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Revisão sistemática da literatura sobre indicadores de sustentabilidade energética

Systematic literature review of energy sustainability indicators

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Resumo: Este artigo apresenta uma revisão sistemática da literatura sobre indicadores de sustentabilidade energética, fundamentada na metodologia Knowledge Development Process – Constructivist (ProKnow-C). Reconhecendo a relação intrínseca entre energia e desenvolvimento sustentável, foram analisados estudos que abordam dimensões técnicas, econômicas, ambientais e sociais dos sistemas energéticos. A pesquisa bibliográfica foi realizada nas bases Scopus e Web of Science, resultando inicialmente em 7.428 trabalhos. Após o processo de filtragem por critérios de relevância, impacto de citações e aderência temática, obteve-se um portfólio final de 12 artigos. Os estudos selecionados demonstram diferentes metodologias de avaliação, como análise multicritério, modelos de equilíbrio geral e análises bibliométricas, além de destacar desafios relacionados à governança, eficiência energética e transição para fontes renováveis. A sistematização dos resultados evidencia a importância dos indicadores como instrumentos de apoio à formulação de políticas públicas e estratégias de transição energética sustentável, bem como aponta lacunas e oportunidades para pesquisas futuras, incluindo maior integração de métricas sociais e análises pós-implementação de políticas energéticas.
Palavras-chave: energia; sustentabilidade; indicadores; políticas energéticas; ProKnow-C.

Abstract: *This paper presents a systematic review focused on energy sustainability indicators, applying a methodology based on Knowledge Development Process – Constructivist (ProKnow-C). Recognizing that sustainable development and energy are intrinsically interconnected, since energy drives industrialization, technological progress, and socioeconomic development, while also contributing to environmental challenges, this study highlights the need for indicators to guide the transition toward cleaner energy systems. A literature search was conducted in Scopus and Web of Science, resulting in a total of 7,428 results. Following a filtering process based on the elimination of duplicates, relevance, citation count, and content adherence, a final bibliographic portfolio of 12 papers was compiled. The selected studies evaluate energy systems from technical, economic, and environmental perspectives. The resulting portfolio provides a theoretical foundation for sustainable energy management and offers insights for future research.*
Keywords: energy. sustainability. indicators; energy policies; ProKnow-C.

1 Introduction

The concept of sustainable development establishes that current growth must meet the needs of the present generation without compromising the ability of future generations to meet theirs (WCED, 1987). Achieving this goal requires a balance between economic growth, environmental preservation, and social equity.

Energy plays a central role in socio-economic development by ensuring access to essential services, driving industrialization, and fostering technological innovation. However, its production and consumption

also generate significant environmental challenges, including greenhouse gas emissions, resource depletion, and ecosystem degradation (Suganthi, 2020; Tete et al., 2023).

In this context, energy sustainability indicators emerge as essential tools to evaluate the performance of energy systems across technical, economic, environmental, and social dimensions. Beyond quantifying efficiency and productivity, these indicators highlight environmental impacts and governance challenges associated with the implementation of clean energy solutions (Rodriguez, Pansera and Lorenzo, 2020).

The advancement of energy sustainability depends on public policies that are more effective when based on concrete data, such as those provided by these indicators. Such an approach supports strategies for diversifying energy matrices, promoting resource efficiency, and balancing production and consumption, thereby ensuring equitable access to energy.

Previous studies have demonstrated the utility of different methodologies in this field: multi-criteria decision models assessing the efficiency of sustainable energy development (Suganthi, 2020); analyses of policy challenges related to governance and infrastructure (Tete et al., 2023); evaluations of energy efficiency and carbon emissions (Rodriguez, Pansera and Lorenzo, 2020); and discussions on the political use of social indicators to guide sustainable development (Boulanger, 2007).

In this context, the objective of this study is to apply the ProKnow-C (Knowledge Development Process – Constructivist) methodology to systematically search for, filter, and select relevant papers on energy sustainability indicators. This process results in a bibliographic portfolio that reflects the current state of research in the field and provides a theoretical foundation for future analyses.

