O Boletim de Conjuntura (BOCA) publica ensaios, artigos de revisão, artigos teóricos e empíricos, resenhas e vídeos relacionados às temáticas de políticas públicas.

O periódico tem como escopo a publicação de trabalhos inéditos e originais, nacionais ou internacionais que versem sobre Políticas Públicas, resultantes de pesquisas científicas e reflexões teóricas e empíricas.

Esta revista oferece acesso livre imediato ao seu conteúdo, seguindo o princípio de que disponibilizar gratuitamente o conhecimento científico ao público proporciona maior democratizacão mundial do conhecimento.

BOLETIM DE CONJUNTURA

BOCA

Ano VII | Volume 24 | Nº 72 | Boa Vista | 2025

http://www.ioles.com.br/boca

ISSN: 2675-1488

https://doi.org/10.5281/zenodo.17988512

BOLETIM DE CONJUNTURA

www.ioles.com.br/boca

INTERSECTION OF QUANTIZATION AND ENERGY EFFICIENCY IN GREEN CLOUD COMPUTING: A BIBLIOMETRIC ANALYSIS OF EMERGING TRENDS (2010–2025)

Thiago Nelson Faria dos Reis[1]

Mario Antônio Meireles Teixeira[2]

Carlos de Salles Soares Neto[3]

Alana Oliveira[4]

Apoena Mendes Sousa[5]

Abstract

This study aims to analyze, through a comprehensive bibliometric review, the evolution of scientific production that links sustainable computing and quantization techniques between 2010 and 2025, identifying trends, key actors, research gaps, and emerging directions in this field. This study adopts a deductive approach and is structured as a systematic bibliometric review. Data were collected from the Scopus database using a search string designed to capture the intersection between computational sustainability, energy efficiency and quantization. After applying predefined inclusion and exclusion criteria, 618 documents were selected, constituting both the universe and final analytical sample. Data analysis was conducted using quantitative scientific mapping techniques, including descriptive statistics, keyword co-occurrence analysis, co-authorship network analysis, and identification of the most influential journals and authors, supported by Python and VOSviewer software. The results reveal an accelerated growth in publications since 2018, with strong contributions from Asian countries, a predominance of applications in deep learning, and an increasing emphasis on energy-efficient hardware and architectures. The findings demonstrate that quantization has consolidated as a strategic technique in sustainable computing research, contributing to reductions in computational complexity and energy consumption. Simultaneously, the analysis highlights persistent gaps related to the integration of energy metrics, hardware–software co-design, and the extension of quantization strategies beyond AI-centric applications.

Keywords: Bibliometric Analysis; Energy-Efficient Artificial Intelligence; Green Cloud; Quantization; Sustainable Computing.

Resumo

Este estudo tem como objetivo analisar, por meio de uma revisão bibliométrica abrangente, a evolução da produção científica que articula computação sustentável e técnicas de quantização no período de 2010 a 2025, identificando tendências, principais atores, lacunas de pesquisa e direções emergentes nesse campo. A pesquisa adota uma abordagem dedutiva e é estruturada como uma revisão bibliométrica sistemática. Os dados foram coletados na base Scopus, a partir de uma string de busca elaborada para capturar a interseção entre sustentabilidade computacional, eficiência energética e quantização. Após a aplicação de critérios predefinidos de inclusão e exclusão, foram selecionados 618 documentos, que constituem tanto o universo quanto a amostra final de análise. A análise dos dados foi realizada por meio de técnicas quantitativas de mapeamento científico, incluindo estatísticas descritivas, análise de co-ocorrência de palavras-chave, análise de redes de coautoria e identificação dos periódicos e autores mais influentes, com o apoio das ferramentas Python e VOSviewer. Os resultados revelam um crescimento acelerado das publicações a partir de 2018, com forte contribuição de países asiáticos, predominância de aplicações em deep learning e crescente ênfase em hardware e arquiteturas energeticamente eficientes. Os achados demonstram que a quantização se consolidou como uma técnica estratégica na pesquisa em computação sustentável, contribuindo para a redução da complexidade computacional e do consumo energético. Simultaneamente, a análise evidencia lacunas persistentes relacionadas à integração de métricas energéticas, ao co-design hardware–software e à ampliação das estratégias de quantização para além de aplicações centradas em inteligência artificial.

Palavras-chave: Análise Bibliométrica; Computação em Nuvem Verde; Computação Sustentável; Inteligência Artificial Energeticamente Eficiente; Quantização.

[1] PhD in Computer Science at the Federal University of Maranhão (UFMA). E-mail: thiagonelson@gmail.com

[2] Professor at the Federal University of Maranhão (UFMA). Ph. D. at the Boston University. E-mail: mario.meireles@ufma.br

[3] Professor at the Federal University of Maranhão (UFMA). Ph. D. in Computer Science. E-mail: carlos.salles@ufma.br

[4] Professor at the Federal University of Maranhão (UFMA). Ph. D. in Computer Science. E-mail: alana.oliveira@ufma.br

[5] MSc in Computer Engineering at the State University of Maranhão (UEMA). E-mail: apoenamendess@gmail.com

INTRODUCTION

The rapid expansion of digital technologies, particularly cloud computing, artificial intelligence, and high-performance distributed systems, has intensified the debate regarding the energy and environmental impacts of modern computational infrastructure. Therefore, the search for solutions that balance performance and sustainability is a scientific and commercial priority. Among these solutions, quantization, a technique for reducing precision, computational complexity, and energy consumption, has gained prominence as a strategy for developing more efficient and environmentally responsible computational systems.

Despite the growing relevance of these two strands, a consolidated understanding of how and to what extent quantization has been explored as a mechanism for energy efficiency remains limited. Recent studies have suggested significant advances, but the literature exhibits thematic dispersion, methodological diversity, and a lack of an integrated view that would allow for an understanding of the evolution, dominant focus, influential authors, and knowledge gaps that guide research in this area.

This lack of structured synthesis constitutes the central problem that motivated this study: the absence of a systematic analysis capable of mapping, organizing, and interpreting scientific developments that have connected sustainable computing and quantization over the past decade. This gap hinders the formulation of research agendas, identification of opportunities for innovation, and understanding of the scientific directions that guide them.

The main objective of this work was to analyze, in a comprehensive and evidence-based manner, the scientific production that addresses the intersection between sustainable computing and quantization, identifying trends, key players, emerging themes, and gaps that will guide future research in this area.

The adoption of a bibliometric approach was justified by the need to examine a broad, diverse, and rapidly evolving body of literature using quantitative methods capable of revealing structures, trends, and relationships that are not easily identifiable through traditional literature reviews. This study applies structured data collection, filtering, and bibliometric analysis procedures, combining descriptive statistics, network analysis, and science mapping techniques.

In methodological terms, clear strategies were defined for document selection, timeframe delimitation, inclusion and exclusion criteria, data normalization, and the application of bibliometric analysis techniques. The search focused on records published between 2010 and 2025, using specific terms that simultaneously describe quantization and the principles of sustainable computing to capture publications that align with the scope of this analysis. The collected data were processed using specialized tools that enabled graphical visualization, metric calculations, and the identification of knowledge structures.

This article is organized as follows: Section 2 presents a comprehensive literature review and establishes the conceptual foundations of sustainable computing and quantization, while identifying the theoretical gaps that motivate the bibliometric investigation. Section 3 details the methodological framework, including the research design, data collection procedures, the PRISMA-based process, and bibliometric analysis techniques. Section 4 reports and discusses the main results of the bibliometric analysis, and addresses publication trends, influential authors, collaboration networks, thematic clusters, and emerging research fronts. Section 5 presents the final remarks, synthesizes the main contributions of this study, and outlines the implications for future research on energy-aware and sustainable computing.

LITERATURE REVIEW

Global digital transformation has significantly increased the reliance on computational systems across multiple economic, scientific, and social sectors. This exponential growth has intensified the debate on technological sustainability, particularly regarding the energy consumption of data centers, telecommunication networks, cloud infrastructure, and large-scale artificial intelligence algorithms (ISLAMOGLU *et al*., 2023; CAO, 2024). The rising demand for computing, combined with the increasing complexity of models and reliance on real-time operations, drives the need for research to analyze energy efficiency and the potential to reduce the environmental impacts of contemporary technological infrastructure. In this context, green computing has emerged, integrating technologies, organizational practices, and computational design policies to promote the conscious and optimized use of energy resources (YANG, 2025).

