can be translated into routines, metrics, and verifiable improvement cycles.

The framework of an ISO 50001 EnMS relies fundamentally on an explicit energy policy backed by executive leadership. The reviewed literature demonstrates that organizations typically begin their EnMS journey by defining an energy policy that expresses their commitment to improving energy performance and mitigating greenhouse gas (GHG). This phase, represented by *Energy Policy (EnMS1*), encompasses formalizing policy statements, allocating appropriate resources, and communicating the policy across the organization. Necessary governance conditions for energy savings initiatives and low-carbon investments are built by securing management support and dedicating financial, human and technical resources. Moreover, circulating the policy internally helps embed energy stewardship into corporate culture, motivating employees to participate in decarbonization efforts. EnMS1 thus serves as strategic entry point through which ISO 50001 aligns corporate strategy with energy and carbon reduction ambitions.

Building on this strategic commitment, ISO 50001 mandates robust planning to establish a technical benchmark for improvement. *Energy Planning (EnMS2)* involves identification of significant energy uses and the establishment of an energy baseline, allowing organizations to understand where energy is consumed most intensively and where improvement opportunities are most relevant. In practice, this requires conducting an energy review to map major operational processes and prioritizing significant energy uses such as production lines, heating and cooling systems, motors, compressed air systems, or any other energy intensive equipment. The development of a rigorous energy baseline is crucial, as it provides the analytical reference point necessary to quantify future efficiency gains and associated carbon reductions. This planning phase supports the treatment of carbon mitigation as a measurable process grounded in actual energy consumption data. A primary differentiator of ISO 50001 is its focus on data tracking and performance evaluation. *Performance Metrics (EnMS3)* focuses on defining energy performance indicators (EnPIs), implementing metering systems, and analyzing energy data. The synthesized literature demonstrates that EnPIs, such as energy consumption per unit of output, provide quantitative metrics that connect energy use to organizational activity, allowing companies to distinguish between absolute reduction in energy use and efficiency improvements relative to production. This data infrastructure is reinforced by sub-meters, sensors, and real time monitoring software that capture high-fidelity operational data. Through regular analysis of energy data against baselines and EnPIs, organizations are able to pinpoint operational anomalies, verify the impact of implemented measures, and demonstrates the carbon reduction benefits of energy savings. Thus, by embedding empirical energy performance as the primary mechanism for carbon mitigation, ISO 50001 differs from broader management standards. The framework also highlights the tactical transition from data analysis and planning to concrete and targeted objectives. *Objectives and targets (EnMS4)* and *Action Planning (EnMs5)* represent the collaborative stage where policy goals and energy review insights are converted into specific, measurable, and time-bound improvement actions. Firms set energy goals which supports broader decarbonization targets and align them with core business. This integration can help position energy performance as a key variable in capital allocation, technological innovation, and long-term asset management. Action planning subsequently defines the concrete steps required to achieve these objectives, including assigning clear responsibilities, allocating tasks, scheduling projects, and establishing evaluation protocols. Through this mechanism, ISO 50001 systematically translates abstract carbon goals into practical engineering and operational improvements.

The implementation phase of the EnMS involves embedding energy management into day-to-day corporate routines. This organizational integration is governed by a cluster of interconnected activities including *Roles and Competency (EnMS6)*, *Training and Awareness (EnMS7)*, *Communication (EnMS8)*, *and Documentation (EnMS9)*. Formally assigning energy responsibilities helps position energy management as a coordinated, cross-functional corporate discipline rather than a function limited to a technical department.. Competency mapping and structured technical training empower operators to identify energy waste, apply efficient operating practices, and support the use of more advanced energy technologies. Simultaneously, internal communication campaigns and performance dashboards maintain the visibility of energy performance, while rigorous documentation and record control provide the transparent audit trail required to track energy consumption and verify emissions reduction claims. These organizational and human factors are crucial, as technical improvements alone remain vulnerable to performance decay without clear responsibilities, employee engagement, and reliable information systems. Moreover, direct carbon mitigation occurs primary through real-time operational execution. *Operational Control (EnMS10)* involves establishing control procedures, maintaining energy-intensive equipment, and standardizing efficient operating practices. These interventions directly reduce unnecessary energy consumption by ensuring that significant energy use operate under optimized parameters. *Energy Efficient Design (EnMs11)* and *Sustainable Procurement (EnMS12)* extend the reach of the EnMS beyond existing assets by embedding energy performance metrics into the design of new facilities, asset purchasing, and capital procurement decisions. Because design and procurement choices lock in an organization's energy profile and carbon path for decades, prioritizing life-cycle energy costs and sourcing high-efficiency equipment allows organizations to expand the decarbonization impact of ISO 50001 beyond internal operations and towards upstream value-chain decisions. The verification and governance loops within the ISO 50001 framework ensure accountability and systematic resilience. Internal Audit (EnMS13), Nonconformity (EnMS14) and Management Review (EnMS15) function as the feedback mechanisms of the PDCA cycle. Internal audits allow firms to verify whether energy procedures are being allowed and whether targets are being actively met. Nonconformity and corrective action processes establish root-cause analysis to investigate performance deviations, preventing recurring inefficiencies. Management reviews then enable senior leadership to evaluate energy performance, assess whether objectives remain appropriate, and update policies, resources, or action plans. These feedback mechanisms prevent the EnMS from degenerating into passive compliance exercise, maintaining its utility as a responsive, active system for energy and emissions improvement. Finally, Continual Improvement (EnMS16) captures the long-term contribution of ISO 50001 to decarbonization. The review indicates that ISO 50001 does not prompt a singular, static reduction, but rather fosters a progressive cycle where organizations repeatedly identify, execute, and verify energy-saving interventions. This continual cycle allows companies to move from basic energy-saving measures toward more advanced efficiency improvements and low carbon investments. Nevertheless, the ultimate decarbonization of ISO 50001 is bounded by its depth of its implementation. While the standard offers an exceptional framework for reducing energy related operational emissions, achieving absolute carbon neutrality requires the integration of external strategies. Therefore, ISO 50001should be understood as a powerful operational and managerial platform for zero-carbon targets, but not a standalone net-zero solution.

Moreover, the systematic review develops an EnMS activity framework illustrating how ISO 50001 promotes decarbonization through a structured sequence of interconnected practices. These include establishing energy-conscious leadership and policy, conducting data-driven energy planning, defining measurable performance indicators, implementing targeted efficiency actions, strengthening employee involvement, controlling energy-intensive operations, and evaluating progress through audits, corrective actions as well as management reviews. This process-oriented perspective clarifies that ISO 50001 contributes to decarbonization not through a single intervention, yet through the cumulative effect of multiple energy management practices embedded deep within organizational routines. Consequently, these finding suggest that future research should further examine how ISO 50001 can be integrated with renewable energy strategies, digital energy monitoring systems, lifecycle-based procurement, and broader net-zero frameworks to maximize its contribution to global climate stabilization.

The study followed a sequential integrative framework. The bibliometric analysis addressed the macro-level structure of the field by identifying dominant journals, thematic clusters, analytical approaches, and collaboration patterns across the ISO 50001 literature. The systematic review then moved to the micro-level by extracting recurrent EnMS activities, implementation practices, and reported sustainability outcomes from the final 111 articles. The integrated model in Fig. 7 developed only after these two stages were compared: bibliometric clusters indicated the main directions of the field, while the coded review results identified the organizational mechanisms through which ISO 50001 is implemented in practice. The model therefore regarded as the synthesis point connecting field-level patterns, article-level evidence, and forward-looking conceptual integration.

4. Discussion

By merging bibliometric analysis with a process-focused systematic review, this study advances the understanding of ISO 50001 by framing it as a management standard for energy performance improvement, decarbonization, CE and corporate sustainability. Integrating science mapping with a process oriented systematic review, enables this research to move beyond treating the standard as merely a certification tool, instead positioning it as an organizational infrastructure through which energy-related objectives embedded into managerial routines. The discussion of the findings highlights two distinct academic contributions: first, the bibliometric analysis reveals how the ISO 50001 research field has evolved intellectually and thematically from 2015 to 2025: second, the systematic review clarifies the potential EnMS activities and sub-activities that drive energy efficiency, carbon reduction, and broader institutional sustainability goals. Together, this dual approach provides a comprehensive framework for conceptualizing how standardized management systems translate high-level environmental targets into continuous and structured corporate improvement.

The findings clarify the distinctions between the current synthesis and related review traditions. Prior bibliometric studies on ISO 50001 predominantly establish the foundational knowledge and emerging research themes, whereas implementation research focuses on energy savings, organizational adoption, and performance enhancement. Our synthesis builds on this evidence but shifts the analytical focus from whether EnMS enhances energy management to how its existing routines interact with broader sustainability decisions. This distinction is significant as empirical evidence indicates that energy-performance enhancements under ISO 50001 are supported; however, these improvements cannot be universally applied to circular-material outcomes, comprehensive value-chain decarbonization, or the achievement of Sustainable Development Goals (SDGs). The proposed mappings of CE and SDG thus broaden the interpretation of EnMS while maintaining the formal scope of the standard [28].

This distinction has become more significant following the release of ISO 50100:2026, which specifies requirements for reducing energy-related greenhouse gas emissions and explicitly details its connection to ISO 50001:2018. The existence of a dedicated decarbonization standard underscores that ISO 50001 should not be presented as a comprehensive tool for achieving carbon neutrality. Instead, ISO 50001 serves as a foundational framework for organizational energy performance, which can support broader decarbonization efforts when integrated with specific emissions targets, carbon accounting, renewable energy strategies, and related standards [107].

The significance of this study is more apparent when contextualized within related research in the ISO 50001 and EnMS literature. Rampasso et al. [26] and Yuriev and Boiral [25] primarily address implementation barriers and critical adoption challenges. In contrast, the current study integrates field mapping with process-level synthesis across a wider range of literature. Jovanović and Filipović [20] create and validate an energy-management maturity model; however, they do not offer the bibliometric overview or the synthesis focused on SDGs and decarbonization presented in this study. Todaro et al. [40] provide a review of organization and management theories within the broader context of environmental management systems research. In contrast, the current manuscript focuses specifically on ISO 50001 and connects EnMS activity coding to outcomes related to energy, carbon, and cautiously considered circularity. Schmitt et al. [30] focus on energy efficiency in industrial manufacturing, while this study broadens the analysis to include research evolution, EnMS activity architecture, SDG alignment, and the conditional relationship among ISO 50001, decarbonization, and circularity. Together, these distinctions characterize the originality of the current review as an integrative, multi-method synthesis rather than a singular thematic evaluation.