2 Literature review

2.1 Sustainable development and energy

As discussed, the concept of sustainability is intrinsically linked to economic growth that preserves environmental quality and ensures the well-being of future generations (Suganthi, 2020). In the energy sector, this relationship is particularly relevant, as energy not only drives industrialization and technological advancement but also constitutes a critical determinant of socioeconomic development.

Nevertheless, conventional approaches to energy production and consumption have generated substantial environmental impacts, including greenhouse gas emissions, depletion of natural resources, and ecosystem degradation (Tete et al., 2023). In this context, the literature highlights the urgent need for strategies that reconcile economic growth with environmental preservation, thereby laying the foundation for a sustainable energy future.

2.2 Energy sustainability indicators

Energy sustainability indicators serve as essential tools to assess and guide the transition toward low-carbon and resilient energy systems. By integrating performance metrics across technical, economic, environmental, and social dimensions, these indicators provide data that enable comparisons of current practices and support the development of evidence-based public policies. Numerous studies have applied these multidimensional perspectives to evaluate energy systems (Hasan et al., 2020; Rodriguez, Pansera and Lorenzo, 2020; Tete et al., 2023).

Methodological advances, such as multi-criteria decision analysis (MCDA), fuzzy hierarchical processing, and data envelopment analysis (DEA), have been employed to synthesize diverse metrics into composite indices. These approaches capture not only technical and economic efficiency but also incorporate environmental and social aspects (Yadegaridehkordi et al., 2020; Bibliometric Analysis of the Energy Efficiency Research, 2022; Lu et al., 2022).

In addition, research on market dynamics and technological innovation highlights the importance of aligning technological progress with environmental performance to promote more effective and sustainable energy transitions (Chowdhury et al., 2020; Azizpanah, Fathi and Taki, 2023).

In summary, energy sustainability indicators represent a vital interdisciplinary framework for the comprehensive evaluation of energy systems. By bridging technical, economic, environmental, and social dimensions, they provide robust support for policy formulation and drive the transition toward cleaner, more efficient, and more equitable energy systems.

3 ProKnow-C

This paper conducts a systematic review to identify relevant studies in the field and to evaluate and synthesize their contributions. For the selection of theoretical references, the ProKnow-C (Knowledge Development Process – Constructivist) methodology was applied. This method involves a structured process of paper selection based on bibliometric analyses combined with the researcher's judgment (Krüger and Borsato, 2019).

The search was carried out between May 27 and 29, 2025, in two databases: Scopus and Web of Science. Two sets of keyword combinations were used. In Web of Science: "Indicator energy" AND "Braz" AND "Sustainability" OR "Braz" AND "Energy Efficiency" AND "Energy System". In Scopus: "Indicator AND Energy" AND "Braz" AND "Sustainability" OR "Braz" AND "Energy Efficiency" AND "Energy AND System". The searches were restricted to research papers published between 2020 and 2025.

The filtering process began by excluding duplicate and inaccessible papers. The next stage consisted of applying selected keywords, which represents a deviation from the original ProKnow-C procedure, as a practical approach to refine the selection and obtain papers specifically related to the topic. Subsequently, papers below the established ranking threshold and those whose titles did not align with the research theme were excluded. Thereafter, the 20% of papers with the lowest citation counts were removed, while retaining only those published within the last two years. Finally, abstracts and full texts were reviewed to complete the filtering process.

The search process yielded a total of 7,428 papers, of which 6,374 were retrieved from the Scopus database and 1,054 from the Web of Science database. From this dataset, the VOSviewer software (version 1.6.20) was employed to generate bibliometric maps (Figures 1 and 2), illustrating the geographical distribution of the researchers' institutions. In these visualizations, the size of the circles and labels is proportional to the frequency of occurrence of each country, while the connections between countries are represented by lines indicating collaborative relationships.