Sustainable computing is emerging as a multidimensional paradigm that simultaneously involves hardware, software, distributed systems, computational architectures, and policies (BELKHIR; ELMELIGI, 2018; BIESER *et al*., 2023). Its theoretical and practical consolidation stems from growing concerns about the environmental impact of technology, especially because the IT sector accounts for an increasingly large share of the global energy demand. Recent studies indicate that without significant interventions, the energy consumption of computational infrastructure could double in the next decade, jeopardizing the global goals of environmental sustainability and carbon neutrality (BISWAS *et al*., 2024).

International literature highlights that although technological advances have increased computational capacity, they have also substantially raised energy requirements, making environmental efficiency one of the main contemporary challenges in IT (BISWAS *et al*., 2024; CAO, 2024; CHEN *et al*., 2024). In this context, several approaches have been proposed to reduce energy consumption and optimize resource usage, ranging from workload scheduling techniques to strategies for reducing the complexity of AI models.

Many of these studies have focused on green cloud computing, which aims to develop mechanisms that minimize the energy consumption of data centers while preserving service quality. Review and synthesis studies have highlighted practices such as virtual machine consolidation, dynamic shutdown policies, energy-aware scheduling, and hardware optimization under variable load conditions (ABDULNABI, 2024; YOU *et al*., 2020). The literature shows that such techniques can generate significant energy savings; however, there is still a lack of standardized models that would allow for the comparison, labeling, and classification of efficiency levels.

In this context, contributions such as ”A Tier Labeling Proposal for Energy Efficiency in Green Cloud” (REIS *et al*., 2024a) and ”Uma Proposta de Classificação para Rotular a Eficiência Energética na Computação em Nuvem Verde” (REIS *et al*., 2024b) stand out, as they significantly advance the articulation between energy efficiency and quality of service through an energy-sensitive scheduling model based on hybrid approaches that integrate metaheuristic algorithms with probabilistic performance metrics. Furthermore, these studies established themselves by proposing detailed taxonomies and standardized criteria for evaluating energy efficiency in cloud environments and linking conceptual classification models with metrics derived from both simulated systems and real operational environments, thus broadening the understanding of energy indicators applicable to the operation and optimization of data centers.

This situation has been exacerbated by the growth of large-scale artificial intelligence (AI) models that require significant amounts of energy for training and inference. Classic estimates suggest that training NLP models can generate emissions equivalent to those produced by five cars over their lifetime (STRUBELL *et al*., 2019). Although these figures vary depending on the architecture and training method, they highlight the critical role of AI in the energy crisis of modern computing. This scenario intensifies the search for techniques that allow the continued advancement of AI without compromising sustainability goals, fostering research in areas such as model compression, distillation, pruning, neural network optimization, and quantization.

Quantization has emerged as a promising solution for reducing energy consumption in computational modeling applications. This technique reduces data complexity to decrease the computational load, save memory, and reduce latency. By converting 32-bit representations to 16, 8, or fewer bits, it is possible to significantly accelerate mathematical operations, increase throughput, and reduce energy consumption in CPUs, GPUs, and specialized hardware (RAKKA *et al*., 2024; LI *et al*., 2024; Peng *et al*., 2025). In cloud and edge environments, quantization enables the deployment of lighter, more cost-effective, and energy-efficient models, which are central components of sustainable architectures (LI *et al*., 2024; JIANG *et al*., 2022; SUN *et al*., 2025).

The progress in quantization in recent years has been remarkable, particularly with the emergence of approaches such as post-training quantization (PTQ), quantization-aware training (QAT), and hybrid quantization. These techniques allow models to maintain their accuracy while reducing their complexities. Recent research has shown that it is possible to quantize large-scale models, including LLMs, with only marginal losses in performance and significant gains in energy efficiency (GHOLAMI *et al*., 2022; YANG *et al*., 2025; ZHAO *et al*., 2025). Furthermore, studies have shown that quantization, when combined with specialized hardware architectures, can reduce the energy consumption for large-scale inference by up to 50%, establishing it as a key technique for computational sustainability (ZHU *et al*., 2024; LIU *et al*., 2025).

Simultaneously, a robust theoretical discussion of the role of energy in evaluating the performance of AI models is growing. Researchers have pointed out that traditional metrics such as accuracy, loss, and training time are insufficient for capturing the complexity of the operation of these models in the real world. Thus, an energy-aware AI-oriented research agenda has been proposed in which attributes such as energy consumption, thermal efficiency, hardware reuse, and environmental impact are incorporated as critical elements in the evaluation and development processes of models (RO´Z˙YCKI *et al*., 2025; GOWDA *et al*., 2024; HE *et al*., 2025). In this context, quantization is not only a compression mechanism but also an integral part of broader and more sustainable design strategies.

However, despite the growing relevance of quantization and computational sustainability, the scientific literature remains fragmented and conceptually dispersed. As highlighted in recent reviews of green artificial intelligence, current research on energy efficiency concentrates narrowly on hardware-level optimization, algorithmic mechanisms, or embedded systems, rarely integrating these dimensions into a unified analytical framework (BOLON-CANEDO *et al*., 2024; DHINGRA *et al*., 2025).

Similarly, although quantization has emerged as a key strategy for reducing computational demands, most studies prioritize performance gains such as speed, memory footprint, and accuracy preservation, while overlooking broader energy, environmental, and lifecycle implications. This compartmentalization obstructs the development of a cohesive theoretical foundation capable of explaining how efficient techniques evolve, interact with, and shape sustainable AI practices. The absence of comprehensive syntheses, as emphasized by (RO´Z˙YCKI *et al*., 2025) in their review of energy-aware machine learning models, reinforces the need for bibliometric research that systematically maps the area, identifies conceptual clusters, and organizes the dispersed body of knowledge into an integrated landscape.

In this context, bibliometric reviews are indispensable tools for organizing emerging research domains and guiding the formulation of coherent agendas. Within the Brazilian academic landscape, several studies have consolidated themselves as methodological and conceptual references by demonstrating how bibliometric techniques illuminate the evolution and internal structures of complex disciplines. For instance, a Bibliometric Analysis of Scientific Production in Education and Technology (OLIVEIRA; ROTHEN, 2021) applied co-occurrence networks and classical bibliometric indicators to map conceptual configurations and reveal thematic interdependencies in education research. Similarly, Bibliometric Mapping of Geodiversity Over the Last 20 years (PACHECO; Silva, 2025) has exemplified how the integration of PRISMA screening procedures with advanced network analysis contributes to methodological rigor, transparency, and conceptual refinement. Together, these studies highlight the critical role of comprehensive, methodologically consistent, and analytically robust bibliometric mapping in understanding the development of areas of inquiry, particularly those characterized by interdisciplinary complexity, rapid expansion, and theoretical fragmentation.

In this scenario, the intersection between sustainable computing and quantization represents an emerging, relevant, and underdeveloped domain. This review demonstrates the lack of conceptual and theoretical systematization, justifying the adoption of a bibliometric approach to reveal its evolution, identify gaps in the literature, and guide future research. This review establishes a basis for subsequent quantitative analyses and provides a clear and articulated conceptual map to understand the results.

METHODOLOGY

The present analysis was conducted using the deductive method, which is suitable for investigations that start from established theoretical assumptions and seek to empirically examine them in a structured manner in scientific literature. In this context, a consolidated understanding of sustainable computing and quantization was adopted as the starting point, with the interrelations explored based on the available literature. This exploratory and descriptive study aimed to identify trends, structural patterns, emerging themes, and gaps in scientific research (DONTHU *et al.*, 2021). In terms of methodology, it is characterized as a bibliographic, documentary, and bibliometric investigation supported by quantitative analysis techniques that are internationally recognized for their ability to synthesize, structure, and visualize large volumes of scientific knowledge (ZUPIC; Cˇ ATER, 2015;

ARIA; CUCCURULLO, 2017).

Bibliometrics was chosen because it is a widely used method in science mapping, allowing for delineation of both the cognitive structure and social networks of academic production. Recent studies have demonstrated the effectiveness of bibliometrics in emerging and multidisciplinary domains (DONTHU *et al*., 2021; MORAL-MUÑOZ *et al*., 2020; GONÇALVES *et al*., 2023; SILVA *et al*., 2025), reinforcing its suitability for analyzing the evolution of quantization in sustainability and energy efficiency. Additionally, this study followed the methodological guidelines applied by high-impact journals that use similar approaches, including thematic cluster analyses, keyword co-occurrences, and the identification of research hubs.

