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Demand-side energy management reimagined: A comprehensive literature analysis leveraging large language models

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ABSTRACT

The landscape of Demand-Side Energy Management (DSM) research is rapidly evolving, shaped by technological innovations and policy developments. This paper presents an exhaustive bibliometric analysis and methodological framework to explore the research trends within the DSM domain. By synthesizing data from Scopus and OpenAlex, we compile a comprehensive dataset of DSM publications that serve as the basis for our analysis. Through rigorous data acquisition and cleaning, we ensure the reliability and relevance of our dataset. We employ state-of-the-art Large Language Models (LLMs) and topic modeling techniques, including GPT and BERTopic, to perform semantic analysis and uncover thematic structures within the literature. Statistical analysis of the literature dataset reveals a steady increase in DSM publications, with significant contributions from prestigious journals and institutions worldwide. We observe that articles are the predominant publication type, while reviews often cite more references and receive higher citation counts. The distribution of publications over time indicates a growing interest in DSM, particularly since 2014. Geographical mapping of institutions highlights key regions contributing to DSM research, with notable outputs from Europe, North America, and East Asia. Coupled with citation network analysis, our approach reveals the influential works and emerging trends that define the scientific progression of DSM research. Our unsupervised topic modeling, powered by BERTopic, clusters the publications into distinct themes, while our advanced visualization techniques using UMAP and t-SNE provide insights into the semantic space of DSM literature. The resulting thematic classification is presented in a hierarchical structure, offering a comprehensive understanding of the field's focus areas. Our citation network analysis, utilizing force-directed graph computation and edge-bundling algorithms, maps the interconnectivity and impact of research contributions, providing a dynamic view of the field's evolution. This study not only charts the landscape of DSM research but also offers a methodological blueprint for future bibliometric analyses. The insights gained from this multi-faceted exploration serve as a valuable resource for researchers, policymakers, and industry practitioners looking to navigate the complexities of DSM and contribute to its scientific advancement.

1. Introduction

Demand-side energy management (DSM) is a pivotal strategy for enhancing the efficiency and sustainability of energy systems amid escalating demand and environmental challenges [1]. By offering various incentives to consumers, such as price signals and environmental awareness, DSM aims to balance energy supply and demand effectively. However, implementing successful DSM strategies requires a holistic approach that considers the technical, economic, social, and environmental aspects of the problem [2]. Moreover, DSM research is an interdisciplinary field that draws from diverse disciplines, such as engineering, economics, psychology, sociology, and environmental science [3]. DSM emerged in the 1970s as a response to the oil crises and has since developed into a sophisticated framework for managing electrical

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demand through financial incentives and educational programs [4]. These measures benefit both utilities and customers by avoiding costly infrastructural investments, improving service quality, and increasing customer satisfaction [5]. Furthermore, DSM plays a significant role in global carbon emission reductions, contributing to an estimated 15% of the reductions needed to achieve the Paris Agreement goals [6]. As countries around the world revise their energy policies to meet stringent environmental targets, optimizing DSM strategies becomes crucial for the sustainability and efficiency of global energy systems.

DSM involves various consumer-driven actions to reduce or shift energy use to off-peak times. Some examples of these actions are using smart devices that can adjust their settings according to the electricity price or availability, adopting dynamic pricing strategies that charge different rates depending on the time of day or the level of demand, and utilizing renewable energy sources that can supplement or replace conventional power generation [7]. DSM has gained a lot of research attention in the past decade because of its many advantages, such as lowering greenhouse gas emissions, enhancing grid reliability, and saving energy costs [8].

However, the DSM literature is not well-organized or integrated, as different studies focus on different aspects and methods of DSM without providing a comprehensive overview [9]. Moreover, DSM faces many challenges and opportunities in both current and future energy scenarios. These include integrating intermittent renewable energy sources that can vary in their output and availability, increasing consumer engagement in energy conservation and demand response programs that can motivate and reward them for changing their energy behavior, advancing smart grid technologies and distributed energy resources that can improve the flexibility and resilience of the grid, and addressing technical, economic, social, and environmental issues that can affect the feasibility and acceptability of DSM initiatives [10]. While recent DSM research has made some progress in tackling some of these issues, there are still limitations and gaps in the literature. For example, many studies focus on specific aspects or methods of DSM without considering the wider context and implications [11].

DSM research has evolved from technical and engineering methods [12] to interdisciplinary perspectives that consider social, economic, and environmental factors [13]. These factors relate to different types of DSM, such as load forecasting, load control, load shifting, and load curtailment [14]. They also reflect the growing complexity and interdependence of DSM challenges and solutions. However, the DSM literature has some research gaps and limitations that need to be addressed. For instance, there is a need for more studies that compare the costs and benefits of different DSM measures and programs across various regions and sectors. This can help policymakers and stakeholders assess the economic viability and social desirability of DSM initiatives. Additionally, more empirical and experimental data are needed on how consumer behavior and psychology affect their participation and satisfaction in DSM programs. This can help design more effective and customized interventions to motivate and enable consumers to adopt DSM practices. Moreover, a major challenge is to integrate DSM with other smart grid technologies and distributed energy resources, such as energy storage, microgrids, and electric vehicles. These technologies can enhance the flexibility and reliability of the grid, but they also create technical and regulatory issues that must be solved. Furthermore, the impact of DSM on electricity market design, regulation, and social equity and environmental justice concerns requires a holistic and interdisciplinary approach that can balance the interests and needs of various actors and stakeholders in the energy system [15].

To the above limitations, challenges and opportunities in DSM, this paper aims to provide a multi-faceted exploration of the DSM literature, covering various aspects such as technical, economic, social, and environmental. It reveals major trends, challenges, and opportunities in DSM research and practice, as well as research gaps and potential future directions. This paper seeks to inform and guide future research endeavors while contributing to the ongoing development and improvement of DSM strategies and technologies. In order to achieve these goals, we employ a novel two-pronged methodological approach that combines bibliometric analysis and network analysis. Bibliometric analysis is a quantitative technique for examining citation patterns and topic evolution within a research field [16], while network analysis explores citation sub-networks and their features for individual papers [17]. Our analysis draws from an extensive dataset gathered from the Scopus database and the OpenAlex platform, covering DSM literature spanning the years 1987 to 2022.

The importance of this study lies in its ability to provide a thorough, systematic, and in-depth overview of the DSM literature over a considerable timeframe, unearthing key trends, underexplored areas, and research gaps. Additionally, gaining insight into the progression of DSM research categories and their interconnections is essential for pinpointing emerging areas of interest, anticipating future developments, and identifying potential interdisciplinary synergies [3]. By examining the thematic evolution, our study sheds light on the shifting focus of DSM research over time, capturing the growing complexity and interconnectedness of the field. To facilitate this understanding, we categorize the literature into ten distinct research themes based on their keywords and citations. We highlight the various methodologies, technologies, and policy implications associated with each theme. Moreover, we discuss the role of interdisciplinary research in DSM and evaluate the opportunities for bridging gaps between various disciplines to develop more robust and comprehensive approaches to DSM challenges.