The bibliometric analysis results highlight that ISO 50001 scholarship has progressively matured from early focus on implementation, certification, and EnMS adoption toward a broader research agenda encompassing energy performance, digitalization, operational optimization, sustainable production, and climate action outcomes. Foundational literature on energy management systems primarily analyzed adoption drivers, certification processes, implementation barriers, and measurable energy savings. In contrast, the thematic structure identified in the study suggest that recent research on ISO 50001 is more closely with energy performance improvement, sustainability integration and climate mitigation [108]. Driven by the post 2015 global sustainability agenda, including the Paris Agreement and the UN SDGs, energy management has increasingly shifted from an operational concern to a core corporate strategy [109,110]. In recent years, energy security concerns and resource scarcities have intensified the pressure on firms to manage and mitigate greenhouse gas emissions, optimize resource efficiency, and restructure corporate practices to support the transition toward low-carbon energy systems [111]. Within this context, ISO 50001 has gained critical relevance far beyond its capacity to deliver immediate utility cost savings. Instead, it serves as a robust mechanism for integrating energy efficiency directly into organizational governance. Empirical insights from ISO 50001 case studies consistently show that firms report cost savings, productivity gains, operational improvements, and GHG emissions mitigation, while implementation research underlines the importance of management support, structed workforce coordination, and cross-functional teams for effective EnMS operation [17,60].

The geographical concentration illustrated in Fig. 5, highlighting Germany, Italy, Spain, the United Kingdom, and France, likely indicates a synergy of robust industrial foundations, energy-efficiency regulations, and well-established applied-research networks within Europe. This region has closely integrated energy and environmental management standards with corporate sustainability and policy instruments [17,20,45]. The United States and Japan are pivotal due to their extensive research systems, developed industrial energy-management programs, and robust digital and engineering infrastructures that facilitate measurement-intensive EnMS research [21,53,112]. The prominence of Brazil and Russia may be associated with the practical significance of energy performance in sectors that are resource- and energy-intensive, where operational efficiency holds immediate economic and environmental relevance [30,108,113]. In contrast, the peripheral representation of emerging economies may indicate reduced certification density, limited access to plant-level energy data, and insufficient institutional support for the publication of ISO 50001-based empirical studies [17,114]. These patterns indicate that research on ISO 50001 is influenced not only by sustainability priorities but also by the interplay of policy capacity, industrial demand, and research infrastructure, which collectively render formal energy management a viable subject for scholarly publication.

This conceptual shift fundamentally redefines how ISO 50001 should be interpreted within the literature. When the ISO 50001 standard is treated as a static certification instrument, its contribution is evaluated mainly in terms of adoption rates, compliance, or formal recognition. Conversely, when it is conceptualized as an organizational energy management infrastructure, its contribution is assessed by the extent to which it transforms energy related decision-making. The systematic review conducted in this research supports the latter interpretation. The empirical evidence demonstrates that EnMS functions through a chain of interconnected processes: leadership defines the direction, energy planning identifies significant energy uses, performance indicators make energy performance measurable, operational controls translate objectives into practice, and audits and management review create feedback loops for continual improvement [115,116]. Therefore, the effectiveness of ISO 50001 depends more on how deeply its practices are internalized across the firm.

Additionally, the strongest evidence concerns the role of ISO 50001 in structuring energy planning, monitoring energy performance, establishing operational controls, reviewing results, and supporting continual improvement. These capabilities can create organizational conditions that are relevant to decarbonization, particularly when energy-performance objectives are coordinated with emissions measurement and low-carbon investment decisions. By systematically lowering energy intensity and elevating process efficiency, these activities indirectly mitigate energy-related emissions; a structural contribution that may have important implications for carbon-mitigation strategies in energy-intensive industries [113]. This interpretation is strongly backed up by the analysis of 83 manufacturing facilities further shows that ISO 50001 can support carbon dioxide mitigations by integrating energy efficiency into operational processes, making it a relevant policy lever for climate action targets [53]. This result aligns with the broader energy efficiency literature, that identifies energy efficiency as one of the immediate and cost-effective pathways to greenhouse gas emissions mitigation, especially in energy intensive sectors where energy represents a crucial source of direct and indirect emissions [117]. Paradoxically, the findings also reveal a clear limitation: ISO 50001 does not explicitly require firms to adopt renewable energy, electrify processes, establish science-based targets, or manage full value-chain emissions [118]. Its climate contribution is therefore enabling rather than determinative. The standard delivers the structural management architecture required execute carbon reduction, but it does not dictate the depth of decarbonization goals, nor does it describe the technological roadmap required to achieve them.

A third core insight relates to the operational mechanics of how ISO

50001 drives broader sustainability objectives. The SDG mapping executed in this research reveals that the standard intersects most robustly with SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) [118]. This thematic alignment is theoretically coherent, as these global targets correspond to the areas where an EnMS exercises its most immediate operational leverage: energy efficiency, responsible resource use, and climate action. Through energy planning, monitoring, operational control, design, procurement, and continual improvement, ISO 50001 provides organizations with a practical blueprint for reducing energy waste, boosting resource productivity, and lowering energy-related emissions. However, the findings of this study also reveal that ISO 50001 standard's contribution to the SDGs is not uniform. While its main impact remains operational and tied to energy metrics, the standard offers only passive or indirect support to broader social, institutional, or partnership-oriented SDGs unless firms deliberately extend the EnMS scope to encompass proactive stakeholder engagement, transparent reporting, inclusive training, or integrated sustainability governance [119].

Furthermore, the systematic results suggest that ISO 50001 creates value when it is internalized within existing organizational functions. This interpretation aligns with ISO 50001 case-study evidence indicating that management support and energy-aware culture are among the most prominent success factors, while weak energy-management culture and lack of internal expertise remain major implementation barriers [114]. While energy management is often segmented as purely technical or engineering task, this research highlights that successful EnMS deployment is fundamentally a cross-functional endeavor. Achieving meaningful energy performance involve leadership strategy, procurement protocols, employees' competence, internal communication, documentation, performance evaluation and management review (S. Y. B. [120]). Therefore, ISO 50001 standard should be understood as a managerial capability rather than only technical energy-efficiency tool. Recent evidence further supports this perspective by framing the standard based EnMS as a way of managing energy as crucial business practice and as a practical pathway to carbon mitigation [121]. The standard provides a common management, but its effectiveness depends on implementation depth, data quality, organizational culture, managerial commitment and the extent to which energy considerations are integrated into day-to-day decision making. The effectiveness of ISO 50001 depends on translating energy objectives into operational routines and continuous improvement practices, as shown by studies integrating ISO 50001 with Lean Six Sigma and Define, Measure, Analyze, Improve, Control (DMAIC)-based energy optimization approaches [51].

Based on the data, several clear pathways emerge for future ISO 50001 research. Notably, the bibliometric mapping identifies a strong trend towards data-driven energy management, driven by emerging topics like digitalization, machine learning, algorithms, automated energy planning. Since the effectiveness of ISO 50001 systems rely on accurately measuring and analyzing energy performance, in this regard Industry 4.0/5.0 technologies such as IoT, big data, analytics, cloud platforms and smart sensors can strengthen EnMS integration and decision making [122]. By adopting these tools, firms can move from manual tracking to real-time monitoring and more accurate verification of energy savings [123]. Moreover, the findings indicate that ISO 50001 research remains more developed in relation to internal energy management than value-chain energy emissions management. Most EnMS activities focus on energy consumption under the firm's direct operational control, which is consistent with the structure of the standard. However, from a decarbonization perspective, this internal focus is inadequate for certain industries. In sectors where upstream materials, logistics, outsourced activities, product use, or end-of-life processes account for large energy footprint, managing internal operations alone is insufficient. This matches recent studies showing growing regulatory and scholarly attention to supply-chain carbon footprints, green supply chain management, and carbon accounting as a necessary dimension of corporate decarbonization [124,125]. Future research should examine how ISO 50001 can be connected more explicitly with digital energy infrastructures, life-cycle thinking, supplier engagement, carbon accounting, and carbon-neutral supply-chain strategy.

The research's findings indicate that ISO 50001 may provide greater value when it is woven into wider corporate and policy frameworks instead of running as a stand-alone technical project. Within the firm, co-implementing alongside other management standard strengthens its impact by connecting energy metrics to environmental management, quality controls, ESG operating, operational efficiency, occupational practices, and corporate climate strategies. This interpretation is consistent with broader research positioning ISO management system standards within corporate sustainability, ESG and SDG agendas [126]. For instance, integration with ISO 14001 aligns energy efficiency with broader environmental objectives and emissions reduction, at the same time ISO 50001 provides a more specific energy-performance orientation, since ISO14001 and EMS can support some energy-management practices but do not impose the same explicit energy performance requirements as EnMS [45]. At the macro policy level, ISO 50001 standard reinforces national and sectoral energy efficiency and decarbonization strategies by translating energy savings opportunities into sustained management practices. While conventional energy audits are sufficient for identifying improvement opportunities, ISO 50001 provides the structural framework required to systematically implement, track, and continuously improve those opportunities over time [20]. Consequently, policymakers can accelerate adoption through incentives, technical assistance, sectoral guidance, and support for digital energy monitoring. This policy intervention is particularly critical for SMEs, which often face financial, technical, and data-related implementation barriers [127]

4.1. Multilayer Integrated ISO 50001, Net Zero and Circular Economy Model

This study develops an integrated ISO 50001, Net Zero and CE model that positions energy management as a strategic mechanism for advancing organizational decarbonization and circular industrial transformation, as illustrated in Fig. 7. In place of viewing ISO 50001 as a certification-oriented management standard, the proposed model conceptualizes it as an enabling architecture through which firms can institutionalize energy efficiency, carbon reduction, renewable energy integration, operational accountability, and resource circularity. Net zero represents the strategic destination of the framework, while ISO 50001 provides the managerial discipline required to progress from energy baselining and performance monitoring toward verified decarbonization outcomes. CE principles further extend this logic by shifting the focus from energy consumption alone to the wider management of materials, waste, product life extension, and closed-loop value creation. Accordingly, the model conceptualizes sustainable industrial performance as the combined outcome of energy excellence, decarbonization capability, and circular resource governance.

Fig. 7 represents an evidence-informed integrative model derived from three interrelated sources within this review. Initially, the managerial core is directly informed by the sixteen EnMS activities and subactivities outlined in Table 2, particularly focusing on policy, planning, energy review, performance indicators, operational control, competence, procurement, auditing, management review, and continual improvement. Secondly, the decarbonization pathway is informed by consistent findings in the reviewed literature, which include energy savings, enhanced monitoring, operational discipline, improved decision-making, and, in certain instances, reported reductions in emissions or alignment with carbon-management strategies. Third, the circular-economy aspect is only partially direct. In the reviewed set, resource efficiency, waste prevention, recovery, and procurement/design-related improvements were consistently supported. In contrast, reverse logistics, remanufacturing, and broader closed-loop value-chain features were less consistently evidenced and are thus included as conceptual extensions that align with the governance logic of ISO 50001. Consequently, the model is characterized as a synthesis framework derived from the review, rather than as a fully empirically validated causal model.