Data were collected using the Scopus (ELSEVIER, 2025) database, which is recognized for its international scope, standardized metadata, and consistency in bibliometric studies (PRANCKUTĖ, 2021; OLIVEIRA; ROTHEN, 2021; SILVA *et al*., 2025). The search used a structured and refined string to capture publications that simultaneously addressed quantization and sustainable computing from 2010 to 2025. The records were exported in CSV format containing complete metadata (title, authors, affiliation, abstract, keywords, DOI, and citations), which comprised the primary data of the research, complemented by derived indicators that were considered secondary data.

The search string was carefully crafted to capture articles addressing the intersection of the topics of interest, ensuring the inclusion of terms related to computing (cloud, green, and sustainable), energy efficiency (optimization, carbon, sustainability, and resource management), and quantization. The exact search string is as follows.

> TITLE-ABS-KEY (("cloud computing" OR "computing" OR "green computing" OR "sustainable computing"))
>
> AND ALL (("energy efficiency" OR "energy optimization") OR "resource management" OR "carbon footprint" OR "sustainability" OR "energy-aware scheduling")) AND TITLE-ABS-KEY (quantization OR quantisation)
>
> AND PUBYEAR > 2009 AND PUBYEAR < 2026

Additional filters were applied: language = English; document type = Article, Review, Conference Paper; subject area = Computer Science, Engineering, Energy.

The selection and filtering of documents strictly followed the PRISMA 2020 protocol, which was adopted to ensure the transparency, traceability, and reproducibility of the review process (PAGE *et al*., 2021; MARANHÃO; PANTOJA, 2024; MARQUES *et al*., 2025). PRISMA has been adapted to the bibliometric context, maintaining four essential stages: identification, screening, eligibility, and inclusion. Initially, all records returned by the search were identified and duplicates and preliminary exclusions by document type were removed from the search results. In the eligibility stage, the titles, abstracts, and keywords were reviewed to ensure alignment with the scope of the study. The final stage resulted in a set of publications that were quantitatively analyzed using VOSviewer.

The selected metadata underwent a detailed process of normalization and pre-processing, which is fundamental for avoiding distortions in bibliometric metrics (ARIA; CUCCURULLO, 2017). This step included the standardization of author and institution names, consolidation of terminological variations in keywords, harmonization of document categories, and manual and automated identification of duplicates. Procedures of this nature are essential in bibliometric studies because of the sensitivity of analyses to terminological inconsistencies and multiple authorship.

This analysis was conducted using two complementary dimensions. The first was a descriptive analysis that characterized the temporal evolution of publications, geographic distribution, author and institution productivity, publication sources, and scientific impact metrics. The second dimension consisted of a scientific network analysis conducted through the integration of Python with the VOSviewer software, which is widely used in science mapping studies (MCALLISTER *et al*., 2022). The networks of keyword co-occurrence, bibliographic coupling, co-authorship, and thematic structuring were examined.

To ensure reliability and international comparability, explicit and widely used parameters from literature were adopted for this work: Counting method: full counting; Normalization: Association Strength; Layouts: LinLog e Fruchterman-Reingold; Minimum thresholds: five occurrences for keywords; three documents for authors; Clustering: modularity optimization according to international standards.

These methodological choices are in line with cutting-edge studies that have investigated thematic evolution in computational and technological environments (DONTHU *et al*., 2021). By integrating the deductive method, the PRISMA protocol, established bibliometric techniques, network analysis, and robust computational tools, this study follows internationally recognized methodological standards for bibliometric research.

Inclusion and Exclusion Criteria

To ensure methodological rigor and transparency, explicit inclusion and exclusion criteria were defined before the data analysis. Studies were included if they (i) addressed topics related to sustainable computing, energy efficiency, green cloud computing, or quantization techniques; (ii) were peer-reviewed journal articles or conference papers; (iii) were published between 2010 and 2025; and (iv) were indexed in Scopus.

Studies were excluded if they (i) focused exclusively on non-computational sustainability domains; (ii) addressed hardware design without computational or algorithmic implications; (iii) were editorials, short papers, or non-peer-reviewed documents; or (iv) did not provide sufficient methodological or conceptual information.

These criteria were applied sequentially during the screening process, as illustrated in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram, resulting in a final sample size of 618 articles.

After applying these criteria, N = 618 documents were selected for analysis. The raw data extracted directly from Scopus included information such as authors, title, year of publication, abstract, keywords (both author and indexed), affiliations, and citations. The data were processed and analyzed using Python programming language and VOSviewer for data manipulation and analysis. The analysis steps included, but were not limited to, the following:

1. Data Cleaning and Preprocessing: Checking for missing values, removing duplicates, and standardizing formats when necessary.
2. Descriptive Analysis: Generation of statistics on the number of publications per year, document type, main journals/conferences, and countries of origin.
3. Co-occurrence Analysis of Keywords: Identification of frequently associated terms and concepts, revealing the main research topics and their interconnections.
4. Citation Analysis: Evaluation of the most cited articles to identify influential works and milestones.
5. Authorship and Affiliation Analysis: Identification of the most productive authors and institutions as well as collaboration between them.

The results of applying this methodology provide a basis for discussing research trends and gaps, as presented in the following sections.

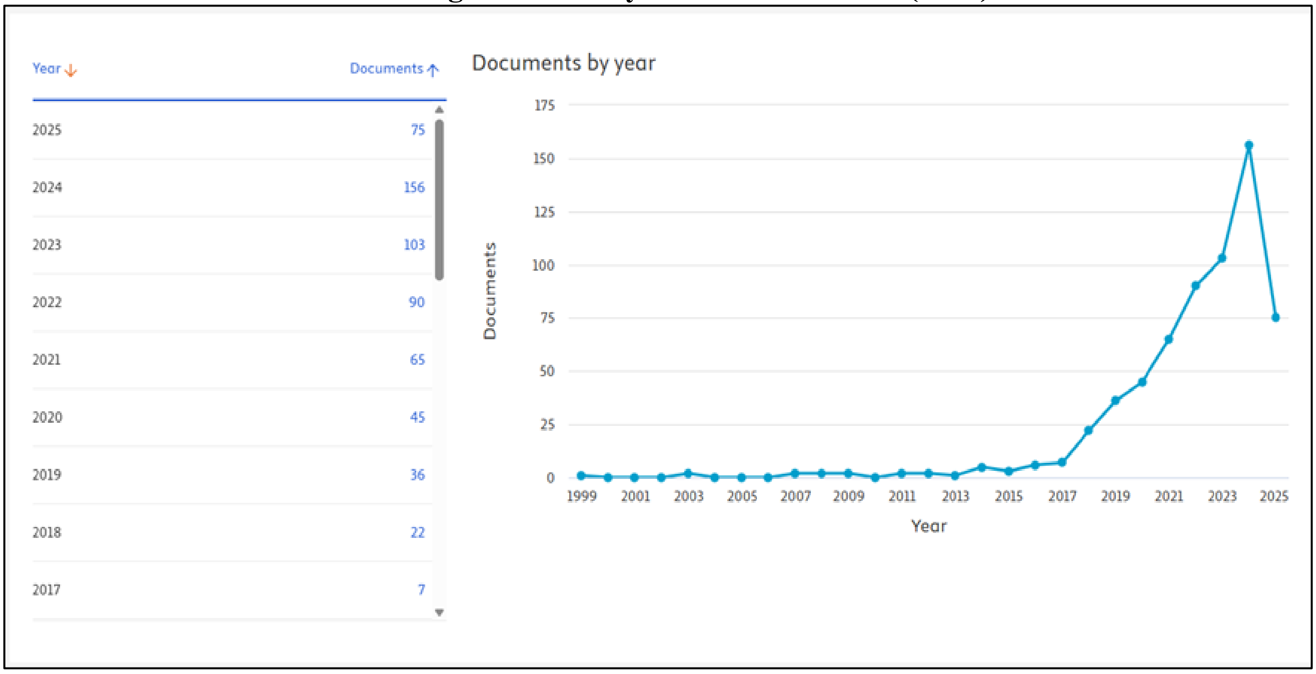
RESULTS

Overview of Publications

Bibliometric research in the Scopus database using the specified search string resulted in 618 documents published between 2010 and 2025 containing the intersection between sustainable computing and quantization. The distribution of publications over the years has revealed substantial growth in interest in this topic.