Our work differs from the previous literature reviews on DSM in terms of the methodological approach and the scope of analysis. While most of the existing reviews focus on specific aspects of DSM. Such as [2,18,19] focus on technical aspects, [18] provides a literature review of various demand side management techniques and propose a new approach using real-time pricing to balance demand and supply more effectively, [2] provides a comprehensive description and analysis of residential demand-side management, and [19] provides a comprehensive review of demand-side management techniques in district heating systems and highlights the potential of DSM techniques for district heating management. [20,21] focus on models aspects, [20] reviews the current research and development trends in demand-side management business models in electricity markets. It analyzes the business models of energy efficiency and demand response providers in different electricity market environments, and [21] provides an extensive literature review of demand-side management architecture, methodology, optimization models and approaches, and a detailed survey of DSM applications in the residential sector. Some reviews focus on policies, such as [22] analyzes and summarizes over 200 pieces of relevant literature to assess the UK's history and current state of demand-side management policy and make policy recommendations. However, there are still some problems to be solved in the above review articles, such as the literature review and survey research of the articles may have selective bias and do not cover all the relevant literature and research; the articles do not involve specific case studies and lack the support of empirical analyses and practical experience. Etc. we adopt a two-pronged methodological framework that combines bibliometric analysis and network analysis. This allows us to capture the evolution and development of DSM research from a holistic and comprehensive viewpoint. We have collected a more comprehensive dataset of literature. We identify ten key research themes based on their semantic information, and we conduct specific case studies on each theme. Consequently, our study provides a more exhaustive and multidimensional perspective, enriching the current understanding of the DSM landscape. The main contributions of this paper are as follows:

- We have meticulously compiled and standardized a comprehensive dataset from Scopus and OpenAlex, creating a high-quality, extensive corpus of DSM literature that underpins our analysis, and we commit to making the original literature data and embeddings open access to foster further research and replication studies in the field.

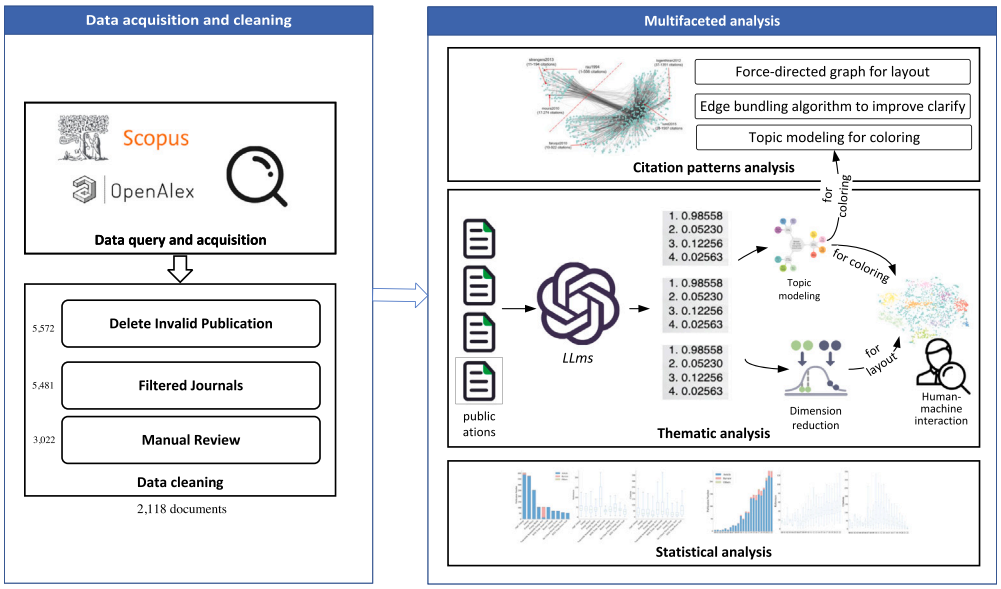

Fig. 1. Overview of our approach.

- We have introduced an innovative approach to semantic analysis in the Demand Side Management (DSM) domain by employing Large Language Models (LLMs), which significantly enhances the accuracy and depth of topical insights gleaned from the literature.
- We have conducted a comprehensive bibliometric and citation network analysis, which has allowed us to uncover the intricate patterns of influence and collaboration within the DSM research community, charting the field's intellectual trajectory.
- We have established a scalable and reproducible research framework that not only serves the DSM community but also provides a methodological blueprint that can be adapted to other scientific disciplines for robust literature analysis and trend mapping.

The remainder of this paper is structured as follows. Section 2 describes the overall methodology. Section 3,4,5 presents the statistical analysis, thematic overview and in-depth analysis results, and citation patterns across thematic categories. Section 7 presents bibliometric analysis platform. Section 8 concludes the paper and presents future work.

2. Methodology

2.1. Overview of our approach

In the following section, we delineate the methodological framework adopted to offer an exhaustive analysis of research trends in the domain of DSM, as depicted in Fig. 1. This framework outlines a structured process that guides our examination of the extensive dataset, enabling us to systematically uncover patterns, themes, and influences within the DSM research landscape. Our methodology serves as a blueprint for navigating the complexities of data processing, semantic exploration, and citation analysis, ultimately contributing to an informed and nuanced understanding of the field's scientific evolution.

Our approach to mapping the scientific research evolution within the large dataset of DSM publications is meticulously designed to provide a comprehensive understanding of the field. We begin with data acquisition and cleaning, ensuring a robust foundation by extracting accurate and relevant information. This step is crucial because it guarantees the integrity of the data, which underpins the validity of subsequent analyses. Next, we employ state-of-the-art Language Models (LLMs) and topic modeling techniques, such as GPT and BERTopic, to perform semantic analysis of the abstracts. This phase allows us to discern the thematic structures and conceptual frameworks that define the DSM research landscape, unveiling the intricate patterns and relationships within the literature. Lastly, we delve into citation network analysis to trace the influence and impact of scientific contributions over time. By constructing and scrutinizing these networks, we ascertain the pivotal works and emerging trends, offering a dynamic and interconnected view of the field's progression. Together, these steps form a robust methodology that is both sequential and interrelated, ensuring that we not only identify but also understand the evolution of research within the DSM domain.

As shown in Fig. 1, we selected Scopus and OpenAlex as our initial data sources for DSM-related publications due to their extensive coverage and reliability. After excluding records with incomplete information, we performed a thorough data cleaning process, resulting in a curated and standardized dataset for our analysis. Further details on data acquisition and processing are provided in the Sections Section 2.2. Following data processing phase, we conducted quantitative statistical assessments of the collected literature based on conference categories and publication times, this step provided us with an overall distribution of DSM publications. Subsequently, leveraging a large language model, we applied embedding techniques to the DSM documents, mapping each publication to a fixed-dimensional vector. We then performed topic clustering on this vector set and executed dimensionality reduction to visually represent the distribution of different topics. Finally, we employed theme division, enabling a network for each theme, and visualization to analyze the literature and identify key topics and citation patterns.

Utilizing a systematic, database-driven approach for literature reviews markedly outperforms manual methods by enabling the analysis of vast datasets, ensuring reproducibility, and enhancing accuracy through uniform metadata. This technique streamlines the review process, uncovers complex trends, and establishes an objective, thorough framework for scholarly investigation.

2.2. Data acquisition and cleaning

As illustrated in Fig. 1, our methodological framework commenced with the procurement of DSM-related publications from Scopus and OpenAlex. The rationale behind selecting these databases lies in their comprehensive coverage and robust indexing of scholarly articles, which are pivotal for a thorough representation of the DSM research landscape. Scopus is renowned for its extensive peer-reviewed content,

while OpenAlex is celebrated for its open-access repository and wide-ranging inclusivity of academic works. To guarantee the integrity and consistency of our dataset, we rigorously filtered out publications that lacked essential information. Following this filtration, we embarked on a meticulous data cleaning process, which was essential to ensure the reliability of our subsequent analyses. This diligent curation effort yielded a refined and standardized dataset of DSM publications, optimized for in-depth trend analysis.