A central contribution of the framework is its expansion of the ISO 50001 boundary from the facility level to the wider value chain. Net-zero progress cannot be fully achieved through internal energy efficiency measures alone, particularly when upstream and downstream activities account for substantial environmental impacts. The model therefore links raw materials, suppliers, manufacturing operations, logistics, product use, collection, recovery, and recycling through coordinated flows of energy, materials, and information. Upstream decisions related to supplier selection, material sourcing, eco-design, and sustainable procurement shape both embodied carbon and resource intensity. Downstream practices, including product stewardship, take-back systems, reuse, repair, refurbishment, remanufacturing, and recycling, determine whether products and materials are discarded as waste or retained within productive circulation. In this sense, the reverse-flow pathway is not a peripheral element of the framework but is conceptualized as a core mechanism for reducing virgin material dependency, lowering lifecycle emissions, and converting end-of-life management into a source of recovered economic and environmental value.

The operational logic of the model is expressed through a staged implementation pathway that translates broad sustainability commitments into managerial routines and measurable actions. The diagnostic stage begins with energy reviews, carbon and material baselines, identification of significant energy uses, and risk–opportunity assessment. Planning then converts these insights into energy performance indicators, action plans, net-zero roadmaps, eco-design priorities, and resource-efficiency targets. At the implementation stage, process optimization, smart monitoring, operational controls, preventive maintenance, and waste-loss reduction support the practical execution of energy and circularity objectives. Measurement and verification connect energy performance monitoring with greenhouse gas accounting, internal audits, corrective actions, and performance review. Finally, circular closure is achieved through take-back systems, repair, reuse, remanufacturing, recycling, and continual improvement. This sequence suggests that circular economy can be viewed as a logical extension of ISO 50001's continual improvement philosophy when energy performance is integrated with material productivity and lifecycle responsibility.

Digitalization functions as a critical enabling infrastructure within the proposed framework. Smart meters, IoT sensors, energy analytics, artificial intelligence, digital twins, renewable energy management systems, and cloud-based dashboards enhance the visibility, accuracy, and responsiveness of energy and carbon performance. These technologies strengthen the monitoring and verification requirements of ISO 50001 by enabling real-time detection of energy waste, improved forecasting, predictive maintenance, automated reporting, and more reliable evidence for decarbonization claims. At the same time, the effective deployment of such technologies depends on cross-functional organizational capabilities, including workforce competence, green procurement, lean operations, innovation culture, sustainable investment, data governance, and supply-chain collaboration. The model therefore avoids a purely technology-driven interpretation of transition and instead emphasizes the alignment of people, processes, data, suppliers, and investment decisions with energy, carbon, and circularity objectives.

Governance is embedded throughout the framework through the coordinated participation of multiple stakeholders. Top management provides strategic direction and resource commitment, energy managers translate objectives into measurable actions, operations teams implement process-level improvements, suppliers support low-carbon and circular inputs, customers influence responsible use and product return systems, and regulators and investors reinforce accountability through compliance, disclosure, and financial expectations. Communities and the natural environment are also incorporated as essential reference points for evaluating the broader legitimacy and societal value of industrial transformation. This governance structure suggests that ISO 50001 becomes more effective when it is integrated into organizational decision-making rather than confined to technical departments. Energy management is therefore repositioned as a collaborative governance system through which firms can align internal operations, external partnerships, and sustainability commitments.

The framework also clarifies how ISO 50001 can support a smart and resilient operating system. Strategy and energy policy establish the direction of change, while process design, engineering, and sustainable procurement translate strategic priorities into operational configurations. Production planning, energy control, quality management, maintenance, inventory coordination, workforce safety, equipment efficiency, demand-side response, and resource productivity collectively shape day-to-day energy, carbon, and material performance. Logistics and warehousing extend the scope of improvement beyond production, while management reviews, benchmarking, lessons learned, improvement projects, and corrective actions sustain the dynamic character of the system. This architecture reflects the central logic of ISO 50001: long-term performance improvement is achieved not through isolated interventions, but through repeated cycles of planning, implementation, verification, correction, and organizational learning.

The expected outcomes of the model can be grouped into three mutually reinforcing dimensions. Energy excellence is reflected in lower energy intensity, more reliable energy data, efficient assets, and a more energy-aware workforce. Decarbonization excellence is reflected in reduced Scope 1 and Scope 2 emissions, improved identification of Scope 3 hotspots, renewable energy integration, and stronger alignment with long-term transition pathways. Circular excellence is reflected in longer product life, improved material efficiency, reverse logistics capability, waste valorization, and reduced reliance on virgin resources. By integrating these outcomes, the model advances a broader interpretation of ISO 50001 beyond conventional energy savings. Its principal contribution lies in proposing how energy management, net-zero strategy, and circular economy could operate as interdependent components of a single transformation framework, where efficiency, emissions reduction, resource circularity, transparency, resilience, and continual improvement reinforce one another rather than function as separate sustainability agendas.

Fig. 7 is presented as an integrative conceptual model rather than an empirically validated causal model. Its pathways synthesize relationships identified across the reviewed literature and extend them to CE and SDG-oriented applications. The model suggests that ISO 50001 can provide a managerial infrastructure through which energy planning, measurement, operational control, procurement, design, competence development, auditing, and continual improvement are connected with broader decarbonization and resource-efficiency initiatives.

5. Future research directions

Based on the synthesized insights in the review, several gaps in the contemporary ISO 50001 literature emerge, outlining important directions for future research. Future research should move beyond asking whether ISO 50001 improves energy performance and examine the conditions under which it supports combined energy, carbon, and circularity outcomes. One promising direction is the development of integrated indicator systems that connect EnPIs and energy baselines with metrics for material efficiency, waste prevention, secondary material use, and product-life extension. A second priority concerns value-chain governance, including how ISO 50001-enabled firms interact with suppliers, logistics providers, and customers when seeking to reduce embodied emissions and strengthen reverse-flow systems. A third agenda involves digitalization, particularly the use of sensor networks, digital twins, traceability systems, and shared dashboards to monitor the joint performance of energy, carbon, and material loops. Sector-specific

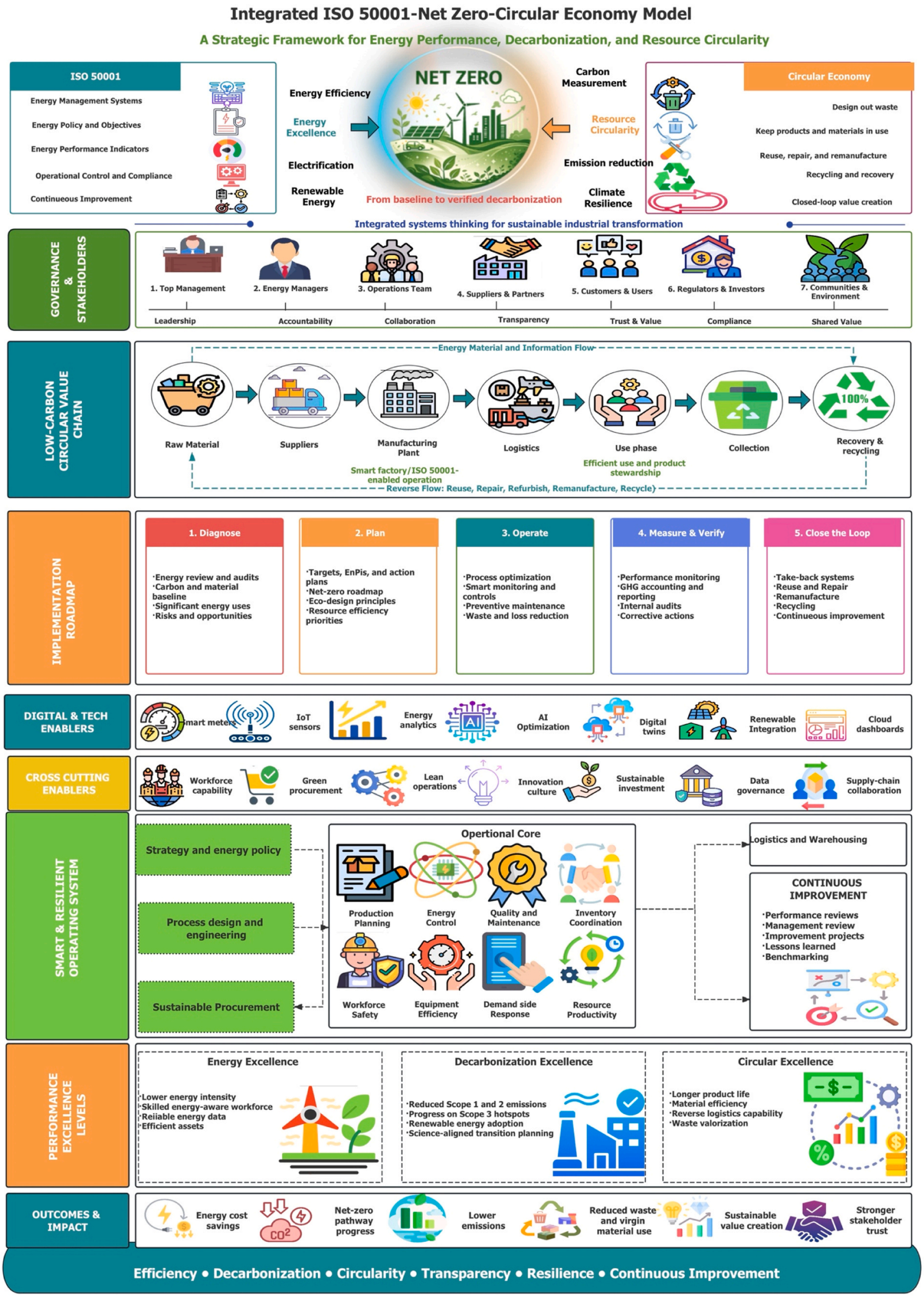

Fig. 7. Proposed integrated ISO 50001, net-zero, and circular-economy conceptual model.

Table 3
Key research gaps and future directions for ISO 50001 and carbon neutrality.