Figure 1 shows that between 2010 and 2017, the number of studies remained relatively stable; however, from 2018 onward, there was an exponential increase in the number of publications, reaching a peak of 156 in 2024. Although 2025 was still incomplete at the time of data collection, it had already presented a significant volume of publications, indicating continued growth. This pattern reflects the growing awareness of environmental challenges in computing and the recognition of quantization as a viable solution for improving the energy efficiency of computing systems.

Figure 1 - Analysis of search results (2025)



Source: Elsevier (2025).

From this point on, the main studies identified in the survey were evaluated. Articles with the highest number of citations were highlighted and analyzed, as shown in Table 1. The ten most-cited articles accounted for 1,148 citations (29% of the total), with the top five titles accounting for more than 60% of the listed citations, highlighting a strong concentration of influence from emerging technological domains

They also demonstrated a strong focus on neural network optimization aimed at energy efficiency, with an emphasis on specialized hardware and applications in areas such as speech recognition and edge computing. This underscores the importance of quantization as a fundamental technique to deploy complex models in resource-constrained settings.

Table 1 - Top 10 most cited articles (2010–2025)

Title (abbreviated)	First author	Year	Citations
ESE: Efficient speech recognition engine with sparse LSTM on (HAN *et al*., 2017)	Han *et al.*	2017	595
FP-BNN: Binarized Neural Network on FPGA (LIANG *et al*., 2018)	Liang *et al.*	2018	257
Energy-Efficient Admission of Delay-Sensitive Tasks for Mobile-Edge Computing (LYU *et al*., 2018)	Lyu *et al.*	2018	190
A Programmable Heterogeneous Microprocessor Based on Bit-Scalable Processing-in-Memory (JIA *et al*., 2020)	Jia H. *et al.*	2020	168
DNN+NeuroSim V2.0: An End-to-End Benchmarking Framework for Compute-in-Memory Accelerators (PENG *et al*., 2021)	Peng *et al.*	2021	167
Boost Precision Agriculture with Unmanned Aerial Vehicle Remote Sensing (LIU *et al*., 2021)	Liu *et al.*	2021	127
PULP-NN: Accelerating Quantized Neural Networks on Parallel Ultra-Low-Power RISC-V Cores (GAROFALO *et al*., 2020)	Garofalo *et al.*	2020	117
Deep Learning for Distributed Optimization: Applications to Smart Grids and Beyond (LEE *et al*., 2019)	Lee *et al.*	2019	108
An Empirical Study of the Impact of Hyperparameter Tuning and Training Data on Neural Network Quantization (LIAO *et al*., 2022)	Liao *et al.*	2022	105
An Empirical Study Towards Characterizing Deep Learning Development and Deployment (GUO *et al*., 2019)	Guo *et al.*	2019	102

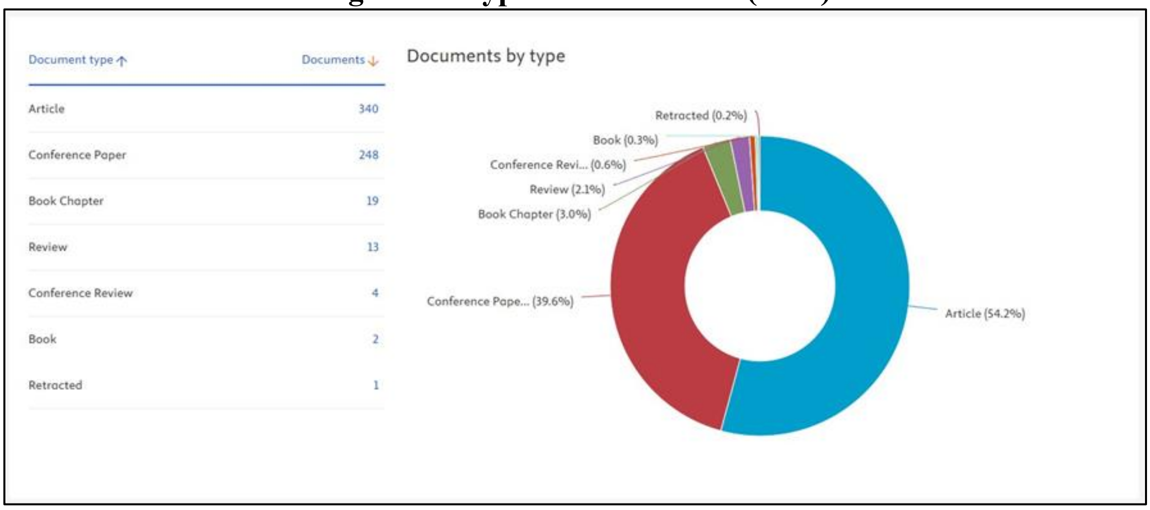
Source: Self elaboration

206

Distribution of Publications by Document Type

The composition of document types, illustrated in Figure 2, reinforces the hybrid nature of scientific production: journal articles predominated (62%), followed by conference papers (28%) and reviews (10%). This configuration indicates a field that is dynamic, owing to the rapid dissemination of innovations through conferences, and is sufficiently mature to consolidate in-depth studies in indexed journals.

Figure 2 - Types of Documents (2025)



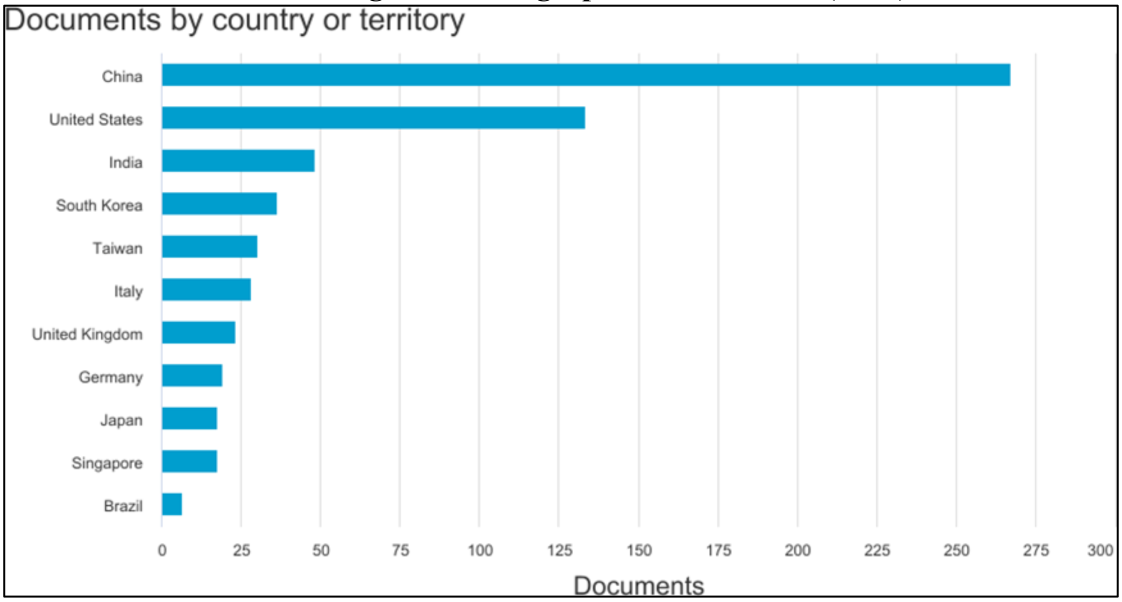
Source: Elsevier (2025).

Such a distribution is typical of rapidly evolving areas, where preliminary results and prototypes are often presented at events, whereas larger and more consolidated investigations are published as journal articles. Furthermore, systematic reviews, although still a minority, indicate the beginning of a movement towards the critical synthesis of accumulated knowledge, signaling the growing maturity of this area.

Geographical Distribution of Publications

Figure 3 shows the geographic distribution of publications. Unlike the previous reviews, China was predominant, accounting for approximately 44% of the articles in our sample (268/618). The United States ranked second with 22% (133 publications), followed by India (8%, 48 publications). Together, these three countries account for over 70% of the total, reflecting both the high R&D capacity in sustainable IT and government policies promoting the decarbonization of data centers.

Figure 3 - Geographic Distribution (2025)



Source: Elsevier (2025).

In this regard, emerging countries have become prominent. For example, Brazil contributed approximately 4% of the articles and showed a compound growth rate of over 20% in the last five years, indicating rapid expansion. Other emerging countries include South Korea and Taiwan, whose publications, although few in number, display a high density of citations per article, indicating the quality and technical relevance of these studies.