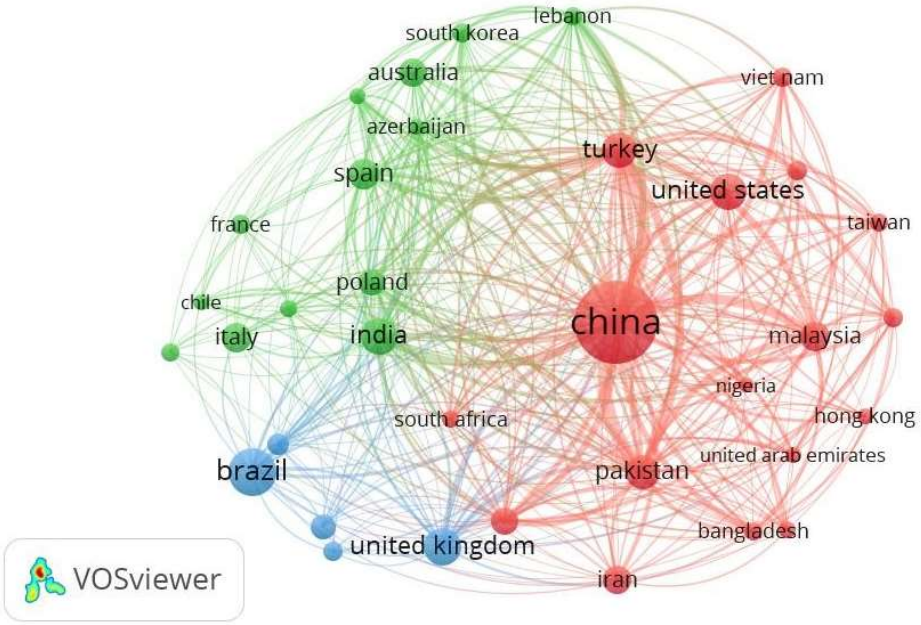

Figure 1. Network visualization of the researchers' institution research from the Scopus database.

Among the 7,428 papers initially identified, 256 were duplicates or inaccessible. The remaining papers were filtered using the keywords Indicators, Energy, Sustainability, and Energy Efficiency. Papers that did not contain any of these terms were excluded, leaving 102. Subsequently, 20% of the papers with the lowest ranking in the ordination process were removed, resulting in 58 papers.

Based on title analysis, only 40 papers were retained. Next, 20% of those with the lowest citation counts were eliminated, while only publications from the last two years were preserved, leading to the removal of one additional paper. The abstracts were then classified according to adherence—low, medium, or high—and only those with medium or high adherence were maintained; the same procedure was applied to the full texts. After this final screening, 12 papers remained, forming the bibliographic portfolio on indicators for energy management in energy sustainability. Figure 3 illustrates the selection process.

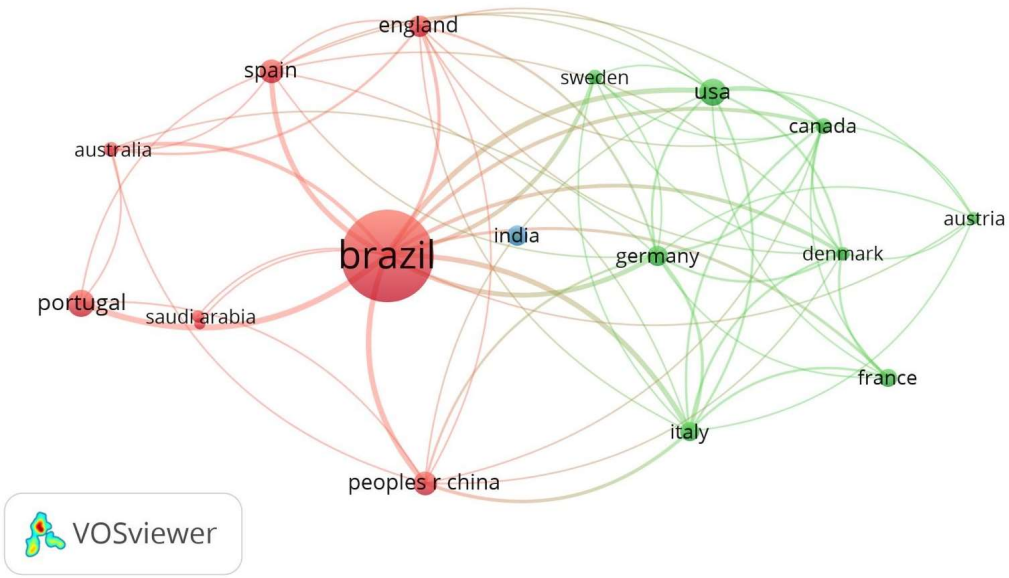

Figure 2. Network visualization of the researchers' institution research from the Web of Science database.