Research Gap / Future Direction	Description and Rationale
Under-Researched Sectors and SME Adoption	Existing ISO 50001 research remains concentrated in large industrial and manufacturing facilities, while sectors such as commercial buildings, transportation, agriculture, hospitality, retail, education, and public services remain less examined. SMEs also face specific barriers, including limited financial resources, lack of internal expertise, staffing constraints, and uncertainty about return on investment. Future studies should develop sector-specific and SME-sensitive EnMS frameworks, including simplified implementation models, cluster-based energy management, and practical business cases that can expand ISO 50001 adoption beyond large energy-intensive industries.
Organizational Integration & Cultural Challenges	ISO 50001 implementation often requires organizational change, cross-functional coordination, and sustained top management commitment. However, many studies still treat culture, employee engagement, and internal communication as general success factors rather than mechanisms that shape long-term energy performance. Future research should examine how energy managers, energy committees, training systems, incentive structures, and management review processes embed energy awareness into daily routines. Longitudinal studies comparing organizations that sustain energy performance improvements after certification with those that experience performance decline would provide valuable evidence.
EnMS and Decarbonization Strategy Alignment	A key gap concerns the limited integration between ISO 50001 initiatives and wider corporate decarbonization or net-zero strategies. In many organizations, EnMS implementation remains focused on energy cost reduction or regulatory compliance rather than being connected to greenhouse gas inventories, climate targets, internal carbon pricing, or science-based targets. Future research should examine whether organizations that integrate ISO 50001 with carbon accounting and climate-risk management achieve stronger emissions-reduction outcomes than those using EnMS as a stand-alone energy-efficiency tool.
Technology Integration and Industry 4.0	Digital technologies such as smart meters, IoT sensors, cloud platforms, artificial intelligence, machine learning, and digital twins offer strong potential to improve ISO 50001 implementation through real-time monitoring, anomaly detection, predictive maintenance, automated reporting, and improved decision-making. However, practical guidance on embedding these technologies into ISO 50001-compliant workflows remains limited. Future research should investigate digital EnMS models, assess the performance effects of AI-enabled energy analytics, and examine implementation challenges related to data quality, cybersecurity, cost, and workforce capability.
Policy Integration and Support Mechanisms	Governments increasingly use ISO 50001 as a policy instrument through energy-audit requirements, tax incentives, subsidies, and regulatory recognition. However, the actual impact of these policy mechanisms on adoption quality, energy performance, and emissions reduction remains insufficiently evaluated. Future studies should compare policy contexts across countries and sectors to identify which incentives, regulations, or support mechanisms most effectively promote meaningful EnMS implementation. Further research should also explore how ISO 50001 can be better aligned with carbon accounting, ESG disclosure, sustainable finance, and broader climate-policy frameworks.

studies are also needed, since circular strategies are likely to differ considerably across manufacturing, process industries, buildings, transport-intensive sectors, and service operations. Moreover, the next phase of ISO 50001 research should focus on whole-system integration, not only standard adoption, and should test how routine energy-management capabilities can be mobilized for wider low-carbon and circular transitions.

One major gap concerns the limited attention given to under researched sectors and small and medium-sized enterprises (SMEs). Most of the existing ISO 50001 literature has focused on large industrial facilities, specially manufacturing and energy intensive sectors where energy use is highly visible and where the business case of energy management is easily quantified. While this focus is economically logical, it leaves significant empirical blind spot given the massive aggregate emissions of under presented sectors including transportation, commercial buildings, agriculture, retail, hospitality, education, and public services. Similarly, SMEs encounter distinctive barriers to ISO 50001 adoption, including limited financial resources, lack of technical expertise, insufficient internal staffing, and ROI uncertainty. To bridge this gaps, future research must pivot towards sector-specific frameworks and examine how ISO 50001 can be adapted to various sectors and organizational sizes. In particular, research should investigate scalable intervention strategies, such as cluster based collective energy management and tailored guidance designed to reduce administrative and financial burdens without compromising the core principles of continual energy performance improvement.

A second crucial relate to the organizational and cultural dimensions of ISO 50001 implementation. While the literature frequently acknowledges that successful EnMS adoption requires leadership commitment, employee engagement and cross-functional coordination, these factors are often framed s generic prerequisites rather than operational mechanisms that actively drive energy performance outcomes. Fundamentally, implementing ISO 50001 is not merely a technical exercise, it demands restructuring of routine operations, decision-making processes, and organizational culture. Too often, energy management is confined to technical departments, limiting its integration into procurement, operations, maintenance, finance, and long-term strategic planning. Future research should therefore investigate how organizational structure and cultural factors shape the effectiveness of ISO 50001 and leverage longitudinal studies to analyze organizations that maintain strong energy performance improvements after certification with those that experience stagnation or decline. Furthermore, such research could study the role of energy manager, energy committees, staff training, incentive systems, internal communication, and top management review in embedding energy awareness into daily practices. A deeper understanding of these human and organizational factors would help explain why firms with similar certification status yield highly variable of energy and carbon performance.

Another important research gap involves the strategic decoupling of ISO 50001 from overarching corporate decarbonization frameworks. While the standard is designed to optimize energy performance, its explicit alignment with net zero targets, carbon neutrality and climate strategies remain neglected in the literature. Several firms adopt ISO 50001 primary as a tactical instrument for energy cost reduction, operational efficiency, or regulatory compliance, leaving its systematic contribution to greenhouse gas (GHG) mitigation largely unexamined. This creates a conceptual and empirical gap between energy governance and carbon management. To reconcile this, future research should investigate the integration of EnMS practices within corporate decarbonization pathways. Specifically, evaluate whether the integration of ISO 50001 with GHG inventories, carbon accounting frameworks, internal carbon pricing, or science-based targets fields superior climate outcomes. Methodologically, future studies would benefit from longitudinal and quasi-experimental designs that track energy performance indicators and associated emissions before and after ISO 50001 implementation. This approach will allow researchers to move beyond general claims of efficiency improvement and provide stronger evidence of the standard contribution to measurable decarbonization.

The integration of digital technologies into ISO 50001 also represents an emerging and underdeveloped research frontier. While the standard dictates a systematic PDCA architecture, many EnMs applications remain bound to legacy data-collection paradigms. The rapid evolution of industry 4.0, including smart meters, IoT sensors, cloud-based platforms, artificial intelligence, machine learning, and digital twins, offer new opportunities to enhance the effectiveness of energy management systems. These technologies can improve real time monitoring, detect anomalies in energy consumption, support predictive maintenance, automate reporting, and enable more dynamic decision-making. Yet, the literature lacks a comprehensive blueprint for systematically embedding these technologies within standard compliant workflows. Future research should explore the concept of a digital EnMS and examine how digital tools can strengthen the PDCA cycle. Pilot studies and industry demonstrations could assess whether IoT enabled monitoring, AI based optimization, or digital twins yield high, long-term energy savings. Concurrently, research should address the challenges associated with digital integration, including data quality, cybersecurity, implementation cost, and the skills required to interpret and act upon energy data. This area offers strong potential for interdisciplinary research linking energy management, information systems, engineering, and sustainability studies.

Furthermore, the policy and institutional context of ISO 50001 adoption remain insufficiently understood. Governments globally re integrating the standard into public policy by linking certification to energy audit mandates, tax relief, and sustainability subsidies. Yet, limited research has evaluated how these policy instruments influence actual organizational outcomes. In practice, managers face a disconnected patchwork of carbon accounting rules, energy audits, efficiency incentives, and ESG disclosure requirements. Without clear integration, ISO 50001may be perceived as one additional compliance requirement rather than a strategic framework connecting energy efficiency and climate action. Future research should therefore assess how different policy mechanisms affect ISO 50001 adoption, implementation quality and energy performance outcomes. Comparative cross-country studies could examine whether organizations operating under strong regulatory or incentive-based frameworks achieve better outcomes than those in less supportive contexts. Additionally, future research should investigate how to seamlessly blend ISO 50001 with corporate climate disclosure and sustainable finance protocols. Such research would support the development of a more unified energy carbon management model, reduce duplication and improve the strategic relevance of ISO 50001 for organizations and policymakers.

Recent sustainability and technology-oriented reviews suggest that future ISO 50001 research should move toward more testable, method-driven, and socially grounded research agendas. Govindan [128] emphasizes the value of operations research methods for supporting SDG-oriented decision-making in supply-chain environments, which is relevant for examining ISO 50001 beyond facility-level energy management and toward value-chain decarbonization and circular resource flows. Raman et al., [129,130] highlighted the role of sustainable technologies, social innovation, and inclusive development in advancing community-oriented sustainability outcomes, suggesting that future EnMS research should examine not only technical performance but also inclusive adoption in SMEs, public organizations, and under-represented regions. Raman et al., [129,130] further stress that advanced AI systems require responsible governance, transparency, and ethical alignment, which is directly relevant to future digital EnMS research involving AI-enabled forecasting, automated energy optimization, and decision-support systems. Building on these insights, the following future research questions and tentative hypotheses are proposed to guide subsequent empirical work.

The future research agenda of ISO 50001 should move beyond the introductory question of whether standard adoption yields efficiency improvement and focusses more critically on how its impact is conditioned by sectoral boundaries, organizational contexts, technological capabilities, and policy environments. How does ISO 50001 implementation differ across SMEs, service sectors, logistics systems, and digital-infrastructure settings compared with large manufacturing firms? Which organizational capabilities explain persistent versus short-lived EnMS outcomes? To what extent does digital maturity change the effectiveness of ISO 50001? Can ISO 50001 support broader decarbonization strategy beyond internal efficiency? How can ISO 50001 support circular-economy transition at the process and value-chain levels? What policy instruments most effectively support the diffusion and quality of ISO 50001 adoption? Expanding the literature in these directions would shift the future research agenda from asking whether ISO 50001 matters to asking under what conditions, through which mechanisms, and in combination with which complementary systems it produces durable energy, carbon, and resource-performance gains (Table 3).

6. Conclusion and implications

This study aimed to address three questions regarding the structure of ISO 50001 research, the EnMS activities through which the standard functions, and its connection to broader sustainability objectives. In addressing RQ1, the review identified sixteen recurring EnMS activities that organize implementation across various domains, including policy, planning, measurement, resourcing, operational control, auditing, management review, nonconformity management, and continual improvement. These activities suggest that ISO 50001 operates through an integrated management cycle rather than through discrete technical interventions.

In addressing RQ2, the findings demonstrate that ISO 50001 offers a systematic organizational structure for managing and continually improving energy performance, while also providing management processes may be relevant to wider decarbonization efforts when they are explicitly connected to carbon objectives. The standard enhances energy baselining, performance visibility, corrective learning, and operational discipline, thereby facilitating more manageable and sustainable energy-related carbon reductions. Simultaneously, the evidence does not substantiate the notion that ISO 50001 certification serves as a direct pathway to achieving net zero. Absolute decarbonization relies on additional strategies, including electrification, renewable energy sourcing, technological substitution, product redesign, and value chain engagement.

In addressing RQ3, the reviewed literature provides robust empirical evidence regarding enhancements in energy performance, operational control, and organizational accountability, with the most evident connections to SDG 7, SDG 12, and SDG 13. The circular economy dimension remains more uncertain. The reviewed articles infrequently assess circular outcomes directly; rather, they propose that EnMS routines may be expanded to enhance resource efficiency, repair, reuse, recycling, and recovery when organizations intentionally broaden the implementation scope. The proposed framework's contribution to the circular economy in this study should be viewed as a structured conceptual extension based on EnMS evidence, rather than as a definitive empirical outcome.

The bibliometric analysis highlights a growing yet fragmented research landscape. Academic discourse on ISO 50001 has converged around several interconnected themes, notably energy management system, energy efficiency, energy performance, sustainability, implementation challenges, and industrial energy optimization. The thematic trajectory indicates a paradigm shift, gradually moving beyond early discussions of certification and formal implementation towards a broader agenda encompassing operational control, continuous monitoring, strategic energy planning, digitalization, and sustainable oriented transformation. Furthermore, the thematic analysis shows that the field is not limited to descriptions of ISO 50001 adoption, but increasingly examines the standard through diverse analytical, managerial, and technical lenses. The most prominent clusters underscore growing interest in the mechanisms through which ISO 50001 contributes to organizational energy performance, while more specialized clusters such as machine learning, energy conservation, and energy planning signal a clear diversification toward data-driven and digitalized energy management paradigms.