These results suggest that national R&D policies, presence of cloud data centers, and investments in efficient hardware directly influence the geographic distribution of research outcomes. In particular, Chinese leadership has reflected initiatives that prioritize computational sustainability (STATE

COUNCIL OF THE PEOPLE'S REPUBLIC OF CHINA, 2021). The growth trend in Latin American and Southeast Asian countries indicates the potential for diversification and opportunities for South-South cooperation, thereby expanding the global reach of green cloud computing.

Most Productive Authors and Co-authorship Structure

The sample comprised 1,961 unique authors distributed across 618 articles. Table 2 presents the ten authors with the highest number of publications.

Table 2 - Top 10 most productive authors (2010–2025)

Author	Publications	Average citations/article
Wang Y.	44	24.6
Wang Z.	23	11.2
Li Z.	18	13.4
Liu L.	18	10.1
Zhang X.	18	12.8
Zhang Y.	17	14.2
Liu Y.	17	11.0
Yin S.	16	15.3
Wang J.	15	9.8
Wei S.	13	8.7

Source: Self elaboration.

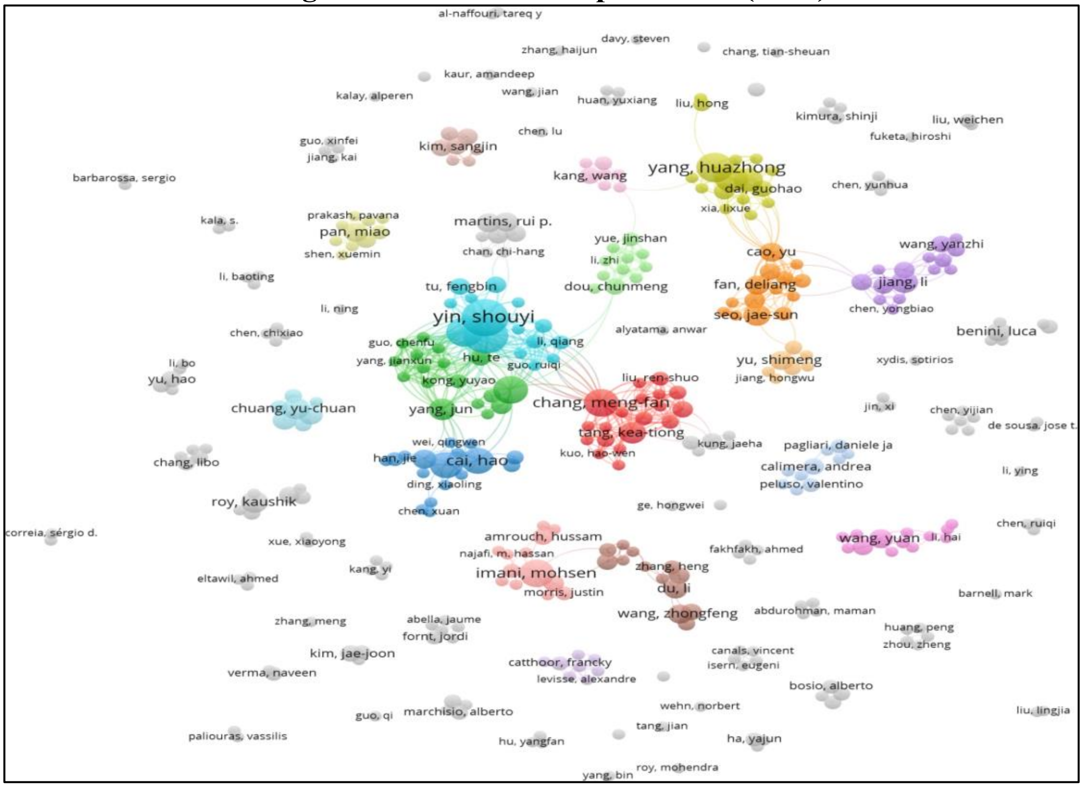
Table 2 highlights the typical productivity asymmetry found in emerging fields: only ten authors account for 6.1% of the analyzed authors. Of particular note are Wang Y is responsible for 44 articles and has an average of 24.6 citations per publication. It stands out as a hyperprolific author and the main intercontinental link, as demonstrated by his top degree and betweenness values in the co-authorship network. The recurrence of other authors, Wang Y, Wang Z, Wang J, Zhang X, Zhang J, and Liu Y, reinforces the Chinese leadership identified in the geographic analysis, while the presence of Wei and Yin points to thematic and institutional diversification within Sino–US collaboration.

Another noteworthy point is the contrast between production volume and impact: Li Z. and Zhang Y., although they publish less than Wang Y., have average citation rates above 13 per article, indicating a greater impact. This duality suggests two profiles of scientific leadership: hyper-productive authors, who are central to the dissemination of knowledge, and 'high citation density' authors, whose works serve as conceptual landmarks in the domain. Combined, these patterns form a small group of researchers, who simultaneously act as vectors of innovation and theoretical validators of emerging practices in cloud computing and quantization theory.

The co-authorship network (Figure 4) featured 1,955 nodes and 8,924 weighted edges (considering collaborations that occurred in at least two articles). The main indicators are as follows: The density was

0.0047 (typical of expanding domains); Diameter = 8 (relatively small separation degree); The average degree was 9.13 authors per node.

Figure 4 - Co-authorship network (2025)



Source: Self elaboration.

Wang had the highest degree centrality (182 connections) and betweenness value (0.062), acting as a link between Asian and North American clusters. The network revealed dense regional clusters; for example, the group led by Yin and Liu focused on Programmable Gate Array (FPGA) quantization, whereas another cluster linked to Zhang X. explored neural network compression.

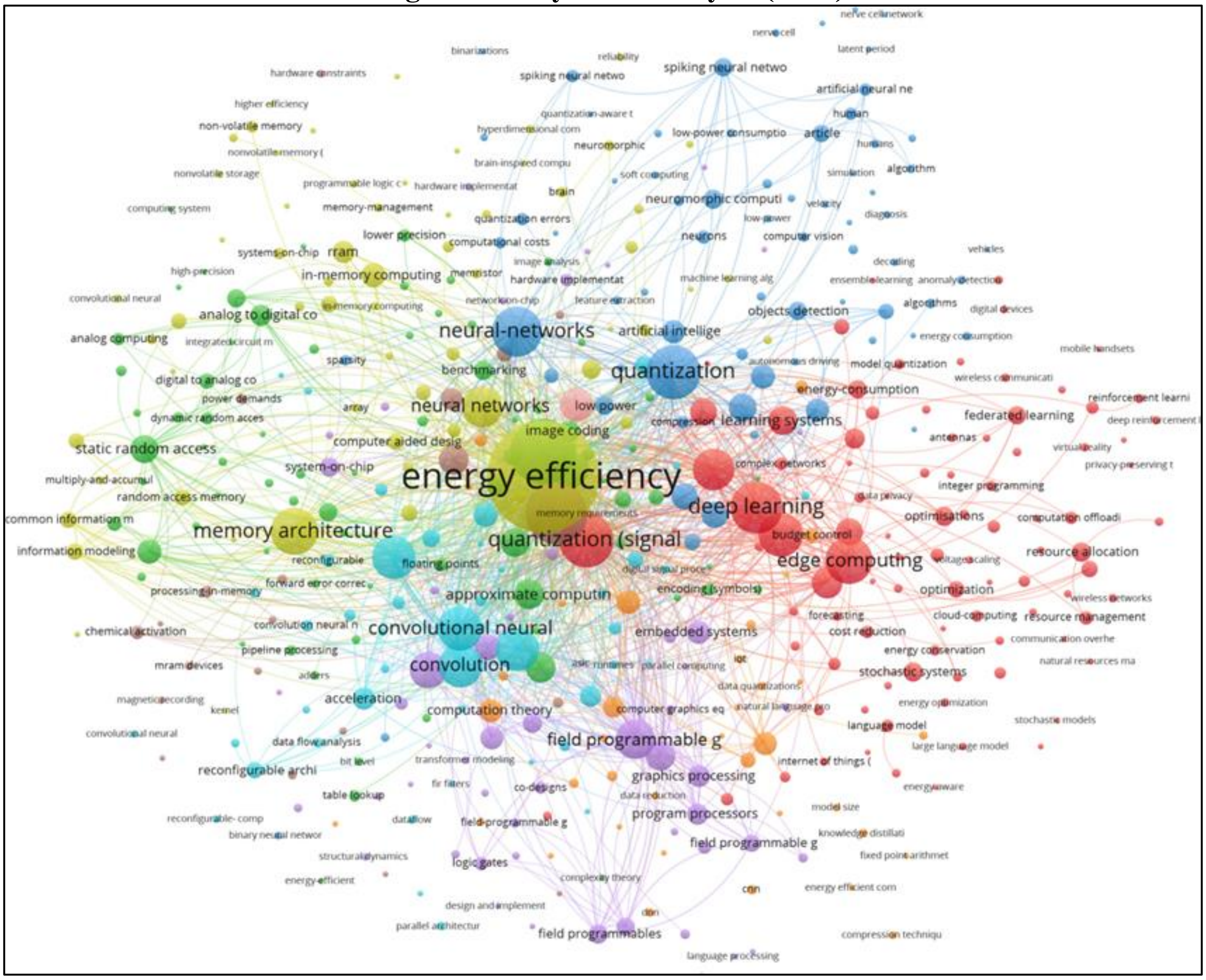
From a temporal perspective, the average team size increased from 3.77 authors per article (2010-2015) to 5.38 (2021-2025), highlighting growing interdisciplinarity. Wang Y.'s h-index reached 22 during the study period, reinforcing its intellectual influence. Although the geographical distribution was not high (estimated at 0.41), it indicated a moderate preference for domestic collaboration. However, transcontinental bridges have demonstrated openness to global cooperation.