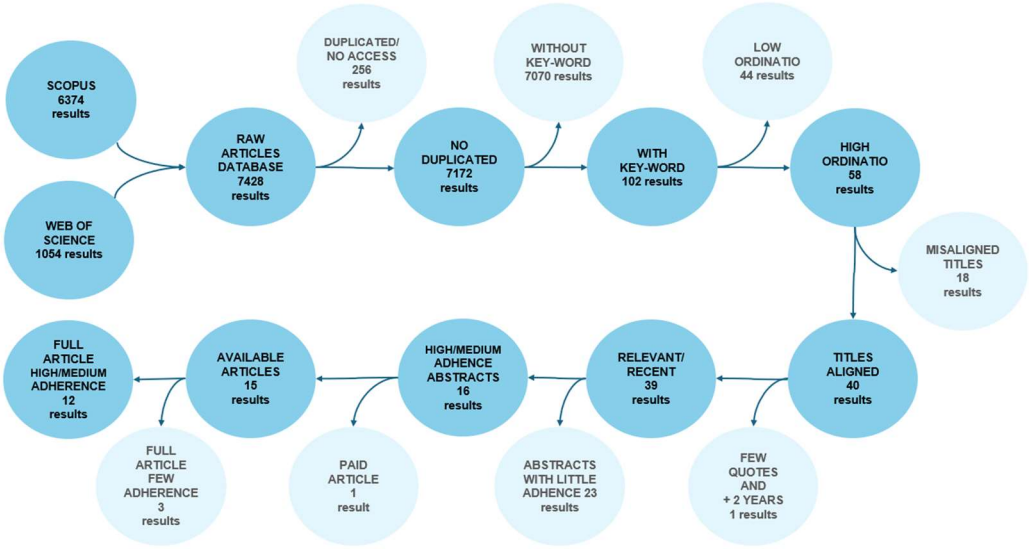

Figure 3. Method used to filter references with results.

To compile the research portfolio, papers published between 2020 and 2025 were systematically selected. Of the studies that met the inclusion criteria, four were published in 2020, two in 2021, one in 2022, four in 2023, and one in 2025. Although a larger number of publications might have been expected in 2020—given that earlier studies have had more time to accumulate citations—recent works from the last two years were retained despite their lower citation counts, ensuring the inclusion of contemporary research. As a result, the distribution of publication years in the final portfolio is balanced. Figure 4 presents this distribution, extracted from the .ris file generated in Mendeley, where each bar indicates the number of bibliographic records (articles, chapters, etc.) indexed for a given year.

Figure 5 presents the 20 journals and conferences most frequently cited in the .ris file retrieved from Mendeley. This analysis highlights the most relevant or preferred scientific outlets within the thematic scope of the study. According to the Qualis classification system of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), the selected papers appear in A1-ranked journals such as Journal of Cleaner Production, Energy Policy, Energy and Buildings, and Journal of Building Engineering, as well as in A2-ranked journals including Energy Reports, Energy, Sustainability and Society, and Energies.