The systematic review identifies the specific EnMS activities and sub-activities through which ISO 50001 functions at the microorganizational level. The results indicate that the standard associated with energy performance enhancements through a structured set of activities, including the establishment of energy policies, energy reviews, energy baselines, energy performance improvement indicators, objectives and targets, operational control, design and procurement, competence development, documentation, communication, internal audits, nonconformity management, management review, and continual improvements. Crucially, these activities do not operate in isolation or as a strict linear sequence; rather, they form a dynamic, interconnected management cycle. This cyclical framework empowers organizations to plan, execute, monitor, assess, and optimize their energy performance. In this sense, ISO 50001 functions as process-oriented management infrastructure that embeds energy considerations directly into day-to-day organizational routines, governance structures, and accountability frameworks.

Despite these contributions, the existing literature reveals considerable limitations. Current research primarily assesses the effectiveness of ISO 50001 using proxy metrics, including reported energy savings, perceived organizational advantages, factors contributing to successful implementation, or outcomes of certification. There is a deficiency in empirical depth concerning rigorous, longitudinal evaluations of energy performance when comparing pre- and post-adoption phases. Furthermore, the literature rarely explores whether ISO 50001 fosters enduring, absolute emissions reductions, or how its impact varies across sectors, countries, firm sizes, and regulatory environments. This limits the ability of the literature to fully assess the standard's contribution to climate actions. Consequently, future research must pivot away from administrative, compliance-focused inquiries toward outcome-oriented empirical designs that examine actual performance trajectories, real word emissions data, and the conditions under which ISO 50001 delivers measurable sustainability benefits. From a theoretical perspective, this research contributes to the literature by contextualizing ISO 50001 scholarship within the broader discussions on energy transition, corporate sustainability, and organizational decarbonization. Its argues that ISO 50001 should not be viewed only as a technical or compliance -mandate; instead, it represents a structured organizational mechanism through which energy performance improvement can be institutionalized. Furthermore, the EnMS activities framework conceptualized herein offers a highly transferable analytical model for dissecting standard operationalization at the process level. By mapping the activities and sub-activities that shape corporate energy behavior, this study illuminates the precise causal pathways linking formal management structures to macro-level sustainability metrics. Consequently, this contributes to management system theory by demonstrating how structured standards foster organizational learning, operational discipline, accountability, and continuous improvement. Methodologically, this study underscores the synergistic value of pairing bibliometric analysis with systematic literature review techniques when navigating an expanding, highly interdisciplinary research domain. This dual-method approach is suited to the ISO 50001 ecosystem, where literature is typically dispersed across different disciplines, including energy policy, industrial engineering, sustainability management, environmental management, and operations management. By bridging thematic mapping with process-level EnMS operations, this paper provides a unified, holistic synthesis.

The findings also carry broader academic implications for research on management standards, energy transitions, sustainability governance, and organizational decarbonization. First, the study contributes to ISO 50001 and EnMS scholarship by clarifying that ISO 50001 should be viewed primarily as a governance framework that enables ongoing improvements in energy performance, rather than as a direct or standalone tool for decarbonization. This distinction is important because it shifts academic attention from the status of certification to the organizational processes by which energy performance is systematically planned, measured, monitored, reviewed, and improved over time. Second, the review contributes to carbon-neutrality literature by showing that energy management standards may provide the organizational infrastructure needed to connect operational energy data with broader climate strategies, including emissions accounting, renewable-energy planning, investment decisions, and sustainability reporting. Third, the study contributes to research on the circular economy and Sustainable Development Goals (SDGs) by distinguishing between empirical evidence directly related to EnMS implementation and more conceptual associations with circular economy and SDG frameworks. This distinction helps prevent overstatement of ISO 50001's role, while still identifying plausible ways in which energy-management practices can support resource efficiency, responsible production, and climate-related objectives. Finally, the hybrid bibliometric and systematic review design offers a methodological contribution by combining field-level knowledge mapping with activity-level synthesis. This approach can support future review studies seeking to connect the intellectual structure of a research field with the operational practices through which management standards are implemented.

This research offers significant practical and policy implications. The practical implication of the integrated model is that organizations may use the EnMS to support coordination across energy, carbon, materials, and value-chain decisions. For managers, this means integrating energy policy with procurement specifications, maintenance routines, product stewardship, demand-side flexibility, and supplier communication, rather than limiting its scope to utility monitoring alone. For policymakers and standard users this suggests that the strategic value of ISO 50001is enhanced when it is linked to electrification roadmaps, integration of renewable energy, improved visibility of indirect (scope 3) emissions, and initiatives that promote repair, reuse, remanufacture, and recycling. For researchers, the implication is equally important: the contribution of ISO 50001 should be assessed not only through direct reductions in energy use, but through its ability to stabilize broader organizational capabilities such as data discipline, cross-functional governance, and continuous improvement that make wider transition strategies more credible and implementable. In this sense, ISO 50001 becomes less a narrow compliance tool and more a platform for structured energy management improvement. For corporate managers, ISO 50001 should be leveraged not merely as a compliance-driven checklist, but a strategic mechanism for anchoring energy performance within core operational governance, with practitioners prioritizing the optimization of EnMS activities that directly support performance improvements. The EnMS activities framework conceptualized in the study provides a basis for evaluating implementation maturity, identifying gaps, and exploring the potential contribution of ISO 50001 to long-term sustainability outcomes. The contribution of the review is therefore to clarify how ISO 50001 may be conceptually positioned as a management platform that could support a broader transition toward low-carbon and resource-efficient organizations, while distinguishing established energy-management evidence from conceptual CE and SDG pathways. For policymakers, the results indicate that ISO 50001 can support national and sectoral decarbonization initiatives, especially within energy intensive industries. However, policy support should extend beyond merely promoting certification and instead prioritize measurable energy performance improvements, verified emissions reductions, and alignment with SDGs and climate commitments. Ultimately, the standard may act as an operational conduit, translating high-level sustainability goals into actionable, micro-level corporate routines.

The multilayer integrated model illustrated in Fig. 7 is proposed as a conceptual framework rather than a validated explanatory model. It was developed by integrating bibliometric patterns, the synthesis of EnMS activities, and a measured expansion towards decarbonization and systematically incorporating decarbonization and circularity-related principles. Empirical validation through case studies, survey-based modeling, expert elicitation, Delphi analysis, or longitudinal implementation research is essential as a subsequent step.

This study supports the relevance of ISO 50001 as a management framework for improving energy performance and suggests it can contribute to organizational decarbonization when it is implemented deeply and linked to broader strategic action. The evidence does not justify the stronger claim that certification alone guarantees carbon neutrality, absolute emissions reduction, or comprehensive circular-economy performance. Rather, ISO 50001 should be understood as an enabling framework: it improves measurement, accountability, coordination, and continual improvement, thereby creating favorable conditions for energy savings, selected emissions reductions, and some resource-efficiency gains. Achieving net-zero pathways and circular transformation still requires complementary measures such as renewable-energy sourcing, electrification, low-carbon procurement, product and process redesign, reverse logistics, and value-chain collaboration.

CRediT authorship contribution statement

Muhammad Ikram: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Jinane Es-sadki:** Writing – original draft, Validation, Investigation, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J. Debbarma, Y. Choi, A taxonomy of green governance: A qualitative and quantitative analysis towards sustainable development, Sustain. Cities Soc. 79 (2022) 103693, https://doi.org/10.1016/j.scs.2022.103693.

[2] Y.A. Solangi, C. Magazzino, Evaluating financial implications of renewable energy for climate action and sustainable development goals, Renew. Sustain. Energy Rev. 212 (2025) 115390, https://doi.org/10.1016/j.rser.2025.115390.

[3] UNIDO - United Nations industrial Development Organization. (2013). *Practical Guide for Implementing an Energy Management System*. https://www.unido.org/sites/default/files/2017-11/IEE_EnMS_Practical_Guide.pdf.

[4] K. Fang, A. Xu, S. Wang, X. Jia, Z. Liao, R.R. Tan, H. Sun, F. Su, Progress towards Sustainable Development Goals in the Belt and Road Initiative countries, J. Clean. Prod. 424 (2023) 138808, https://doi.org/10.1016/j.jclepro.2023.138808.

[5] Z. Shi, X. Yang, Q. Jin, Y. ho Chiu, L. Zhang, Roadmap to achieve sustainable energy development: Is energy security important to the path to SDG7: Affordable and Clean Energy -Sustainable Development Goals? Renew. Energy 251 (2025) 123425 https://doi.org/10.1016/j.renene.2025.123425.

[6] S. Vengatesan, A. Jayakumar, K.K. Sadasivuni, FCEV vs. BEV — A short overview on identifying the key contributors to affordable & clean energy (SDG-7), Energy Strategy Rev. 53 (2024) 101380, https://doi.org/10.1016/j.esr.2024.101380.

[7] X. He, S. Khan, I. Ozturk, M. Murshed, The role of renewable energy investment in tackling climate change concerns: Environmental policies for achieving SDG-13, Sustain. Dev. 31 (3) (2023) 1888–1901, https://doi.org/10.1002/sd.2491.

[8] UNCC. (2015). *The Paris Agreement*.

[9] International energy agency (IEA) report https://www.iea.org (2022), Accessed 10th august 2026.

[10] M., A.S. Sing, M.M. Beno, Enhancing energy efficiency in educational institutions: a scalable, integrated framework for cost-effective and sustainable energy management, Environ. Dev. Sustain. (2025) 1–28, https://doi.org/10.1007/s10668-025-06388-w.

[11] H. Dion, M. Evans, Strategic frameworks for sustainability and corporate governance in healthcare facilities; approaches to energy-efficient hospital management, Benchmarking 31 (2) (2024) 353–390, https://doi.org/10.1108/BIJ-04-2022-0219.

[12] M. Wigger, P. Burggräf, F. Steinberg, A. Becher, B. Heinbach, Integrating artificial intelligence into energy management: A case study on energy consumption data analysis and forecasting in a German manufacturing company, Energy AI 21 (2025) 100576, https://doi.org/10.1016/j.egyai.2025.100576.

[13] L.J. Pagulayan, A.D. Calderon, Baseline, Benefits, Barriers, and Beyond: A Review of ISO 50001 Energy Management System Implementation in the AI-Driven Data Center Industry, Energies 19 (11) (2026) 2550, https://doi.org/10.3390/en19112550.