We utilized Scopus to retrieve rich metadata for publications related to demand-side management (DSM) in energy, including titles, authors, abstracts, keywords, references, citations, and the year of publication. Two specific searches were conducted: one using the terms `demand-side AND management` with `energy`, and the other combining `demand-side AND response` with `energy`. After de-duplicating the results based on DOIs, we identified 5,572 unique documents. Despite its comprehensive coverage, Scopus falls short in mapping the full citation network of the publications. To address this, we incorporated OpenAlex, an open-access platform that provides extensive citation data through its API, encompassing a wide range of publications from various sources. Through OpenAlex, we extracted the citation network for the papers initially identified in Scopus. Furthermore, while Scopus and OpenAlex form the core of our data collection strategy, we acknowledge that integrating additional databases such as IEEE xplore could enhance our analysis. Such integration would potentially expand our citation network and metadata pool, leading to an even more robust and interconnected research landscape. Our approach is flexible and scalable, allowing for the inclusion of other relevant academic databases to complement our primary sources.

We then performed several cleaning steps to ensure the validity and consistency of the data. Firstly, we removed publications with null values for abstract or reference, as these fields were critical to our analysis, and in this process, we released 391 documents. Next, we filtered journals in other areas and periodicals on the alert list, and the list of remained journals is shown in Appendix A.5. In this step, we removed a total of 2,859 publications. Finally, To retain only journal literature, we manually reviewed the source publication names of publications to exclude conference proceedings and book types, releasing 204 documents in this step. These meticulous cleaning steps, shown in Fig. 1, systematically reduced the initial 5,572 papers to 2,118. The resulting publications provided the basis for our subsequent bibliometric and network analyses and formed the core of our research methodology.

2.3. Enhanced literature classification through llm-driven semantic analysis

In tackling the challenge of organizing an extensive corpus of over 2000 academic papers, we introduce a methodologically robust classification system underpinned by the semantic analysis capabilities of large language models (LLMs). Our approach is not merely an exercise in categorization but a sophisticated synthesis of content that captures the intricate nuances of DSM research.

Embedding Generation: Initially, each publication undergoes a transformation into a vectorized representation via LLMs. This critical step leverages the extensive pre-training of models like GPT-3.5 [23] on diverse textual data, enabling the capture of nuanced semantic information within high-dimensional embeddings. The model ID used is "text-embedding-ada-002", and the classifier used is "cl100k_base". The ability of LLMs to produce such rich embeddings lies at the core of our methodology, providing a foundational layer for the subsequent unsupervised learning process.

Unsupervised Topic Modeling: With the publications represented as embeddings, we utilize BERTopic [24], an advanced unsupervised machine learning algorithm, to identify and label the main topic words from the papers. BERTopic operates on the principle of clustering semantically similar embeddings, allowing it to discern patterns and groupings within the data that represent different topics. This step is critical because it relies on the inherent structure of the data rather than predefined categories, enabling the discovery of emergent themes that accurately reflect the research landscape.

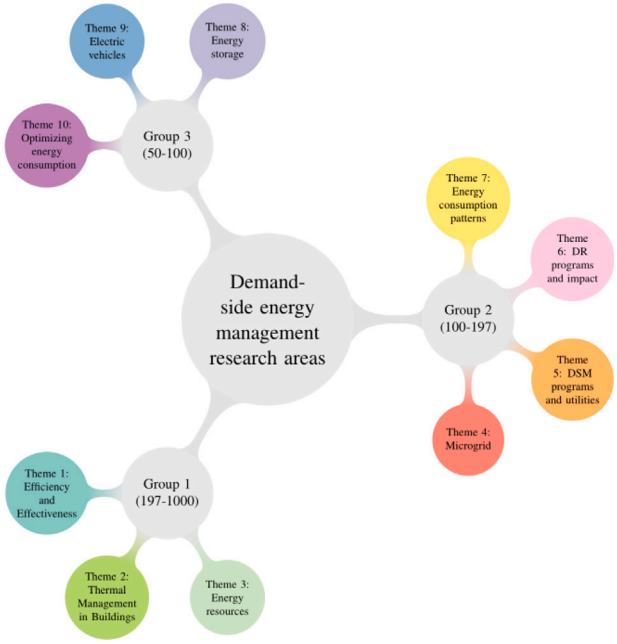

Fig. 2. Hierarchical classification of over 2000 demand-side energy management papers into three main research groups and related themes, with node coloring consistent across subsequent figures to represent thematic similarities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Theme Synthesis: Following the extraction of main topic words, we distill the essence of each cluster into a concise, impactful short sentence that captures the primary focus of the papers within—what we term as "themes". This synthesis requires a careful consideration of both the computational output from BERTopic and the scholarly insight to ensure that each theme is not only semantically grounded but also practically meaningful and accessible to researchers and practitioners alike.

Thematic Structure Integration: The final step involves integrating these themes into a hierarchical knowledge structure. Each paper is linked to a primary theme that aligns with its core contribution, while the multi-dimensional tags from the BERTopic model provide additional layers of understanding. This hierarchical integration facilitates a dual-purpose exploration: a high-level overview for quick thematic navigation and the ability to delve into specific topics for detailed research insights. The synthesized themes are visually represented in Fig. 2, showcasing the hierarchical classification of over 2000 DSM papers into distinct research groups and related themes.

To visually interpret the semantic space of DSM publications, we applied dimensionality reduction techniques UMAP and t-SNE to LLM-generated embeddings, color-coding the resulting two-dimensional scatter plots by BERTopic-derived topic categories. Fig. 3 illustrates that UMAP outperforms t-SNE in clarity of thematic clustering, suggesting its superior capability in preserving both local and global data structures. This visualization not only aids in understanding thematic distribution but also guides researchers in exploring the intricate landscape of DSM research.

In essence, our LLM-embedded topic discovery and thematic synthesis process is a powerful blend of cutting-edge computational techniques and scholarly curation. By mapping documents to embeddings via LLMs, employing BERTopic for unsupervised topic labeling, and summarizing thematic content with precision, we establish a robust and dynamic framework for organizing and understanding the extensive literature in the DSM field.

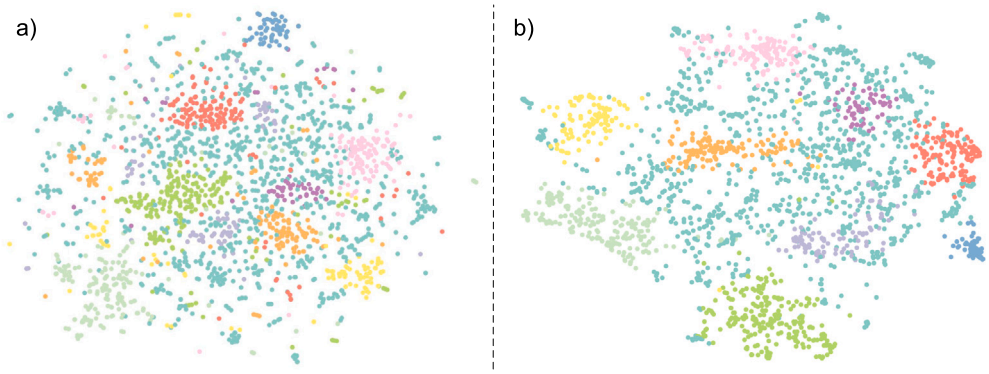

Fig. 3. Visualization of DSM literature embeddings, showcasing (a) the best result of t-SNE and (b) the best result of UMAP. Both methods are parameter-sensitive, and optimal clustering was achieved through fine-tuning. For t-SNE, parameters were set to $perplexity = 15$, $learning\_rate = 100$, and $init = \texttt{random}$. For UMAP, optimal settings were $n\_neighbors = 15$ and $min\_dist = 0.05$, better in balancing local and global structure in the reduced dimensional space. Node coloring is consistent across both charts, indicating thematic similarities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.4. Tracing citation patterns to illuminate the research landscape through network analytics

Our investigation into the citation patterns within the domain of DSM serves as the third pillar of our analytical approach. The primary goal is not to pinpoint the most influential and impactful papers – a notion that oversimplifies the intricate dynamics of scientific influence – but rather to unravel the complex web of citation relationships that underpin the field. This intricate analysis sheds light on the broader scholarly discourse and the interconnectivity of research contributions over time.