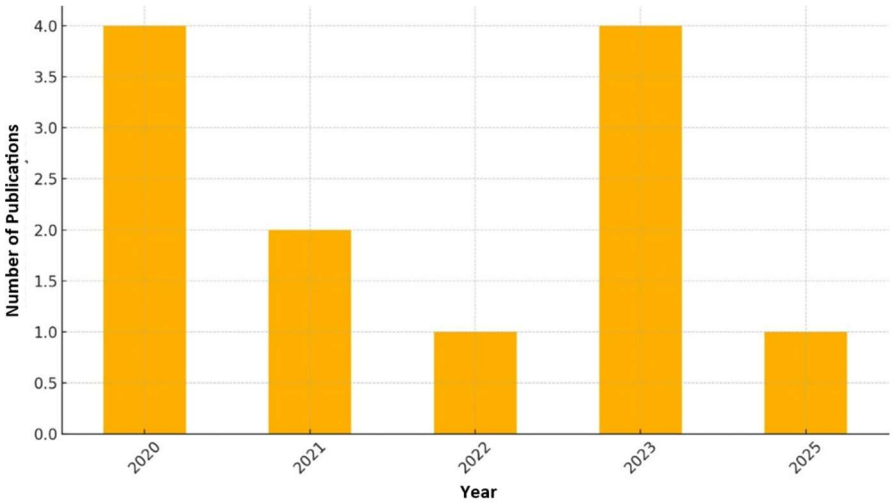

Figure 4. Number of publications per year.

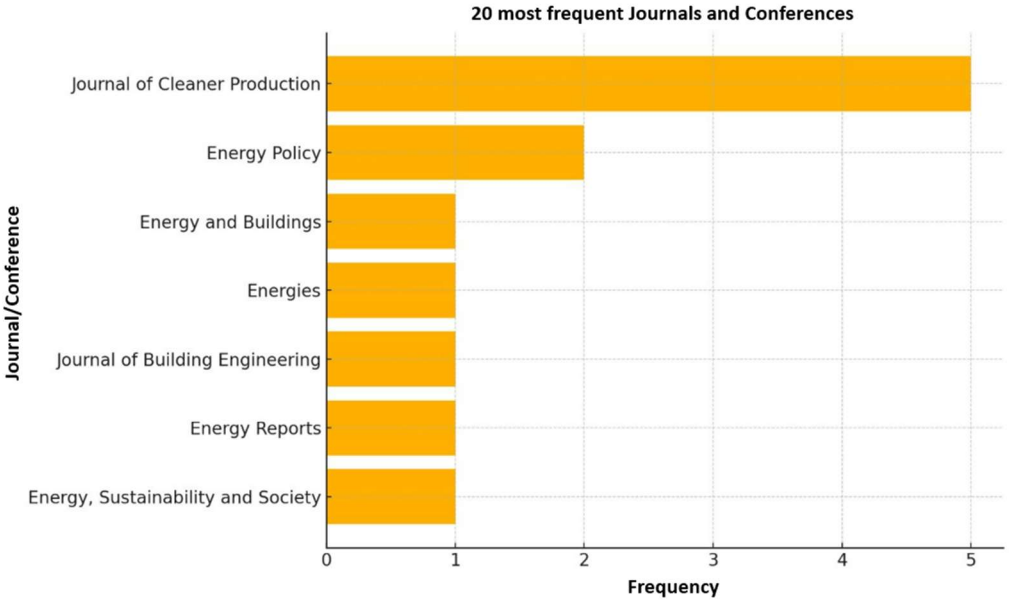

Figure 5. Journals in the Bibliographic Portfolio.

Regarding the scientific impact of the papers in the portfolio, Figure 6 highlights the five publications with the highest recognition within the bibliographic collection, measured in terms of citation counts and influence within their respective research fields. This analysis allows us to identify the works that have made the most significant contribution to the scientific community in the thematic area under study.

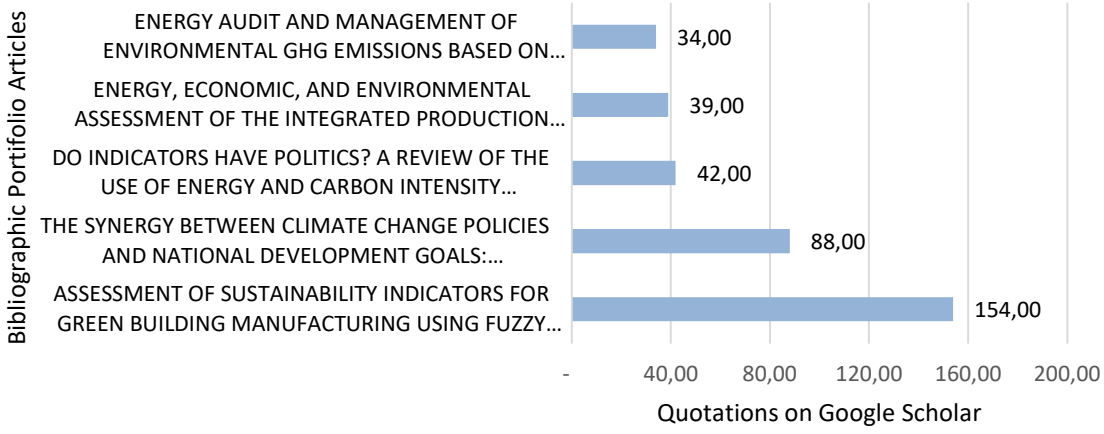

Figure 6. Papers with higher number of quotations among the bibliographic portfolio (2025).