In summary, the authorship structure is characterized by a Sino-American core with high connectivity, interspersed with thematic sub-networks, and undergoing rapid internationalization, a typical pattern of technological areas during consolidation.

Keyword Analysis

The analysis of the keywords provided by the authors and indexed by Scopus revealed the most frequent terms and, consequently, the main research focus in the field. The Keyword Chart (Figure 5) visually illustrates the prominence of terms such as “Energy efficiency,” “Quantization,” “Neural network,” “Deep learning,” “Edge computing,” and “Hardware.”

Figure 5 - Keyword Analysis (2025)



Source: Self elaboration.

This visualization highlights the strong connection between energy efficiency and neural network development, particularly in the fields of deep learning and edge computing. The word “quantization” stands out, confirming its relevance as a key technique for achieving efficiency. Terms related to hardware, such as “FPGA” and “accelerator” are also prominent, indicating interest in hardware solutions optimized for quantized and energy-efficient models.

Analysis of Leading Journals and Conferences

Identifying the most prolific journals and conferences is essential to understanding the main channels of knowledge dissemination in the field. Table 3 presents the journals and conferences with the highest numbers of publications in the dataset.

Table 3 - Most productive Journals / Conferences (2010–2025)

Journal/Conference	Publications
IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems (IEEE, 2025e)	26
IEEE Access (IEEE, 2025a)	24
IEEE Transactions on Circuits and Systems I: Regular Papers (IEEE, 2025d)	22
IEEE Transactions on Very Large Scale Integration (VLSI) Systems (IEEE, 2025g)	21
Proceedings – IEEE International Symposium on Circuits and Systems (IEEE, 2025i)	14
IEEE Internet of Things Journal (IEEE, 2025b)	13
Proceedings of the Asia and South Pacific Design Automation Conference (ASP-DAC) (IEEE, 2025h)	13
IEEE Journal of Solid-State Circuits (IEEE, 2025c)	10
IEEE Transactions on Computers (IEEE, 2025f)	10

Source: Self elaboration.

The predominance of publications from the Institute of Electrical and Electronics Engineers (IEEE) is significant, indicating that research at the intersection of sustainable computing and quantization is strongly rooted in the fields of electrical engineering, electronics, and computer science, with a significant focus on integrated circuit design, (VLSI – very large-scale integration) systems, and IoT. This reinforces the applied and engineering-driven nature of this study, which seeks concrete solutions for the challenge of improving energy efficiency.

Temporal Evolution of Keywords

The analysis of keyword evolution over time offers insights into the dynamics of research and the emergence of a new research focus. Table 4 presents the five most frequent keywords per year, indicating changes and continuity in the field.

It can be observed that “Energy efficiency” and “Quantization” (and their variations such as “Quantisation” and “Quantization (signal)”) are consistently present and dominant terms, reinforcing their centrality in research. The emergence and growing prominence of “deep learning”, “neural networks” and “edge computing” since 2019 indicate a shift in focus towards the application of quantization techniques in AI models and their deployment on edge devices. This suggests that research is becoming more specialized and focused on practical solutions to the challenges of energy efficiency in distributed AI scenarios.

Table 4 - Temporal evolution of the most frequent keywords (2011–2025)

Year	Keywords
2011	G.723.1, MP-MLQ, Target tracking, Fast codebook search, Speech coding, Energy model
2012	Evolutionary computing, Binaural hearing aids, Low computational cost, Speech-processing, Statistical signal processing, Algorithms
2013	Algorithms, Bayesian networks, Communication, Monte Carlo methods, Sensor networks
2014	Energy efficiency, Energy conservation, Design, Approximate computing, Generalized learning vector quantization
2015	Fading, Nanoelectronics, Quantization, Post-CMOS, Energy efficiency
2016	Green computing, Optimization, Quantization, Energy utilization, vector quantization
2017	Energy efficiency, Model compression, Clustering, Forecasting, Hardware acceleration
2018	Energy efficiency, Hardware, Quantization (signal), Green computing, Energy utilization
2019	Energy efficiency, Deep learning, Green computing, Memory architecture, Quantization
2020	Energy efficiency, Network architecture, Green computing, programmable gate arrays (FPGA), Deep neural networks
2021	Energy efficiency, Edge computing, Network architecture, Deep learning, Memory architecture
2022	Energy efficiency, Quantisation, Neural networks, Quantization (signal), Deep learning
2023	Quantization (signal), Energy efficiency, Quantisation, Convolutional neural network, Network architecture
2024	Quantization (signal), Quantisation, Energy efficiency, Edge computing, Neural networks
2025	Edge computing, Quantisation, Neural networks, Energy, Energy efficiency

Source: Self elaboration.

DISCUSSION

This bibliometric review maps the scientific evolution of research at the intersection of sustainable computing, green cloud computing, and quantization techniques. The results indicate that this research domain is undergoing a clear process of consolidation, characterized by sustained growth in scientific output, increasing thematic diversification, and the gradual incorporation of more sophisticated analytical and methodological approaches.

Temporal analysis revealed a pronounced increase in the number of publications from 2018 onward. This inflection point coincided with the rapid expansion of artificial intelligence models, particularly deep learning architectures that require substantial computational power. Consequently, concerns regarding energy consumption, scalability, and environmental impact have become central to these discussions. The observed growth pattern indicates that energy efficiency is no longer treated as a secondary optimization objective but as a fundamental design constraint in modern computational systems.

This temporal acceleration observed from 2018 onward is consistent with the findings reported in previous bibliometric and survey-based studies on sustainable computing and energy-aware artificial intelligence. In a review by Biswas *et al.* (2024) and Bolón-Canedo *et al.* (2024) identified the late 2010s as a turning point driven by the rapid expansion of deep learning models and the corresponding increase in computational and energy demands.

Likewise, Donthu *et al.* (2021) emphasize that emerging technological fields often experience exponential publication growth once practical and societal constraints such as energy consumption and environmental impact become central research drivers. The temporal pattern identified in this study reinforces the interpretation that quantization has transitioned from a niche optimization technique to a core strategy in sustainability-oriented computing research.

Bibliometric indicators further demonstrate that research on sustainable computing and quantization spans multiple disciplines including distributed systems, computer architecture, optimization, machine learning, software engineering, and data science. This multidisciplinary characteristic reflects the complex nature of the problem, which requires solutions that operate simultaneously at the infrastructure, algorithm, and architectural levels.

The thematic clustering analysis highlighted two dominant areas of research. The first focuses on infrastructure-level optimization, particularly in cloud computing environments, emphasizing energy-aware resource management, virtualization strategies, and data center efficiency. The second front focuses on algorithmic-level optimization, where techniques such as quantization, compression, and reduced-precision computation are employed to decrease model complexity, memory usage, and execution costs. These clusters demonstrate the parallel evolution of hardware and model-oriented approaches for improving energy efficiency.