To this end, we leverage citation data from OpenAlex to construct comprehensive citation networks for each topic of interest. These networks, visualized as graphs where nodes represent publications and edges denote citations, provide a structural map of how knowledge in the DSM field is interconnected. Through this mapping, we discern patterns of citation that reflect the field's evolving landscape, including foundational works, key contributors, and emergent trends.

To enhance the visualization of these networks, we employ two advanced graph visualization techniques: force-directed graph computation [25] and edge-bundling algorithms [26]. The former assigns node positions based on simulated physical forces, creating a layout where connected works cluster naturally, thereby revealing the latent structure of the research field. The latter technique simplifies the graph by merging and streamlining edges with similar trajectories, improving the overall legibility and emphasizing principal citation pathways.

Along with our citation network analysis, we also conducted a statistical examination of the networks, considering aspects such as publication years, journal frequencies, and average citation counts across topics. This multifaceted analysis enables us to trace the temporal distribution of research efforts, gauge the relative prominence of journals within the discourse, and assess the ripple effect of citations throughout the academic community. Section 5 will detail the insights gleaned from our exploration of citation patterns, offering a dynamic, interconnected perspective on the progression of the DSM research landscape.

3. Statistical analysis the literature dataset

Our analysis rigorously scrutinized the collated DSM literature data. We dissected the dataset by categorizing the literature types, assessing the citation counts, and evaluating the impact and reach of each category. Further, we distilled insights along the dimensions of publication journals, temporal trends, and institutional contributions. This multifaceted statistical examination furnishes a nuanced understanding of the domain's research landscape, pinpointing leading journals, tracking the field's progression, and mapping the global research institution distribution. This section equips a holistic perspective on the literature, laying a robust groundwork for subsequent inquiry and exploration.

Fig. 4 details the counts of different publication types along with their citation and reference statistics. Articles lead with 1,946 entries, reviews at 154, conference articles with 10, and other forms, including editorials and letters, totaling 18. Reviews, with their extensive coverage, not only reference more sources but also receive more citations, as evidenced by their higher citation averages and upper limits.

Fig. 5 shows the top 10 journals that publish the most literature on the topic. *Applied Energy* is the leading journal with 387 papers, accounting for 18.27% of the total literature. Among the selected journals, *Renewable and Sustainable Energy Reviews* has a higher proportion of Reviews, which results in a higher mean number of references and citations. On the other hand, *IEEE Transactions on Smart Grid* only publishes Articles, but it is one of the most prestigious journals in the smart grid field, with an impressive citation score.

Fig. 6 shows the trends of literature quantity and quality over time. The total number of literature has been increasing steadily, with a sharp increase in 2014. The number of references fluctuated significantly before 2010, but then stabilized at an average of around 40. Similarly, the number of citations varied considerably during the first five years, but then showed a steady increase, reaching the highest points in 2010 and 2012 before declining consistently after 2012.

Fig. 7 presents the geographical distribution of institutions associated with the published articles, with a focus on Europe, North America, and East Asia. Denmark, North China, and the UK stand out as regions with the highest densities of published articles.

Appendix A.1 shows details of the number of publications by institution. Aalborg University from Denmark is at the forefront with 33 articles, closely followed by North China Electric Power University with 31 articles. From the UK, Oxford University and Imperial College London make significant contributions, underscoring the research strength and expertise of these regions in the field of Demand Side Management (DSM). Appendices A.2 and A.3 provide a deeper look into the top 10 authors, ranked by both their publication volume and citation counts, highlighting their individual contributions and areas of research. The collected affiliation data stem from the most recent articles of the authors. Notably, Shengwei Wang at Hong Kong Polytechnic University leads in the number of published articles. His wide-ranging research interests include building automation systems, smart grids, uncertainty analysis, and pivotal technologies such as AI and IoT. In terms of average citations, Hamed Mohsenian-Rad stands out. His position as a Professor of Electrical Engineering at the University of California, Riverside, complements his research endeavors in power systems, with a particular focus on data analysis, monitoring, and optimization within smart grids. For detailed rankings and metrics, please refer to the relevant tables in the appendix.

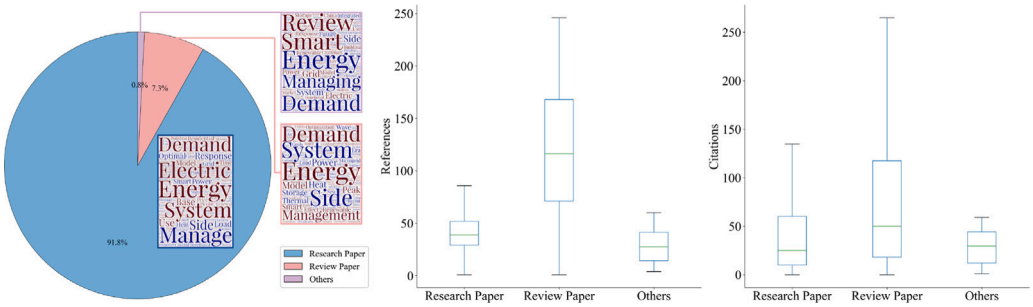

Fig. 4. Publication distribution according to different types, where "Others" include Short Communications, Editorial Comments, Letters to the Editor, and Technical Notes.

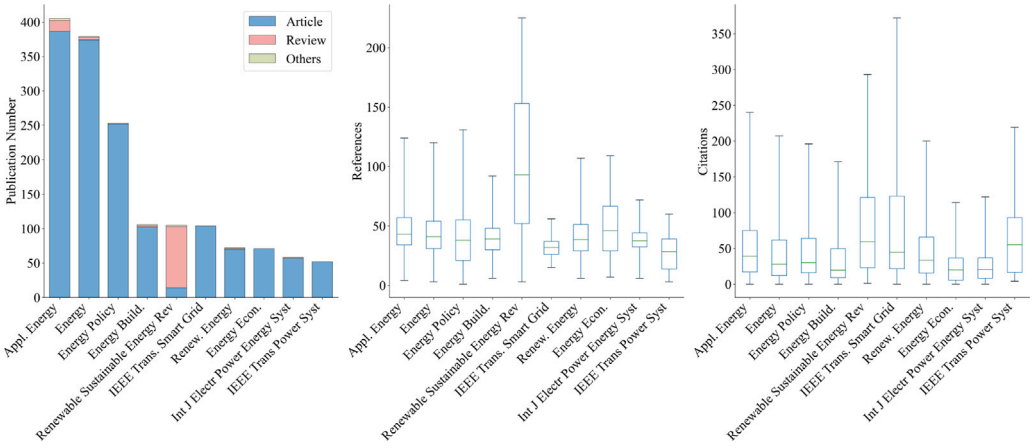

Fig. 5. Distribution of the top-10 journals based on overall output.

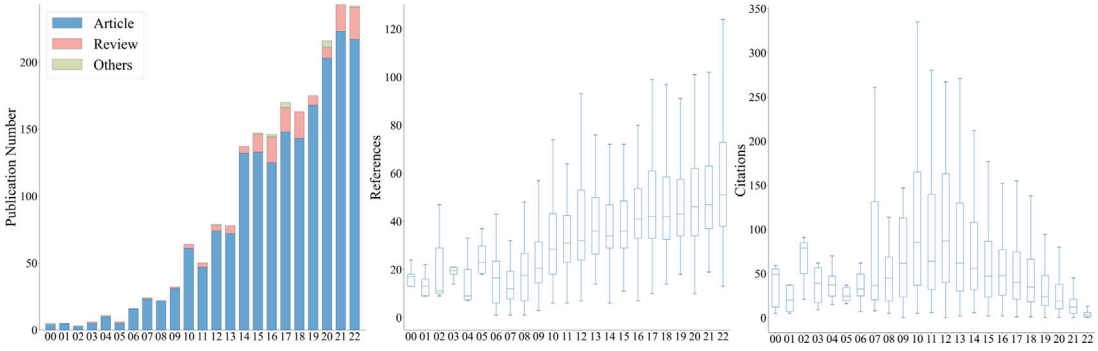

Fig. 6. Distribution of papers across publication year since 2000.