The 12 papers are authored by a total of 56 researchers. This analysis helps identify central or recurring researchers in the studied theme; however, in the current portfolio, each author appears in only one paper.

Among these, six papers are authored by researchers from institutions within the same country, one of which has a single author. The remaining papers feature contributions from institutions across different countries. The countries represented in the bibliographic portfolio are as follows: Malaysia (3 authors), Vietnam (1 author), Saudi Arabia (9 authors), Iraq (1 author), New Zealand (1 author), Canada (1 author), Spain (10 authors), the United Kingdom (3 authors), Brazil (11 authors), Colombia (2 authors), Iran (6 authors), Burkina Faso (3 authors), India (1 author), Australia (2 authors), and China (2 authors). These distributions are illustrated in Figure 7.

Figure 7. Cloud key words that most appeared in the papers of the bibliographic portfolio.

Although the analyzed papers primarily focus on energy sustainability indicators, they differ in addressing secondary aspects such as energy efficiency, environmental impact, public policies, and the transition to renewable energy. For instance, a green construction study uses a fuzzy model to evaluate sustainability indicators in building manufacturing (Yadegaridehkordi et al., 2020), complementing a bibliometric analysis mapping trends in renewable energy research (García-Lillo et al., 2023). Future research could integrate energy justice indices and hybrid methods in the former, and emphasize local applications and comparative methods in the latter.

In energy policy and sustainable development, studies investigate the integration of climate policies with economic growth (Hasan et al., 2020) and challenges in energy security in West Africa (Tete et al., 2023), highlighting governance, infrastructure, and social factors. In developing countries, multicriteria models measure energy efficiency based on natural resource use (Suganthi, 2020), while DSGE models assess policy impacts on renewable energy expansion (Debel and Wang, 2025). Future work could incorporate post-implementation evaluations and emerging technologies.

Other studies explore efficient energy systems (Ocampo Batlle et al., 2021) and the use of energy intensity and carbon emissions metrics to inform policy (Rodriguez, Pansera and Lorenzo, 2020), suggesting opportunities to include social and political indicators. Multicriteria decision-making is further emphasized in studies on sustainable resource use and energy optimization in buildings and construction (Triana, Lamberts and Sassi, 2021; González-Prieto et al., 2023).

Overall, these studies converge on the need for integrated policies, emerging technologies, and adaptive governance to support a sustainable energy transition. They also point to future research opportunities to evaluate economic and social impacts, validate methodologies, and implement strategies that enhance energy sustainability. Table 1 summarizes each paper's approach and suggests directions for future research.

Table 1. Research Approaches.

(Continue)