The coexistence of infrastructure and algorithmic-level research fronts identified in this study aligns with prior conceptual classifications proposed in the literature. Surveys on green cloud computing highlight infrastructure-oriented strategies, such as energy-aware scheduling, virtualization, and data center optimization, as the dominant approaches (YOU *et al*., 2020; BISWAS *et al*., 2024). Conversely, recent reviews on efficient artificial intelligence emphasize algorithmic techniques, including quantization, pruning, and model compression, as essential mechanisms for reducing computational and energy costs (GHOLAMI *et al*., 2022; ZHU *et al*., 2024).

The present bibliometric findings corroborate these dual trajectories, revealing that they have largely evolved in a parallel rather than an integrated manner, reinforcing the need for cross-layer frameworks that jointly address infrastructure efficiency and model-level optimization.

Geographical analysis has revealed a significant expansion in contributions from emerging countries, indicating widespread concerns regarding computational sustainability. This trend is consistent with the increasing accessibility of advanced computational technologies and growing awareness of environmental challenges associated with digital infrastructure. Additionally, the observed growth in international co-authorship networks underscores the collaborative and transnational nature of the research in this field.

Although the results demonstrate consistent growth and thematic diversification, the discussion of these findings reveals important conceptual and structural limitations of the current body of the literature. Despite parallel advancements in infrastructure-oriented and algorithmic approaches, this field remains fragmented. Studies have often focused on isolated layers such as hardware efficiency, model compression, and embedded systems, without establishing integrative frameworks that cohesively connect these aspects.

This conceptual fragmentation has been noted explicitly in recent studies. Różycki *et al*. (2025) argue that energy-aware machine learning research remains dispersed across isolated technical domains, lacking unified evaluation frameworks that combine performance, energy, and environmental metrics. Similarly, Bolón-Canedo *et al*. (2024) observed that much of the green AI literature prioritizes efficiency gains without systematically addressing life cycle impacts or sustainability trade-offs. The findings of this study empirically substantiate these critiques by demonstrating that research clusters remain weakly interconnected through bibliometric mapping. This reinforces the argument that the field is yet to converge towards a cohesive theoretical paradigm capable of integrating quantization into holistic, sustainable computing strategies.

This fragmentation hinders the development of standardized evaluation methodologies and limits the comparability of results across studies. Although quantization has emerged as a central technique for reducing the computational complexity and energy consumption, many studies have emphasized performance improvements without explicitly addressing broader environmental or sustainability metrics. Consequently, quantization is frequently regarded as technical optimization rather than a core component of holistic and sustainable computing strategies.

The absence of a unified theoretical framework restricts the ability to trace the historical evolution of a field and identify dominant paradigms and research gaps with greater clarity. The results of this bibliometric analysis suggest that future research would benefit from greater conceptual integration between infrastructure-level energy management and model-level optimization methods. Bridging these perspectives is essential for advancing comprehensive energy-aware computing models that simultaneously consider the performance, scalability, and environmental impact.

From a forward-looking perspective, our findings highlight several promising avenues for future research. These include the development of standardized energy benchmarks, integration of quantization techniques into large-scale data center simulators, design of hybrid hardware–software architectures, and creation of predictive models capable of estimating energy consumption under different workload scenarios. Such efforts could contribute to reducing conceptual fragmentation and strengthening the empirical foundation of sustainable computing.

Finally, this analysis reinforces the central role of bibliometric reviews in emerging interdisciplinary fields. Bibliometric analyses provide valuable guidance to researchers, institutions, and policymakers by systematically mapping trends, identifying dominant research clusters, and identifying conceptual gaps. The results presented here indicate that it is undergoing a conceptual transition towards integrating computational sustainability into the core of scientific and technological decision making. In this sense, quantization and energy-aware computing are no longer peripheral concerns but fundamental elements that will shape the future of computational research and practice.

FINAL REMARKS

This bibliometric review provides a structured and comprehensive overview of the scientific landscape at the intersection of sustainable computing, green cloud infrastructure, and quantization techniques. By systematically mapping publications, thematic clusters, and collaboration networks, this study clarifies how this research domain has evolved, and identifies its main conceptual and methodological trajectories.

The findings indicate that quantization has moved beyond its traditional role as a performance optimization technique, and is increasingly positioned as a strategic mechanism for broader sustainability-oriented computing. Simultaneously, the analysis revealed that the literature remains fragmented across infrastructure- and model-level approaches, highlighting the absence of integrated frameworks capable of jointly addressing performance, energy efficiency, and environmental impact.

From a methodological perspective, this study reinforces the relevance of bibliometric reviews in the organization of emerging interdisciplinary fields. The use of scientific mapping techniques enables the identification of dominant research fronts, underexplored themes, and structural gaps that are not easily captured by narrative reviews.

Despite its comprehensive scope, this work is methodologically limited by its reliance on a single bibliographic database (Scopus), which, although widely recognized, may exclude relevant contributions indexed in complementary sources and non-English publications.

The evidence synthesized here indicates that future advances in sustainable computing will depend on stronger integration of hardware-aware optimization, algorithmic efficiency, and energy-centric evaluation metrics. This review offers a reference framework to support future empirical studies, comparative analyses, and the development of standardized benchmarks focused on energy-aware artificial intelligence and cloud computing applications.

Overall, this study positions computational sustainability as a foundational pillar of contemporary computing research, demonstrating that quantization and energy-aware design are not auxiliary optimizations but central determinants of future scientific innovation, technological development, and policy-oriented decision-making in digital infrastructure.

By consolidating dispersed research streams, this study contributes to positioning energy-aware quantization as a foundational pillar of sustainable computing research, with implications that extend beyond technical optimization toward policy, infrastructure planning, and long-term digital sustainability.

REFERENCES

ABDULNABI, H. “Cloud computing strategies and approaches for better energy efficiency and environmental impact”. **Al-Iraqia Journal for Scientific Engineering Research**, vol. 3, n. 3, 2024.

ARIA, M.; CUCCURULLO, C. “Bibliometrix: An r-tool for comprehensive science mapping analysis”. **Journal of informetrics**, VOL. 11, N. 4, 2017.

BELKHIR, L.; ELMELIGI, A. “Assessing ict global emissions footprint: Trends to 2040 & recommendations”. **Journal of Cleaner Production**, vol. 177, 2018.

BIESER, J. C. *et al*. “ A review of assessments of the greenhouse gas footprint and abatement potential of information and communication technology“. **Environmental Impact Assessment Review**, vol. 99, 2023.

BISWAS, D. *et al*. “A succinct state-of-theart survey on green cloud computing: Challenges, strategies, and future directions“. **Sustainable Computing: Informatics and Systems**, vol. 44, 2024.

BOLØN-CANEDO, V. *et al*. “A review of green artificial intelligence: Towards a more sustainable future”. **Neurocomputing**, vol. 599, 2024.

CAO, N. **Towards carbon-aware**: Power monitoring in cloud computing (Master’s thesis). Espoo: Aalto University, 2024.

CHEN, L. *et al*. “A survey on computer vision detection, visual slam algorithms, and their applications in energy-efficient autonomous systems”. **Energies**, vol. 17, n. 20, 2024.

DHINGRA, P. *et al*. “Atleus: Accelerating transformers on the edge enabled by 3d heterogeneous manycore architectures”. **IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems**. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

DONTHU, N. *et al*. “How to conduct a bibliometric analysis: An overview and guidelines”. **Journal of Business Research**, vol. 133, 2021.

ELSEVIER. “Scopus”. **Elsevier** [2025]. Available at: <www.elsevier.org>. Accessed on: 12/07/2025.

GAROFALO, A. *et al*. “Pulp-nn: Accelerating quantized neural networks on parallel ultra-low-power risc-v processors”. **Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences**, vol. 378, n. 216, 2020.

GHOLAMI, A. *et al*. “A survey of quantization methods for efficient neural network inference”. **ArXiv**, vol. 3, 2022.

GONÇALVES, C. A. *et al*. "Adoption of cloud computing in the organizations: a bibliometric analysis of this technology within a digital transformation contexto". **Revista de Administração da UFSM**, vol. 16, n. 3, 2023.

GOWDA, S. N. *et al*. "Watt for what: Rethinking deep learning's energy-performance relationship". **European Conference on Computer Vision**. London: Springer, 2024.