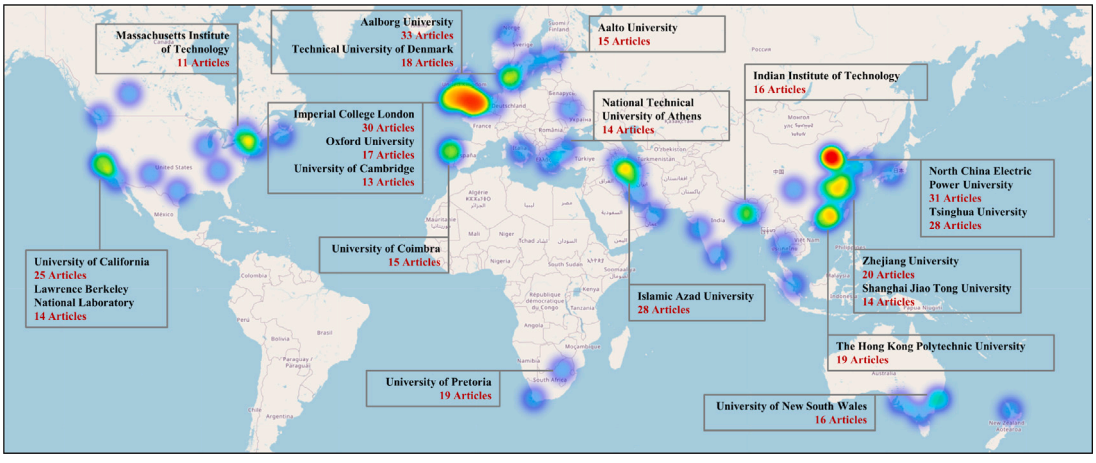

Fig. 7. Geographical distribution of institutions. Circle size indicates the number of publications by the institution.

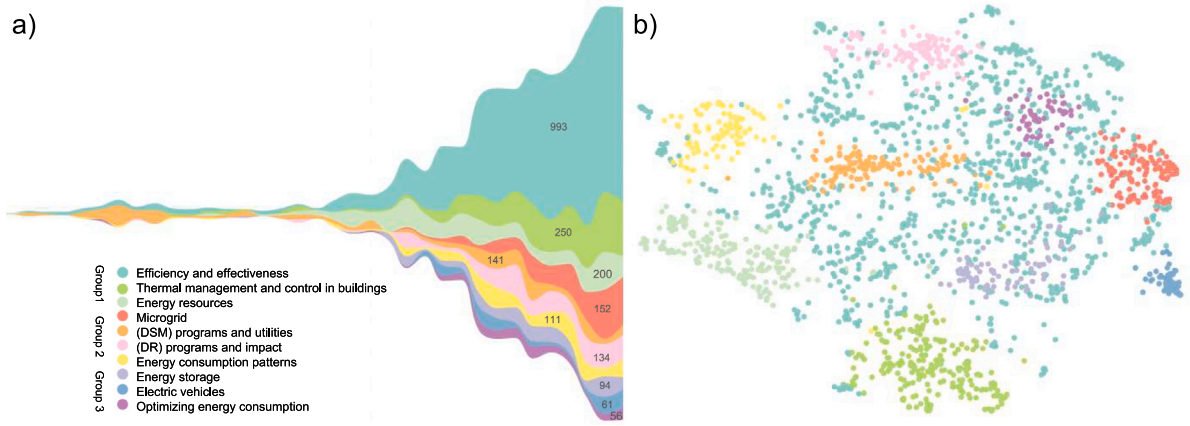

Fig. 8. Figure a has the year of publication on the horizontal axis and the number of publications per theme on the vertical axis. The width of each river indicates the popularity of each theme in a given year. Figure b shows the result of UMAP on a 2D plane.

4. Thematic overview and in-depth analysis results

We extract topical keywords from the extensive corpus of these academic papers. Through this method, we aggregate distinct *topics* into overarching *themes*, thereby achieving a hierarchical taxonomy of the document collection. We have further classified the themes into three *groups* based on the quantity of associated publications. Specifically, Group 1 encompasses themes with a range of 197 to 1000 papers, Group 2 includes themes with 100 to 197 papers, and Group 3 comprises themes with fewer than 100 papers. This structured classification facilitates nuanced understanding and organization of the scholarly materials. We commence by presenting a broad overview of the identified themes and their corresponding topics, providing a macroscopic perspective of the subject matter. Subsequently, we delve into the specifics of each theme, discussing the relevant papers in detail to furnish a comprehensive understanding of the thematic categorizations within the corpus. In detail,

Group1 (accounting for 65.6% of total papers): Theme 1 concerns to improve the **efficiency and effectiveness** of power systems through innovative demand-side management and optimization strategies (950 papers). It appears to focus on the management and distribution of electrical power, with significant terms such as power, system, electricity, and management being mentioned. The topic also references smart and proposed systems, indicating a potential discussion of modern and innovative approaches to power management. Furthermore, the issue includes load and model elements, suggesting a possible analysis of power usage and system modeling. Theme 2 is centered around the **thermal management and control in buildings** (243 papers). It seems to focus on the intersection of energy management and building design, with an emphasis on thermal management and control as key factors in achieving sustainability and energy efficiency goals. The key terms include heat, thermal, heating, building, storage, and flexibility. Theme 3 focuses on the consumption and supply of **energy resources** particularly electricity and gas, and its impact on economic growth, emissions, and prices (197 papers). The key terms include consumption, electricity, gas, emissions, China, and economic. China seems to be a relevant country in this context, possibly due to its large population and energy demands. The topic suggests an interest in exploring the relationship between energy consumption, economic development, and environmental sustainability.

Group 2 (account for 24.6% of total papers): Theme 4 related to **microgrid** management and proposed systems that aim to reduce the cost of power and manage load more efficiently (142 papers). The topic appears to be about optimizing the management of microgrids to improve their efficiency and reduce costs. The key terms include microgrid, mg, management, cost, and load. Theme 5 concerns demand-side management **(DSM) programs and utilities**, focusing on improving efficiency and reducing costs (137 papers). Key terms include DSM, programs, utility, utilities, electricity, efficiency, and cost. Theme 6 concerns demand response **(DR) programs and their impact** on the electricity market (133 papers). These programs aim to manage the load on the power grid by incentivizing customers to reduce their electricity usage during peak demand periods, which can help stabilize the electricity market and lower prices. The key terms include dr, response, programs, market, and price. The topic focus on the technical aspects of these programs, such as how they are implemented in the system, as well as their impact on customers and the electricity market. Theme 7 is related to analyzing and modeling **energy consumption patterns** using data (108 papers). Key terms include data, consumption, load, model, profiles, and forecasting. The topic appears to be interested in using data analysis techniques to better understand and predict electricity consumption and load, with the ultimate goal of improving the efficiency and sustainability of energy usage.

Group3 (accounting for 9.8% of total papers): Theme 8 relates to the importance of **energy storage** in renewable energy systems, with an emphasis on various technologies such as batteries, hydrogen, and photovoltaic systems (92 papers). Key terms include storage, PV, system, battery, power, renewable, wind, solar, hydrogen, and photovoltaic. Theme 9 concerns **electric vehicles** and their charging infrastructure (61 papers). The key terms include charging, electric, vehicles, EV, vehicle, and station. Theme 10 is related to **optimizing energy consumption** and cost management through a distributed scheduling algorithm (55 papers). Key terms include users, proposed, algorithm, consumption, and cost. The topic seems to be focused on optimizing energy consumption and cost management through a distributed scheduling algorithm.