Paper	Approach	Suggested Future Research
Yadegaridehkordi et al. (2020)	Application of Decision-Making Trial and Evaluation Laboratory to assess sustainability indicators for green building manufacturing in Malaysia, using the Green Building Index. Results highlight Energy Efficiency and Indoor Environmental Quality as the most critical factors, while Water Efficiency and Innovation ranked lower.	Energy justice index; integration of hybrid methods for a more comprehensive evaluation
Hasan et al. (2020)	A quantitative approach with relevant indicators to assess the impact of climate policies on emissions reduction in Bangladesh. It examined the synergy between mitigation efforts and national development goals through trend analysis and scenario projections, providing insights to improve sustainability strategies.	Indicator framework aligned with the SDGs; integration of emerging technologies.
Rodriguez, Pansera and Lorenzo (2020)	Review of how energy and carbon intensity indicators are framed in public debates and policy discussions. Public documents, reports, and policy briefs were analyzed from think tanks, consulting groups, environmental organizations, and policymakers to understand how these indicators influence decision-making.	Studies on the political use of indicators; evaluation of economic viability.
Ocampo Batlle et al., (2021)	Quantitative approach based on Life Cycle Assessment to evaluate the energy, economic, and environmental impact of the integrated production of palm oil biodiesel and sugarcane ethanol.	Inclusion of social impacts; analysis of costs and benefits at a large scale.
Taherzadeh-Shalmaei et al., (2023)	Multi-objective optimization approach using Genetic Algorithm and Data Envelopment Analysis to assess energy consumption and greenhouse gas emissions in mushroom production.	Inclusion of well-being and justice; use of econometric models such as DSGE.
Tete et al. (2023)	Multiple-Criteria Decision Analysis, specifically the Fuzzy Analytical Hierarchy Process and Preference Ranking Organization Method for Enrichment Evaluations method, to assess energy security performance in the electricity sectors of West African Economic and Monetary Union countries.	Comparative analysis between similar countries; integration of social and technological factors.
Triana, Lamberts and Sassi (2021)	Application of Life Cycle Energy Assessment to evaluate energy efficiency in Brazilian social housing, introducing a Sustainability Index to assess long-term performance across three climate scenarios.	Longitudinal evaluation of public policies; integration with governance.
Suganthi (2020)	Multi-criteria fuzzy Analytical Hierarchical Processing model to assess sustainable energy development efficiency, using natural resources as inputs and various indices as outputs to evaluate the country's resource utilization.	Integration of technical and environmental metrics.

Table 1. Research Approaches.

(Conclusion)

García-Lillo et al. (2023)	Bibliometric analysis to examine key trends in renewable energy and sustainable development, analyzing 8,349 papers to highlight research growth, influential contributions, and sustainability transitions.	Local practical applications; use of comparative methods.
Gholami Rostam and Abbasi (2022).	Conceptual model using the Accumulated Negative Sustainability Indicator to integrate Construction and Demolition Waste impacts into building energy optimization, balancing sustainability indicators through multi-objective optimization.	Integration with mobility and land use; real-time monitoring.
González-Prieto et al. (2023)	Pareto optimization to prioritize sustainability-focused retrofitting in electricity decarbonization scenarios, evaluating economic and environmental indicators for a heritage office building in Spain.	Replication in other contexts; evaluation of social and environmental impacts.
Debel and Wang (2025)	Study of model to assess renewable energy policies in Ethiopia, highlighting strong links to sustainable development but revealing policy challenges in translating energy transitions into broader outcomes.	Post-implementation evaluation; analysis of governance and emerging technologies.

4 Conclusion

This study applied the ProKnow-C methodology to identify and analyze a representative bibliographic portfolio on energy sustainability indicators, encompassing technical, economic, environmental, and social dimensions. The review showed that while most works emphasize the development of indices and models to evaluate energy efficiency and environmental impacts, other approaches also address institutional, political, and social aspects, reflecting the complexity of the subject.

The reviewed papers converge on the importance of indicators as tools to guide public policies and energy transition strategies, but they differ in methodological approaches, ranging from multi-criteria decision models and bibliometric analyses to macroeconomic models and life cycle assessments. This methodological diversity expands the possibilities of application but also highlights the need for greater integration between quantitative and qualitative approaches, particularly concerning social dimensions, governance, and energy justice.

The systematization of the portfolio confirms that energy sustainability indicators are essential tools to support policy design, monitor energy system performance, and guide sustainable development strategies. However, important gaps remain regarding longitudinal assessments of policy impacts, applicability of models across regional contexts, and empirical validation of proposed indicators.

Accordingly, this study highlights relevant opportunities for future research: (i) integration of social and equity metrics into indicator design; (ii) adoption of hybrid methods combining quantitative modeling and qualitative analyses; (iii) post-implementation evaluations of energy policies; and (iv) closer attention to the interplay between technological innovation, governance, and social participation. These directions reinforce the role of indicators not only as measurement tools but also as strategic mechanisms to foster the transition toward cleaner, more resilient, and inclusive energy systems.

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