GUO, Q. *et al*. "An empirical study towards characterizing deep learning development and deployment across different frameworks and platforms". **Proceedings 34th IEEE/ACM International Conference on Automated Software Engineering**. Cham: IEEE, 2019.

HAN, S. *et al*. "Ese: Efficient speech recognition engine with sparse LSTM on FPGA". **Proceedings ACM/ International Symposium on Field-Programmable Gate Arrays**. Monterey: SIGDA, 2017.

HE, Q. *et al*. "Two-dimensional materials based two-transistor-two-resistor synaptic kernel for efficient neuromorphic computing". **Nature Communications**, vol. 16, n. 1, 2025.

IEEE - Institute of Electrical and Electronics Engineers. **Ieee access**. Washington: IEEE, 2025a. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

IEEE - Institute of Electrical and Electronics Engineers. **Ieee internet of things journal**. Washington: IEEE, 2025b. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

IEEE - Institute of Electrical and Electronics Engineers. **Ieee journal of solid-state circuits**. Washington: IEEE, 2025c. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

IEEE - Institute of Electrical and Electronics Engineers. **Ieee transactions on circuits and systems i**: Regular papers. Washington: IEEE, 2025d. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

IEEE - Institute of Electrical and Electronics Engineers. **Ieee transactions on computer-aided design of integrated circuits and system**s. Washington: IEEE, 2025e. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

IEEE - Institute of Electrical and Electronics Engineers. **Ieee transactions on computer**s. Washington: IEEE, 2025f. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

IEEE - Institute of Electrical and Electronics Engineers. **Ieee transactions on very large scale integration (vlsi) systems**. Washington: IEEE, 2025g. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

IEEE - Institute of Electrical and Electronics Engineers. **Proceedings of the asia and south pacific design automation conference (asp-dac)**. Washington: IEEE, 2025h. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

IEEE - Institute of Electrical and Electronics Engineers. **Proceedings of the ieee international symposium on circuits and systems (iscas)**. Washington: IEEE, 2025i. Available at: <www.ieee.org>. Accessed on: 12/07/2025.

ISLAMOGLU, G. *et al*. " Ita: An energy-efficient attention and softmax accelerator for quantized transformers". **Proceedings of the International Symposium on Low Power Electronics and Design**. Portland: IEEE, 2023.

JIA, H. *et al*. " A programmable heterogeneous microprocessor based on bit-scalable in-memory computing". **IEEE Journal of Solid-State Circuits**, vol. 55, n. 9, 2020.

JIANG, H. *et al*. " Post training quantization after neural network". **14th International Conference on Computer Research and Development**. Washington: IEEE, 2022.

LEE, H. *et al*. " Deep learning for distributed optimization: Applications to wireless resource management". **IEEE Journal on Selected Areas in Communications**, vol. 37, n. 10, 2019.

LI, M. *et al*. " Contemporary advances in neural network quantization: A survey". **International Joint Conference on Neural Networks**. Washington: IEEE, 2024.

LIANG, S. *et al*. " Fp-bnn: Binarized neural network on fpga". **Neurocomputing**, vol. 275, 2018.

LIAO, L. *et al*. "An empirical study of the impact of hyperparameter tuning and model optimization on the performance properties of deep neural networks". **ACM Transactions on Software Engineering and Methodology**, vol. 31, n. 3, 2022.

LIU, J. *et al*. (2021). "Boost precision agriculture with unmanned aerial vehicle remote sensing and edge intelligence". **Remote Sensing**, vol. 13, n. 21, 2021.

LIU, K. *et al*. " Low-bit model quantization for deep neural networks: A survey". **arXiv**, vol. 1, 2025.

LYU, X. *et al*. " Energy-efficient Admission of delay-sensitive tasks for mobile edge computing". **IEEE Transactions on Communications**, vol. 66, n. 1, 2016.

MARANHÃO, G.; PANTOJA, M. J. "Teletrabalho e qualidade de vida dos servidores públicos: uma revisão sistemática de literatura". **Boletim de Conjuntura (BOCA)**, vol. 20, n. 60, 2024.

MARQUES, S. C. *et al*. "O papel da heurística do afeto na percepção de riscos e aceitação de tecnologias alimentares emergentes: Uma revisão sistemática". **Boletim de Conjuntura (BOCA)**, vol. 21, n. 63, 2025.

MCALLISTER, J. T. *et al*. "Mapping a discipline: a guide to using vosviewer for bibliometric and visual analysis. **Science and Technology Libraries**, vol. 41, n. 3, 2022.

MORAL-MUÑOZ, J. A. *et al*. "Software tools for conducting bibliometric analysis in science: an up-to-date review". **Profesional de la Información**, vol. 29, n. 1, 2020.

OLIVEIRA, I.; ROTHEN, J. C. "Análise bibliométrica da produção acadêmica em periódicos científicos sobre os processos de autoavaliação institucional na educação superior brasileira". **Boletim de Conjuntura (BOCA)**, vol. 8, n. 22, 2021.

PACHECO, J. T. R. R.; SILVA, J. M. F. "Mapeamento bibliométrico sobre geodiversidade e serviços ecossistêmicos". **Boletim de Conjuntura (BOCA)**, vol. 23, n. 68, 2025.

PAGE, M. J. *et al*. " Prisma 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews". **BMJ**, vol. 372, 2021.

PENG, R. *et al*. Real-time fire detection algorithm on low-power endpoint device. **Journal of Real-Time Image Processing**, vol. 22, n. 1, 2025.

PENG, X. *et al*. "Dnn+neurosim v2: An end-to-end benchmarking framework for compute-in-memory accelerators for on-chip training". **IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems**, vol. 40, n. 11, 2021.

PRANCKUTE, R. "Web of science (wos) and scopus: The titans of bibliographic information in today's academic world". **Publications**, vol. 9, n. 1, 2021.

RAKKA, M. *et al*. "A review of stateof-the-art mixed-precision neural network frameworks". **IEEE Transactions on Pattern Analysis and Machine Intelligence**, vol. 46, n. 12, 2024.

REIS, T. N. F. *et al*. "A tier labeling proposal for energy efficiency in green cloud". **Journal of Sustainability Research**, vol. 6, n. 1, 2024a.

REIS, T. N. F. *et al*. "Uma proposta de classificação para rotular a eficiência energética na computação em nuvem verde". **Boletim de Conjuntura (BOCA)**, vol. 17, n. 49, 2024b.

RŐZYCKI, R. *et al*. "Energy-aware machine learning models—a review of recent techniques and perspectives". **Energies**, vol. 18, n. 11, 2025.

SILVA, C. A. *et al*. "A água como bem comum: Um estudo bibliométrico em âmbito internacional". **Boletim de Conjuntura (BOCA)**, vol. 24, n 71, 2025.

STATE COUNCIL OF THE PEOPLE'S REPUBLIC OF CHINA. **The 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China (2021–2025)**. Beijing: State Council, 2021.

STRUBELL, E. *et al*. "Energy and policy considerations for deep learning in NLP". **Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics**. Florence: Association for Computational Linguistics, 2019.

SUN, X. *et al*. "Drvit: Dynamic redundancy-aware vision transformer accelerator via algorithm and architecture co-design on FPGA". **Journal of Parallel and Distributed Computing**, vol. 199, 2025.

YANG, B. "Lightweight federated learning for energy-efficient english corpus distribution and optimization in edge-cloud collaboration networks". **Internet Technology Letters**, vol. 8, n. 4, 2025.

YANG, J. *et al*. "A survey on neural network quantization". **Proceedings of the 2025 6th International Conference on Computer Information and Big Data Applications**. Washington: IEEE, 2025.

YOU, X. *et al*. "A survey and taxonomy on energy aware data management strategies in cloud environment". **IEEE Access**, vol. 8, 2020.

ZHAO, L. *et al*. "A 90.1db sndr, 180.2db fomsndr, 10khz bw gmc-based . adc with capacitive input feedforward and duty-cycled gm technique". **Proceedings of the Custom Integrated Circuits Conference**. Washington: IEEE, 2025.

ZHU, X. *et al*. "A survey on model compression for large language models". **Transactions of the Association for Computational Linguistics**, vol. 12, 2024.

ZUPIC, I.; ČATER, T. "Bibliometric methods in management and organization". **Organizational research methods**, vol. 18, n. 3, 2015.

BOLETIM DE CONJUNTURA (BOCA)

Ano VII | Volume 24 | Nº 72 | Boa Vista|2025

http://www.ioles.com.br/boca