Thematic insights were extracted using the BERTopic algorithm, with themes delineated by key topic words (refer to Section 2.3). A theme river diagram (see Fig. 8.a) visualizes the shifting research interests over time, plotting publication years against thematic publication volumes. The diagram's fluctuating river widths represent each theme's varying prominence. Notably, Group 1 themes exhibit sustained growth in scholarly attention. Theme 1, accounting for nearly half of the post-2008 literature, focuses on enhancing power system efficiency via demand-side management—a cornerstone of the field. Since 2010, Theme 4 has explored microgrid management optimization, aiming at performance gains and cost reductions. Meanwhile, Theme 9, surfacing in 2011, signifies the escalating engagement with electric vehicles and their charging frameworks, likely spurred by the rise of new energy vehicles.

5. Citation patterns across thematic categories

In our study, we analyze the DSM literature's citation network using a top-down methodology. We begin with a collective analysis

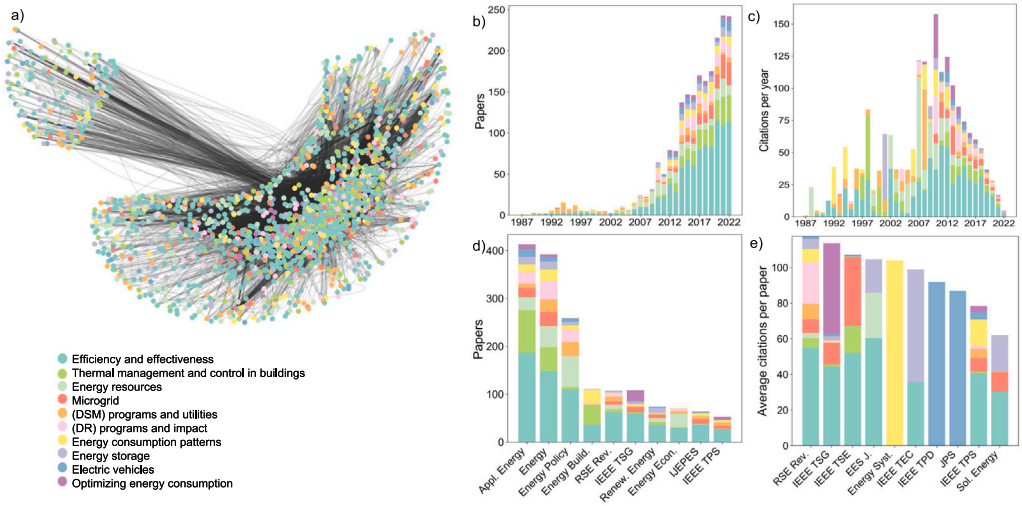

Fig. 9. The citation network of the literature.

of all themes and then dissect each theme individually, revealing their evolution and interconnections. The citation network is visualized through a force-directed graph, leveraging edge bundling for clarity, and is generated with NetworkX [27] in Python and d3.js [28] for the graphical output.

Fig. 9(a) illustrates the citation network for the entire literature corpus. Each node in this network represents an article, with each edge indicating a citation relationship between the article. From this global perspective, we discern several key trends and changes in the literature. The citation network is divided into two distinct parts. The literature on the right has a much closer citation relationship, and the literature on the left mostly assumes the role of being cited.

Fig. 9(b) indicates two distinct spikes in publications: the first from 2007 to 2013 and the second from 2019 to 2022. The initial surge may reflect technological advancements and policy shifts that spurred research interest during that period. The second increase aligns with the global push for Sustainable Development Goals [29], carbon neutrality, and Net zero emissions [30], suggesting a direct influence of these initiatives on research activity.

The bar chart in Fig. 9(c) shows that the average number of citations peaked in 2010, observing that Theme 10 and Theme 6 accounted for a large proportion, so we analyzed articles from these themes in 2010. The contribution of theme 10 is mainly from literature [31] has a high number of citations. The articles in Theme 6 all have a high number of citations. Such as [32]presents a demand response model that considers interruptible/curtailable loads and capacity market programs, and [33]investigates demand response experiences in European countries and at the EU level to understand what facilitates or hinders the development of demand response in Europe. Their contents are all related to demand side response, indicating that articles on demand side response have a high impact in this period.

Fig. 9(d) reveals that Applied Energy, Energy, Energy Policy, and Energy and Buildings are among the journals with the highest number of publications, suggesting their importance in disseminating research findings in this field.

Finally, as shown in Fig. 9(e), Renewable and Sustainable Energy Reviews has the highest average number of citations per paper, indicating its significant impact and influence in the field of energy consumption and management.

Next, we will conduct a targeted citation network and statistical data analysis for each theme. Statistical data analyses were conducted from both a temporal and journal perspective, with statistical indicators of the number of publications and the average number of citations. We aim to provide a concise and insightful statistical exploration of each theme.

5.1. Theme 1: novel demand-side management techniques for enhancing power system efficiency and effectiveness

Theme 1 delves into innovative management and optimization techniques to bolster the efficiency and effectiveness of power systems. Power systems are complex networks that deliver electricity from generation sources to end-users, ensuring adequate supply, quality, and security of service. Power systems face various challenges, such as increasing demand, environmental constraints, aging infrastructure, and integration of renewable energy sources. Therefore, novel techniques are needed to enhance the performance and sustainability of power systems in the face of these challenges.

This theme encompasses a multitude of research areas that address the challenges and opportunities of power system management and optimization in different contexts and applications. Among others, [34] provides an insightful introduction to Smart Grid and its associated technologies, focusing on how it can revolutionize the traditional power system by enabling bidirectional communication, automation, and intelligence. [35] discusses the sustainable design, integration, and operation of energy systems, emphasizing the crucial role of renewable energy resources and the necessity for sustainable operations in the current energy landscape. [36] offers a comprehensive review of transition pathways towards a more electric, digitalized, and decarbonized energy system, underlining the importance of strategic decisions and policy support in achieving this transformation. [37] presents a two-stage dynamic management strategy in energy communities, highlighting the potential of community-based approaches in managing energy resources and facilitating energy transactions among prosumers. [38] explores the flexibility requirement for large-scale renewable integration, underscoring the challenges posed by variable renewable energy sources and the role of flexible resources in addressing these challenges. [39] discusses industrial flexibility as a form of demand-side response, while [40] focuses on the strategic design optimization of multi-energy systems, both emphasizing the need for flexible and responsive strategies in managing energy demand and supply. Lastly, [41] investigates the role of demand response in residential electricity distribution, demonstrating its potential in addressing major concerns such as energy conservation and peak demand management. These studies collectively provide a comprehensive understanding of the novel techniques for enhancing power system efficiency and their practical implications. They also provide valuable insights for designing and implementing effective power system management and optimization strategies in various scenarios.