[14] L.A.I. Carrera, L. Díaz-Tato, G.J. Barroso García, Y.C. Alvarez, Y. Valdivia Nodal, M.A. Cruz-Pérez, J. Rodríguez-Reséndiz, Intelligent Computational Modeling of ISO 50001 Energy Performance Indicators for Sustainable Energy Management Systems: A Systematic Review, Algorithms 19 (7) (2026) 533, https://doi.org/10.3390/a19070533.

[15] T.A. Alka, R. Raman, M. Suresh, Critical success factors for successful technology innovation development in sustainable energy enterprises, Sci. Rep. 15 (1) (2025) 14138, https://doi.org/10.1038/s41598-025-98725-2.

[16] M. Ikram, Redesigning the Value Chain: A Net-Zero Circular Economy Approach to Resource Retention, Bus. Strategy Environ. (2026), https://doi.org/10.1002/bse.70591.

[17] F.L. Moreno, H. Fuchs, W. Miller, P. Therkelsen, The global policy landscape of ISO 50001 energy management systems, Energy Policy (2026) 115198, https://doi.org/10.1016/j.enpol.2026.115198.

[18] M.S. Stephen, S.A. Valsalan, Energy efficiency and ISO 50001:2018 implementation in seafood processing industries: A comprehensive analysis and strategic framework, Clean. Energy Syst. 10 (2025) 100173, https://doi.org/10.1016/j.cles.2025.100173.

[19] IEA.org/weo. (2017). *Iso 50001 Energy Management System*. When Recognition Matters WHITEPAPER. https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100400.pdf.

[20] B. Jovanović, J. Filipović, ISO 50001 standard-based energy management maturity model - Proposal and validation in industry, J. Clean. Prod. 112 (2016) 2744–2755, https://doi.org/10.1016/j.jclepro.2015.10.023.

[21] H. Fuchs, A. Aghajanzadeh, P. Therkelsen, Identification of drivers, benefits, and challenges of ISO 50001 through case study content analysis, Energy Policy 142 (2020) 111443, https://doi.org/10.1016/j.enpol.2020.111443.

[22] V. António da Silva Gonçalves, F.J. Mil-Homens dos Santos, Energy management system ISO 50001:2011 and energy management for sustainable development, Energy Policy 133 (2019) 110868, https://doi.org/10.1016/j.enpol.2019.07.004.

[23] L.G. Mkhaimer, M. Arafeh, A.H. Sakhrieh, Effective implementation of ISO 50001 energy management system: Applying Lean Six Sigma approach, Int. J. Eng. Bus. Manag. 9 (2017) 1–12, https://doi.org/10.1177/1847979017698712.

[24] W.A. Pelser, J.C. Vosloo, M.J. Mathews, Results and prospects of applying an ISO 50001 based reporting system on a cement plant, J. Clean. Prod. 198 (2018) 642–653, https://doi.org/10.1016/j.jclepro.2018.07.071.

[25] A. Yuriev, O. Boiral, Implementing the ISO 50001 System: A Critical Review, ISO 9001 ISO 14001 New. Manag. Stand. (2018) 145–175, https://doi.org/10.1007/978-3-319-65675-5_9.

[26] I.S. Rampasso, G.P.M. Filho, R. Anholon, R.A. de Araujo, G.B.A. Lima, L.P. Zotes, W.L. Filho, Challenges presented in the implementation of sustainable energy management via ISO 50001:2011, Sustain. (Switz.) 11 (22) (2019) 6321, https://doi.org/10.3390/su11226321.

[27] G. Dall'O', S. Ferrari, E. Bruni, 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 Build. 219 (2020) 110029, https://doi.org/10.1016/j.enbuild.2020.110029.

[28] M. Pandin, S. Sumaedi, A. Yaman, M. Ayundyahrini, N.K. Supriatna, N.W. Hesty, ISO 50001 based energy management system: a bibliometric perspective, Int. J. Energy Sect. Manag. 18 (6) (2024) 1938–1963, https://doi.org/10.1108/IJESM-08-2023-0001.

[29] Y. Jin, Y. Long, S. Jin, Q. Yang, B. Chen, Y. Li, L. Xu, An energy management maturity model for China: Linking ISO 50001:2018 and domestic practices, J. Clean. Prod. 290 (2021) 125168, https://doi.org/10.1016/j.jclepro.2020.125168.

[30] T. Schmitt, S. Mattsson, E. Flores-García, L. Hanson, Achieving energy efficiency in industrial manufacturing, Renew. Sustain. Energy Rev. 216 (2025) 115619, https://doi.org/10.1016/j.rser.2025.115619.

[31] A. Zhang, M. Farooque, T.M. Choi, Y. Liu, Individual Producer Responsibility-based Product Take-back, Circular Product Design and Firm Performance, Br. J. Manag. 37 (1) (2025) e70022, https://doi.org/10.1111/1467-8551.70022.

[32] M. Ikram, J. Es-sadki, ISO 14001, Carbon Neutrality, and the Sustainable Development Goals: A Bibliometric and Systematic Review of Environmental Management Systems, Corp. Social. Responsib. Environ. Manag. (2026), https://doi.org/10.1002/csr.70820.

[33] J. Hulland, Bibliometric reviews—some guidelines, J. Acad. Mark. Sci. 52 (4) (2024) 935–938.

[34] D. Moher, A. Liberati, J. Tetzlaff, D.G. Altman, Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement, J. Clin. Epidemiol. 62 (10) (2009) 1006–1012, https://doi.org/10.1016/j.jclinepi.2009.06.005.

[35] S. Agrawal, P. Oza, R. Kakkar, S. Tanwar, V. Jetani, J. Undhad, A. Singh, Analysis and recommendation system-based on PRISMA checklist to write systematic review, Assess. Writ. 61 (2024) 100866, https://doi.org/10.1016/j.asw.2024.100866.

[36] T.A. Alka, M. Suresh, S. Mandal, W.L. Filho, R. Raman, Large language models in sustainable energy systems: a systematic review on modeling, optimization, governance, and alignment to sustainable development goals, Energies 19 (6) (2026) 1588, https://doi.org/10.3390/en19061588.

[37] D. Apostolou, A Literature Review on Energy Management Systems and Their Application on Harbour Activities, Energies 18 (18) (2025) 4887, https://doi.org/10.3390/en18184887.

[38] V.K. Singh, P. Singh, M. Karmakar, J. Leta, P. Mayr, The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis, Scientometrics 126 (6) (2021) 5113–5142, https://doi.org/10.1007/s11192-021-03948-5.

[39] N.M. Todaro, G. Gionfriddo, O.U.R. Khan, T. Daddi, Enablers and Constraints of Environmental Sustainability Integration: A Structuration Perspective on Professional Sports Organizations, Bus. Strategy Environ. 34 (7) (2025) 8620–8648, https://doi.org/10.1002/bse.70035.

[40] N.M. Todaro, T. Daddi, F. Testa, F. Iraldo, Organization and management theories in environmental management systems research: A systematic literature review, Bus. Strategy Dev. 3 (1) (2020) 39–54, https://doi.org/10.1002/bsd2.77.

[41] L. Hu, H. Zhu, L. Xie, B. Li, B. Qu, Q. Liao, R. Tao, Fire prevention and extinguishing technologies in coal spontaneous combustion: a bibliometric and systematic review, J. Therm. Anal. Calorim. 149 (22) (2024) 12609–12633, https://doi.org/10.1007/s10973-024-13755-8.

[42] M. Dahlgren, T. Björkman, F. Noda, J. Ogawa, Y. Yamashita, G. Siciliano, P. De Los Reyes, C. Kramer, Models for driving energy efficiency nationally using Energy management, Eceee Ind. Summer Study Proc. 1 (2) (2014) 101–112.

[43] A. Haeri, K. Rezaie, An approach to evaluate resource utilization in energy management systems, Energy Sources Part. B Econ. Plan. Policy 11 (9) (2016) 855–860, https://doi.org/10.1080/15567249.2012.756080.

[44] P. Karcher, R. Jochem, Success factors and organizational approaches for the implementation of energy management systems according to ISO 50001, TQM J. 27 (4) (2015) 361–381, https://doi.org/10.1108/TQM-01-2015-0016.

[45] I. Laskurain, I. Heras-Saizarbitoria, M. Casadesús, Fostering renewable energy sources by standards for environmental and energy management, Renew. Sustain. Energy Rev. 50 (2015) 1148–1156, https://doi.org/10.1016/j.rser.2015.05.050.

[46] N.S. Mahmood, A.A. Ajmi, S. Sarip, H.M. Kaidi, M.A. Suhot, K.R. Jamaludin, H.H. A. Talib, Modeling energy management sustainability: Smart integrated framework for future trends, Energy Rep. 8 (2022) 8027–8045, https://doi.org/10.1016/j.egyr.2022.06.023.

[47] J.M. Tejera, G. Rios, T. Martínez, M. Palacios, Energy management systems in copper smelting: The atlantic copper case study, in: Green Energy and Technology, 0, Springer, 2018, pp. 251–269, https://doi.org/10.1007/978-3-319-54199-0_14.

[48] W. Wongsapai, Performance Tracking of Thailand's Energy Management System under Energy Conservation Promotion Act, Energy Procedia 100 (2016) 448–451, https://doi.org/10.1016/j.egypro.2016.10.200.

[49] Z. Zhang, C. Luo, G. Zhang, Y. Shu, S. Shao, New energy policy and green technology innovation of new energy enterprises: Evidence from China, Energy Econ. 136 (2024) 107743, https://doi.org/10.1016/j.eneco.2024.107743.

[50] S. Alotaibi, H. Alogaili, K. Alawwad, S. Aljarallah, 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 17 (11) (2025) 5131, https://doi.org/10.3390/su171151.

[51] A. Trubetskaya, O. McDermott, S. McGovern, Implementation of an ISO 50001 energy management system using Lean Six Sigma in an Irish dairy: a case study, TQM J. 35 (9) (2022) 1–24, https://doi.org/10.1108/TQM-08-2022-0252.

[52] K.B. Debnath, M. Mourshed, Forecasting methods in energy planning models, Renew. Sustain. Energy Rev. 88 (2018) 297–325, https://doi.org/10.1016/j.rser.2018.02.002.

[53] P. Fitzgerald, P. Therkelsen, P. Sheaffer, P. Rao, Deeper and persistent energy savings and carbon dioxide reductions achieved through ISO 50001 in the manufacturing sector, Sustain. Energy Technol. Assess. 57 (2023) 103280, https://doi.org/10.1016/j.seta.2023.103280.

[54] E. Andersson, H. Dernegård, M. Wallén, P. Thollander, Decarbonization of industry: Implementation of energy performance indicators for successful energy management practices in kraft pulp mills, Energy Rep. 7 (2021) 1808–1817, https://doi.org/10.1016/j.egyr.2021.03.009.

[55] J.A. Lopez-Leyva, Energy efficiency for wine companies: Regional sustainability initiatives in the Guadalupe valley from a transdisciplinary perspective, Clean. Energy Syst. 2 (2022) 100014, https://doi.org/10.1016/j.cles.2022.100014.