The citation network depicted in Fig. 10(a) represents the relevance of various papers within this theme. The dense cluster on the right

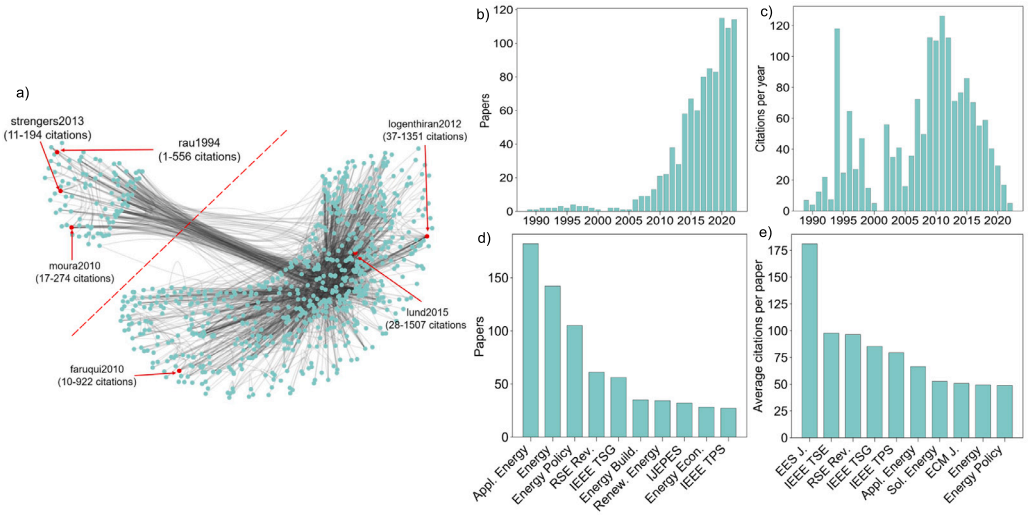

Fig. 10. The citation network and statistical analysis of Theme 1. It includes: (a) main view: citation network diagram for Theme 1; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

side of the network consists of highly cited papers, indicative of their significant influence within this theme. Prominent among these are Lund, Peter D.'s comprehensive review on methods and technologies for managing large-scale variable renewable electricity schemes [42], and Logenthiran T.'s innovative research on a novel demand side management strategy that leverages load shifting techniques for future smart grids [43]. In contrast, the nodes on the network's left side, which have a low out-degree, are predominantly theoretical or conceptual papers. These papers, despite not citing many others within the network, have been influential in their own right. For instance, Strengers, Yolande's paper, which reinterprets the problem of peak electricity demand through the lens of social practice theories and proposes innovative ways to engage consumers in demand response programs [44].

The annual publication trend, as portrayed in Fig. 10(b), demonstrates a seven-fold increase in the number of articles published since 2005. Fig. 10(c) reveals two notable peaks in citations around 1995 and 2012. Despite the limited number of publications in the early years, their impact has been considerable. For example, Rau, Narayan S.'s 1994 paper, which proposes an optimal method for locating distributed resources in a meshed network, has been widely cited in subsequent studies [45]. Similarly, Faruqui, Ahmad's investigation of in-home displays' effectiveness in shaping consumer energy consumption behavior has significantly influenced later research [46]. Figs. 10(d) and (e) present the top ten journals within Theme 1, ranked by the number and average citations of their publications, respectively.

5.2. Theme 2: thermal management and control

Theme 2 addresses the issue of thermal management and control in buildings, which is a crucial aspect of energy efficiency and comfort. Thermal management and control refers to the process of regulating the indoor temperature and humidity levels in buildings, as well as the heat transfer between buildings and their surroundings. Thermal management and control can help reduce energy consumption and greenhouse gas emissions, as well as improve occupant health and well-being. However, thermal management and control also poses various challenges, such as complex dynamics, uncertainty, variability, and nonlinearity. This theme explores the recent literature on thermal management and control from a citation network perspective, focusing on the modeling, analysis, optimization, and implementation of thermal systems in buildings.

This theme encompasses a variety of research topics that address the challenges and opportunities of thermal management and control in different contexts and applications. [47] demonstrates the role of a resilient strategy for optimal demand response in online voltage security assessment, providing a new perspective on managing thermal systems. [48], on the other hand, presents an automated stochastic model for evaluating the impact of various shades of gray on the energy flexibility in buildings, highlighting the significance of thermal storage and control strategies. [49,50] delve into the use of predictive control for thermal management. The former emphasizes the real-time state of charge estimation in thermal grids and district heating, while the latter focuses on dynamic indoor comfort management in buildings. [51,52] explore the role of thermal energy storage in managing energy demand. [51] presents energy flexibility curves to characterize the demand response potential of Belgian residential buildings, while [52] discusses the electrification of residential heating, cooling, and hot water supply in the context of emission reduction goals. The study by [53] aims to minimize operational costs through a dynamic, data-driven optimization framework, while [54] explores the economic benefits of thermal storage capacity in district heating pipelines to improve cost-efficiency. Lastly, [55,56] focus on the technological aspects of thermal management. [55] discusses energy flexibility in buildings through smart demand-side management, while [56] presents heat consumption scenarios in rural residential buildings, underscoring the impact of advanced control strategies on energy consumption. These studies collectively provide a comprehensive understanding of thermal management and control, offering valuable insights for its practical application.

The citation network shown in Fig. 11a, is clearly separated from Theme 1 and the overall network. The network exhibits a dense cluster of citations, indicating a high level of interconnection among the articles. A major example is Arteconi, A.'s work in 2012, which provides a comprehensive review of the current applications of thermal storage for demand-side management [57]. This article has received the most citations in the network and has influenced many subsequent studies. The most cited research paper is Xue, Xue's paper in 2014, which develops a fast chiller power demand response control strategy for commercial buildings [58]. Fig. 11(b) illustrates the annual distribution of publications in Theme 2. Until 2010, the number of articles in this theme was relatively low. However, despite the lower publication count, the average citation count for these articles is notably higher, especially in 1998 (As shown in Fig. 11(c)). This indicates that the research conducted

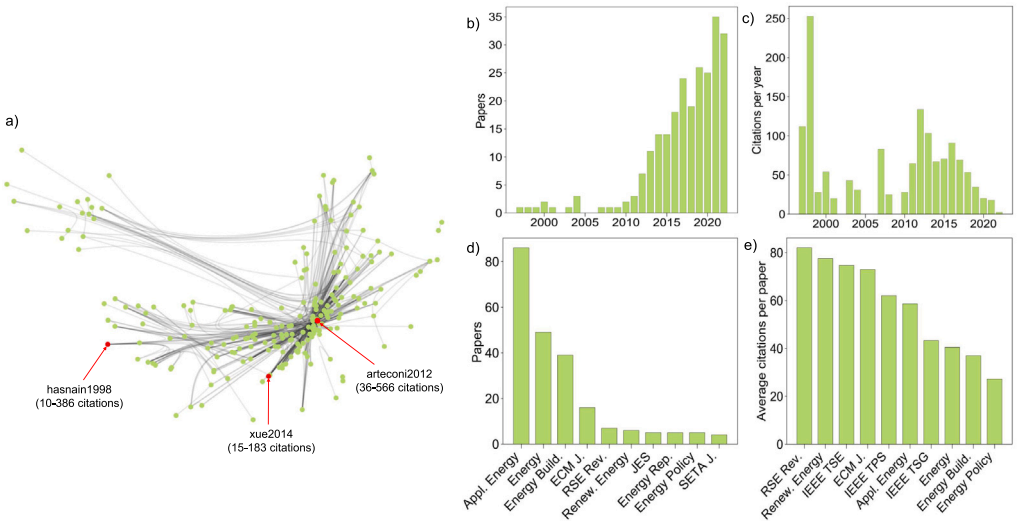

Fig. 11. The citation network and statistical analysis of Theme 2. It includes: (a) main view: citation network diagram for Theme 2; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

during that period in Theme 2 had a impact and attracted recognition from the academic community. The most cited one is by Hasnain, S.M. at 1998 discusses the advantages and disadvantages of two commonly used thermal energy storage technologies, chilled water and ice storage, for off-peak air conditioning applications [59]. Fig. 11(d) shows the main journals, which are mostly specialized journals like *Applied Energy*, *Energy*, and *Energy and Buildings*. Fig. 11(e) compares the top ten journals for Theme 2 by average citation count. The top three journals with the average number of citations are Renewable and Sustainable Energy Reviews, Renewable Energy, and IEEE Transactions on Smart Grid. Though these journals have a low number of publications, they have also played a significant role in the development of the theme. Such as [60] explores the application areas and control methods of heat pumps in smart grids. And [61] demonstrates that actively controlled residential heat pumps can reduce peak power demand in buildings, thereby reducing the additional investment costs of grid reinforcement.