[56] M. Moghadasi, N. Izadyar, A. Moghadasi, H. Ghadamian, Applying machine learning techniques to implement the technical requirements of energy management systems in accordance with ISO 50001:2018, an industrial case study, Energy Sources Part. A Recovery Util. Environ. Eff. 47 (2) (2025) 2011989, https://doi.org/10.1080/15567036.2021.2011989.

[57] J.S. Towslee, Energy Management Key Performance Indicators (EnPIs) and Energy Dashboards, Energy Manag. Effic. Process. Ind. (2015) 349–360, https://doi.org/10.1002/9781119033226.ch27.

[58] K. Zhou, S. Yang, Understanding household energy consumption behavior: The contribution of energy big data analytics, Renew. Sustain. Energy Rev. 56 (2016) 810–819, https://doi.org/10.1016/j.rser.2015.12.001.

[59] A. Fichera, R. Volpe, E. Cutore, Energy performance measurement, monitoring and control for buildings of public organizations: Standardized practises compliant with the ISO 50001 and ISO 50006, Dev. Built Environ. 4 (2020) 100024, https://doi.org/10.1016/j.dibe.2020.100024.

[60] T. Knayer, N. Kryvinska, The difference between energy management systems and environmental management systems on the implementation of cross-sectional technologies in enterprises, Energy Rep. 13 (2025) 1691–1704, https://doi.org/10.1016/j.egyr.2025.01.030.

[61] R. Pereira, J. Figueiredo, R. Melicio, V.M.F. Mendes, J. Martins, J.C. Quadrado, Consumer energy management system with integration of smart meters, Energy Rep. 1 (2015) 22–29, https://doi.org/10.1016/j.egyr.2014.10.001.

[62] R. Ford, J. Hardy, Are we seeing clearly? The need for aligned vision and supporting strategies to deliver net-zero electricity systems, Energy Policy 147 (2020) 111902, https://doi.org/10.1016/j.enpol.2020.111902.

[63] T. Hansen, J. Andersson, J. Finstad, J. Hanson, H. Hellsmark, T. Mäkitie, A. Nordholm, M. Steen, How aligned are industry strategy and government policy for the decarbonization of energy-intensive process industries? Clim. Policy 24 (9) (2024) 1149–1162, https://doi.org/10.1080/14693062.2024.2363490.

[64] H. Kanneganti, B. Gopalakrishnan, E. Crowe, O. Al-Shebeeb, T. Yelamanchi, A. Nimbarte, K. Currie, A. Abolhassani, Specification of energy assessment methodologies to satisfy ISO 50001 energy management standard, Sustain. Energy Technol. Assess. 23 (2017) 121–135, https://doi.org/10.1016/j.seta.2017.09.003.

[65] H. Lund, P.A. Østergaard, D. Connolly, B.V. Mathiesen, Smart energy and smart energy systems, Energy 137 (2017) 556–565, https://doi.org/10.1016/j.energy.2017.05.123.

[66] C. Schützenhofer, Overcoming the efficiency gap: energy management as a means for overcoming barriers to energy efficiency, empirical support in the case of Austrian large firms, Energy Effic. 14 (5) (2021) 45, https://doi.org/10.1007/s12053-021-09954-z.

[67] M. Wetter, P. Ehrlich, A. Gautier, M. Grahovac, P. Haves, J. Hu, A. Prakash, D. Robin, K. Zhang, OpenBuildingControl: Digitizing the control delivery from building energy modeling to specification, implementation and formal verification, Energy 238 (2022) 121501, https://doi.org/10.1016/j.energy.2021.121501.

[68] S. Coelho, M. Russo, R. Oliveira, A. Monteiro, M. Lopes, C. Borrego, Sustainable energy action plans at city level: A Portuguese experience and perception, J. Clean. Prod. 176 (2018) 1223–1230, https://doi.org/10.1016/j.jclepro.2017.11.247.

[69] R. Ghafari, F.H. Kabutarkhani, N. Mansouri, Task scheduling algorithms for energy optimization in cloud environment: a comprehensive review, Clust. Comput. 25 (2) (2022) 1035–1093, https://doi.org/10.1007/s10586-021-03512-z.

[70] L.A. Iturralde Carrera, A.L. Álvarez González, J. Rodríguez-Reséndiz, J. M. Álvarez-Alvarado, Selection of the Energy Performance Indicator for Hotels Based on ISO 50001: A Case Study, Sustain. (Switz.) 15 (2) (2023) 1568, https://doi.org/10.3390/su15021568.

[71] I. Kshanh, M. Tanaka, Comparative analysis of MCDM for energy efficiency projects evaluation towards sustainable industrial energy management: Case study of a petrochemical complex, Expert. Syst. Appl. 255 (2024) 124692, https://doi.org/10.1016/j.eswa.2024.124692.

[72] R. Moradpour, H. Ardi, A. Tavakoli, Design and implementation of a new SEPIC-based high step-up DC/DC converter for renewable energy applications, IEEE Trans. Ind. Electron. 65 (2) (2017) 1290–1297, https://doi.org/10.1109/TIE.2017.2733421.

[73] W. Bevan, S.L. Lu, M. Sexton, Skills required to deliver energy efficient school retrofit buildings, Eng. Constr. Archit. Manag. 27 (10) (2020) 3051–3073, https://doi.org/10.1108/ECAM-03-2019-0126.

[74] J. Chen, X. Tang, K. Yang, A unified benchmark for deep reinforcement learning-based energy management: Novel training ideas with the unweighted reward, Energy 307 (2024) 132687, https://doi.org/10.1016/j.energy.2024.132687.

[75] D. Coraci, S. Brandi, A. Capozzoli, Effective pre-training of a deep reinforcement learning agent by means of long short-term memory models for thermal energy management in buildings, Energy Convers. Manag. 291 (2023) 117303, https://doi.org/10.1016/j.enconman.2023.117303.

[76] H. Khajehpour, Y. Saboohi, G. Tsatsaronis, Environmental responsibility accounting in complex energy systems, J. Clean. Prod. 166 (2017) 998–1009, https://doi.org/10.1016/j.jclepro.2017.08.013.

[77] B. Pieterse, K. Agyekum, P. Manu, S.R. Mohandes, C. Cheung, A. Yunusa-Kaltungo, Examining critical project management skills for successful delivery of major maintenance projects: insights from the United Kingdom energy sector, Eng. Constr. Archit. Manag. 31 (4) (2024) 1556–1584, https://doi.org/10.1108/ECAM-07-2022-0658.

[78] S. Renström, Supporting diverse roles for people in smart energy systems, Energy Res. Social. Sci. 53 (2019) 98–109, https://doi.org/10.1016/j.erss.2019.02.018.

[79] Y. Fernando, P.S. Bee, C.J.C. Jabbour, A.M.T. Thomé, Understanding the effects of energy management practices on renewable energy supply chains: Implications for energy policy in emerging economies, Energy Policy 118 (2018) 418–428, https://doi.org/10.1016/j.enpol.2018.03.043.

[80] M. Halis, M. Halis, Impact of energy management systems, pro-environmental energy consumption, and awareness on performance outcomes: a serial mediated-moderated modeling with PLS-SEM, Environ. Sci. Pollut. Res. 29 (18) (2022) 26910–26921, https://doi.org/10.1007/s11356-021-17867-8.

[81] L.B.M. Sutton, T. Le Roux, Sustainable internal communication and digital trends amidst an energy crisis: can a middle ground be found in South Africa? J. Commun. Manag. 29 (5) (2024) 1–17, https://doi.org/10.1108/JCOM-04-2024-0060.

[82] D. Talbot, O. Boiral, GHG reporting and impression management: An assessment of sustainability reports from the energy sector, J. Bus. Ethics 147 (2) (2018) 367–383, https://doi.org/10.1007/s10551-015-2979-4.

[83] K. Zhou, C. Fu, S. Yang, Big data driven smart energy management: From big data to big insights, Renew. Sustain. Energy Rev. 56 (2016) 215–225, https://doi.org/10.1016/j.rser.2015.11.050.

[84] S. Daroon, W. Wongsapai, T. Jaitiang, W. Thepsaskul, V. Raksakulkarn, P. Muangjai, Analysis of structure and data validation processes of energy management system in designated facilities in Thailand, Energy Rep. 9 (2023) 327–334, https://doi.org/10.1016/j.egyr.2023.09.031.

[85] R. Hitchin, I. Knight, Daily energy consumption signatures and control charts for air-conditioned buildings, Energy Build. 112 (2016) 101–109, https://doi.org/10.1016/j.enbuild.2015.11.059.

[86] S.K. Rathor, D. Saxena, Energy management system for smart grid: An overview and key issues, Int. J. Energy Res. 44 (6) (2020) 4067–4109, https://doi.org/10.1002/er.4883.

[87] M. Benedetti, V. Cesarotti, V. Introna, From energy targets setting to energy-aware operations control and back: An advanced methodology for energy efficient manufacturing, J. Clean. Prod. 167 (2017) 1518–1533, https://doi.org/10.1016/j.jclepro.2016.09.213.

[88] L.W. Vieira, A.D. Marques, J. Duarte, R.P. Zanardo, P.S. Schneider, F.A.C. Viana, A.J. da Silva Neto, F.R. Centeno, J.D. Hunt, J.C.M. Siluk, Operational guide to

stabilize, standardize and increase power plant efficiency, Appl. Energy 315 (2022) 118973, https://doi.org/10.1016/j.apenergy.2022.118973.
[89] N. Firdaus, H. Ab-Samat, B.T. Prasetyo, Maintenance strategies and energy efficiency: a review, J. Qual. Maint. Eng. 29 (3) (2023) 640–665, https://doi.org/10.1108/JQME-06-2021-0046.
[90] X. Gao, B. Knueven, J.D. Siirola, D.C. Miller, A.W. Dowling, Multiscale simulation of integrated energy system and electricity market interactions, Appl. Energy 316 (2022) 119017, https://doi.org/10.1016/j.apenergy.2022.119017.
[91] A. Kaab, M. Sharifi, H. Mobli, A. Nabavi-Pelesaraei, K. wing Chau, Combined life cycle assessment and artificial intelligence for prediction of output energy and environmental impacts of sugarcane production, Sci. Total. Environ. 664 (2019) 1005–1019, https://doi.org/10.1016/j.scitotenv.2019.02.004.
[92] P. Kilintzis, E. Samara, L. Topaloglou, G. Avlogiaris, D. Kafetzopoulos, The role of Green Public Procurements in energy transition: the case of Western Macedonia, J. Innov. Entrep. 12 (1) (2023) 87, https://doi.org/10.1186/s13731-023-00354-4.
[93] A. Boharb, A. Allouhi, R. Saidur, T. Kousksou, A. Jamil, Energy conservation potential of an energy audit within the pulp and paper industry in Morocco, J. Clean. Prod. 149 (2017) 569–581, https://doi.org/10.1016/j.jclepro.2017.02.090.
[94] C.E. Kontokosta, D. Spiegel-Feld, S. Papadopoulos, The impact of mandatory energy audits on building energy use, Nat. Energy 5 (4) (2020) 309–316, https://doi.org/10.1038/s41560-020-0589-6.
[95] J. Schleich, T. Fleiter, Effectiveness of energy audits in small business organizations, Resour. Energy Econ. 56 (2019) 59–70, https://doi.org/10.1016/j.reseneeco.2017.08.002.
[96] E. Iribar, I. Sellens, L. Angulo, J.M. Hidalgo, J.M. Sala, Nonconformities, Deviation and Improvements in the Quality Control of Energy Performance Certificates in the Basque Country, Sustain. Cities Soc. 75 (2021) 103286, https://doi.org/10.1016/j.scs.2021.103286.
[97] S. Kim, Y.R. Lee, M.K. Kim, Flexible risk control strategy based on multi-stage corrective action with energy storage system, Int. J. Electr. Power Energy Syst. 110 (2019) 679–695, https://doi.org/10.1016/j.ijepes.2019.03.064.
[98] S. Mischos, E. Dalagdi, D. Vrakas, Intelligent energy management systems: a review, Artif. Intell. Rev. 56 (10) (2023) 11635–11674, https://doi.org/10.1007/s10462-023-10441-3.
[99] X. Zeng, Q. Huang, Y. Liu, Q. Qin, Decoding China's hydrogen development: A content analysis of policy objectives and instruments, Renew. Sustain. Energy Rev. 217 (2025) 115729, https://doi.org/10.1016/j.rser.2025.115729.
[100] C. Gahm, F. Denz, M. Dirr, A. Tuma, Energy-efficient scheduling in manufacturing companies: A review and research framework, Eur. J. Oper. Res. 248 (3) (2016) 744–757, https://doi.org/10.1016/j.ejor.2015.07.017.
[101] S. Jamshidi, K.W. Nafi, A. Nikanjam, F. Khomh, Evaluating machine learning-driven intrusion detection systems in IoT: Performance and energy consumption, Comput. Ind. Eng. 204 (2025) 111103, https://doi.org/10.1016/j.cie.2025.111103.
[102] P. Kivimaa, H. Entsalo, Synergies and tensions between decarbonisation, security and strategic autonomy in EU energy policy, Environ. Innov. Soc. Transit. 59 (2026) 101109, https://doi.org/10.1016/j.eist.2026.101109.
[103] S. Huang, H. Tan, Evaluating the effects of green supply chain, digital technologies, and energy prices on renewable energy innovations: A way forward for an emerging economy, Energy Econ. 141 (2025) 108038, https://doi.org/10.1016/j.eneco.2024.108038.
[104] B. Peñate-Suarez, J.A. de la Fuente-Bencomo, G. Melián-Monroy, S.Y. Arenas Urrea, R. González-Almenara, L. García-Rodríguez, The worldwide lowest specific energy consumption measured in a seawater desalination plant – Real integration and opportunities of improvement, Energy Convers. Manag. X 30 (2026) 101682, https://doi.org/10.1016/j.ecmx.2026.101682.
[105] W. Peng, S. Anenberg, J. Bistline, M. Budolfson, S.M. Constantino, K. Crawford, K. Davis, P. DeCarlo, A. Fawcett, H. Hashimoto, C. Helgeson, X. Huang, G. Iyer, K. Keller, H. Kennard, K.M. Kennedy, R. Laumbach, V.S. Limaye, E. Mayfield, Y. Xie, Seizing the policy opportunities for health- and equity-improving energy decisions, One Earth 8 (2) (2025), https://doi.org/10.1016/j.oneear.2024.12.007.
[106] X. Yang, H. Zhou, J. Gao, Enhancing renewable energy productivity and energy efficiency of energy projects: How does cost of capital influence? Energy Strategy Rev. 57 (2025) 101608 https://doi.org/10.1016/j.esr.2024.101608.
[107] ISO. (2024). *ISO/CD 50100.3 Energy management systems and energy savings –Decarbonization — Requirements with guidance for use Under development*. ISO - International Organization for Standardization. https://www.iso.org/standard/87925.html. Access date: August09, 2026.
[108] A.B.L. de Sousa Jabbour, S.A. Verdério Júnior, C.J.C. Jabbour, W. Leal Filho, L. S. Campos, R. De Castro, Toward greener supply chains: is there a role for the new ISO 50001 approach to energy and carbon management? Energy Effic. 10 (3) (2017) 777–785, https://doi.org/10.1007/s12053-016-9478-z.
[109] N. Finnerty, R. Sterling, S. Contreras, D. Coakley, M.M. Keane, Defining corporate energy policy and strategy to achieve carbon emissions reduction targets via energy management in non-energy intensive multi-site manufacturing organisations, Energy 151 (2018) 913–929, https://doi.org/10.1016/j.energy.2018.03.070.
[110] D. Li, J. Li, S. Tan, T. Mahmood, Business, finance, energy strategy, and sustainability integration: A holistic approach to corporate responsibility in the green era, Energy Strategy Rev. 58 (2025) 101656, https://doi.org/10.1016/j.esr.2025.101656.
[111] H. Sun, M. Ikram, M. Mohsin, Q. Abbas, Energy Security and Environmental Efficiency in OECD Countries: Pathways to Sustainable Growth. Energy Security, Transition, and Economic Growth, World Scientific, 2025, pp. 47–63, https://doi.org/10.1142/9789819812608_0003.
[112] A. McKane, P. Therkelsen, A. Scodel, P. Rao, A. Aghajanzadeh, S. Hirzel, J. O'Sullivan, Predicting the quantifiable impacts of ISO 50001 on climate change mitigation, Energy Policy 107 (2017) 278–288, https://doi.org/10.1016/j.enpol.2017.04.049.
[113] V. Koval, N. Shmygol, V. Udovychenko, H. Hrinchenko, D. Kravets, L. Kapranova, Comparative assessment of energy-related environmental impact management systems and decarbonisation policies in energy transitions, Energy Explor. Exploit. (2026) 01445987261443387, https://doi.org/10.1177/01445987261443387.
[114] R. Agrawal, L. De Tommasi, P. Lyons, S. Zanoni, G.K. Papagiannis, C. Karakosta, A. Papapostolou, A. Durand, L. Martinez, G. Fragidis, M. Corbella, L. Sileni, L. Neusel, M. Repetto, I. Mariuzzo, T. Kakardakos, E.L. Güemes, Challenges and opportunities for improving energy efficiency in SMEs: learnings from seven European projects, Energy Effic. 16 (3) (2023) 17, https://doi.org/10.1007/s12053-023-10090-z.
[115] P. Dickemann, How do companies manage energy? A systematic literature review on energy cost accounting, energy efficiency, and energy management, Appl. Energy 397 (2025) 126372, https://doi.org/10.1016/j.apenergy.2025.126372.
[116] P.H. Jensen, J. Cross, D. Polanco-Lahoz, Lean and continuous improvement use and success in energy-based utilities, Int. J. Lean Six. Sigma 17 (3) (2025) 863–893, https://doi.org/10.1108/IJLSS-03-2024-0053.
[117] M. Prada, I.F. Prada, M. Cristea, D.E. Popescu, C. Bungău, L. Aleya, C.C. Bungău, New solutions to reduce greenhouse gas emissions through energy efficiency of buildings of special importance – Hospitals, Sci. Total. Environ. 718 (2020) 137446, https://doi.org/10.1016/j.scitotenv.2020.137446.
[118] C. Bataille, L.J. Nilsson, F. Jotzo, Industry in a net-zero emissions world: New mitigation pathways, new supply chains, modelling needs and policy implications, Energy Clim. Change 2 (2021) 100059, https://doi.org/10.1016/j.egycc.2021.100059.
[119] L.M. Ronalter, C.F. Poltronieri, M.C. Gerolamo, ISO management system standards in the light of corporate sustainability: a bibliometric analysis, TQM J. 35 (9) (2023) 256–298, https://doi.org/10.1108/TQM-09-2022-0279.
[120] S.Y.B. Huang, The effect of sustainable leadership on the adoption of renewable energy strategy, Energy Effic. 18 (6) (2025) 72, https://doi.org/10.1007/s12053-025-10359-5.
[121] N. Haidar, M. Attia, S.M. Senouci, E.H. Aglzim, A. Kribeche, Z.B. Asus, New consumer-dependent energy management system to reduce cost and carbon impact in smart buildings, Sustain. Cities Soc. 39 (2018) 740–750, https://doi.org/10.1016/j.scs.2017.11.033.
[122] V. Introna, A. Santolamazza, V. Cesarotti, Integrating Industry 4.0 and 5.0 Innovations for Enhanced Energy Management Systems †, Energies 17 (5) (2024) 1222, https://doi.org/10.3390/en17051222.
[123] S. Ahmadi-Karvigh, A. Ghahramani, B. Becerik-Gerber, L. Soibelman, Real-time activity recognition for energy efficiency in buildings, Appl. Energy 211 (2018) 146–160, https://doi.org/10.1016/j.apenergy.2017.11.055.
[124] M. Hettler, L. Graf-Vlachy, Corporate scope 3 carbon emission reporting as an enabler of supply chain decarbonization: A systematic review and comprehensive research agenda, Bus. Strategy Environ. 33 (2) (2024) 263–282, https://doi.org/10.1002/bse.3486.
[125] M. Liew, J. Cao, Accounting for Carbon Emissions Through Green Supply Chain Management: A Systematic Literature Review, Bus. Strategy Environ. 34 (7) (2025) 8281–8304, https://doi.org/10.1002/bse.70021.
[126] I. Hristov, C. Searcy, Integrating sustainability with corporate governance: a framework to implement the corporate sustainability reporting directive through a balanced scorecard, Manag. Decis. 63 (2) (2025) 443–467, https://doi.org/10.1108/MD-10-2023-1995.
[127] T. Mandel, Z. Pató, Towards effective implementation of the energy efficiency first principle: a theory-based classification and analysis of policy instruments, Energy Res. Social. Sci. 115 (2024) 103613, https://doi.org/10.1016/j.erss.2024.103613.
[128] K. Govindan, Applications of advances in operations research methods to achieve sustainable development goals (SDGs) in a supply chain management environment: review and future direction of research, Ann. Oper. Res. 349 (2) (2025) 425–450, https://doi.org/10.1007/s10479-025-06643-3.
[129] R. Raman, T.A. Alka, M. Suresh, P. Nedungadi, Social entrepreneurship and sustainable technologies: Impact on communities, social innovation, and inclusive development, Sustain. Technol. Entrep. 4 (3) (2025) 100110, https://doi.org/10.1016/j.stae.2025.100110.
[130] R. Raman, R. Kowalski, K. Achuthan, A. Iyer, P. Nedungadi, Navigating artificial general intelligence development: societal, technological, ethical, and brain-inspired pathways, Sci. Rep. 15 (1) (2025) 8443, https://doi.org/10.1038/s41598-025-92190-7.