5.3. Theme 3: consumption and supply of energy resources

Energy consumption and supply are crucial factors that affect the economic and environmental well-being of societies. However, these factors are also influenced by various challenges such as climate change, population growth, urbanization, and industrialization. Theme 3 aims to explore the complex and dynamic aspects of energy consumption and supply across various forms of energy, including electricity, gas, renewable, fossil, and nuclear energy. It also examines how these aspects impact economic growth, emissions, and prices.

This theme covers a broad range of research topics that address the challenges and opportunities of consumption and supply of energy resources in different contexts and applications. Some of the research topics are: (1) Energy consumption forecasting: Accurate forecasting techniques are essential for managing energy resources efficiently and effectively. [62,63] propose novel methods based on artificial neural networks and fuzzy logic to predict electricity and gas consumption at different scales, such as households, buildings, and regions. (2) Renewable energy integration: Renewable energy sources offer a clean and sustainable alternative to fossil fuels, but they also pose technical and economic challenges for energy systems. [64] analyzes the feasibility of renewable energy systems in various regions and sectors, such as Africa, Asia, Europe, and agriculture. [65] optimizes the management of energy supply chain networks under uncertainty, considering factors such as demand variability, supply disruptions, and carbon emissions. (3) Smart grid technologies: Smart grids are modernized electricity networks that use advanced technologies to enhance grid reliability, efficiency, and flexibility. [66] investigates the benefits and challenges of smart grid technologies in improving power quality, reducing losses, and enabling demand response programs. [67] designs and operates optimal energy storage systems in microgrids, taking into account technical constraints, operational costs, and market prices. (4) Policy instruments: Policy instruments are regulatory frameworks that influence the behavior and outcomes of energy markets. [68] examines the effects of different policy instruments on energy consumption patterns, prices, and emissions. It evaluates the impact of carbon taxes, subsidies, standards, and trade agreements on various forms of energy, such as electricity, gas, coal, oil, and biomass. [69] discusses the challenges associated with implementing policy instruments in developing countries, where institutional capacity and data availability are often limited. (5) Economic models: Economic models are analytical tools that help understand the dynamics and interactions of different agents in the energy market. [70] estimates the price elasticity of electricity demand and supply using econometric models. It analyzes how price changes affect the quantity demanded and supplied of electricity in different regions and sectors. [71] analyzes the strategic behavior of electricity producers and consumers using game-theoretic models. It studies how producers compete in oligopolistic markets and how consumers respond to dynamic pricing schemes.

These studies collectively contribute to a comprehensive understanding of the factors influencing the consumption and supply of energy resources. They also provide valuable insights for designing and implementing effective energy management strategies and policies in various scenarios.

The citation network depicted in Fig. 12(a) shows a sparse network and no apparent citation core. Fig. 12(b) illustrates the late development of the topic, with the number of articles gradually increasing from the early 2000s. Notable peaks in the publication count are observed in 2010 and 2021, suggesting significant growth and interest in the theme during those periods. Fig. 12(c) depicts that the average citation count in 2007 exceeds the other years. This suggests that some publications from 2007 have played a crucial role in influencing and driving the research direction within Theme 3. The most cited papers in 2007 are Lund, Henrik's article explores the role of renewable energy (wind, solar, wave, and biomass) in sustainable development strategies [72], and Chen, Sheng-Tung's article explores the relationship between GDP and electricity consumption in developing Asian countries, emphasizing

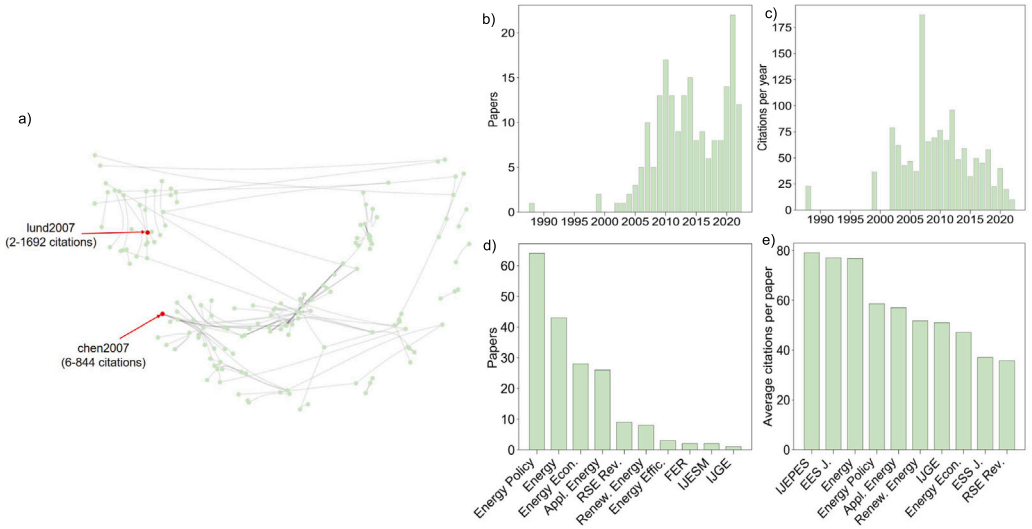

Fig. 12. The citation network and statistical analysis of Theme 3. It includes: (a) main view: citation network diagram for Theme 3; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

the importance of ensuring sufficient electricity supply for fostering economic development [73]. Fig. 12(d) and Fig. 12(e) provide insights into the journal information statistics. It is observed that some journals appear more frequently in Theme 3 compared to the previous thematic analyses such as *Energy and Environmental Science* and *International Journal of Green Energy*. This suggests a shift towards greater focus on environmental sustainability within the context of energy and economic development, as reflected in the choice of these journals for publishing related research.

5.4. Theme 4: microgrid management

Microgrids are small-scale power systems that can operate independently or in coordination with the main grid. They are composed of distributed energy resources (DERs), such as renewable generation, energy storage, and controllable loads. Microgrid management involves the optimal operation and control of these DERs to achieve various objectives, such as minimizing cost, maximizing reliability, enhancing resilience, and reducing emissions. This theme specializes in the management of microgrids and their interaction with the main grid.

This theme covers a wide array of research areas that address the challenges and opportunities of microgrid management in different contexts and applications. Some of the research areas are: (1) Energy management in microgrids: Energy management in microgrids focuses on how to coordinate and optimize the operation of DERs in microgrids. [74,75] propose novel methods and models to minimize the total cost and emissions of microgrids while ensuring power balance and quality. They consider factors such as renewable generation, energy storage, load demand, grid conditions, and market prices. (2) Intelligent systems in microgrid management: Intelligent systems in microgrid management applies artificial intelligence and machine learning techniques to enhance the performance and efficiency of microgrids. [76,77] develop intelligent algorithms and controllers to optimize the scheduling and operation of microgrids under uncertainty and dynamic conditions. They use reinforcement learning to balance supply and demand, manage DERs, and participate in electricity markets. (3) Stability and reliability in microgrid management: Stability and reliability in microgrid management aims to improve the resilience of microgrids against disturbances and faults. [78] designs adaptive and distributed controllers to maintain the stability and security of microgrids under various scenarios. They use robust control strategies to cope with uncertainties, nonlinearities, and communication delays. (4) Economic aspects of microgrid management: Economic aspects of microgrid management examines the effects of different pricing schemes and regulatory frameworks on microgrid operation and cost. [79,80] analyze the trade-offs between economic benefits and technical constraints in microgrid operation. They propose optimal bidding strategies for microgrid participation in electricity markets. They also evaluate the impact of regulatory frameworks on microgrid operation and cost. (5) Operational aspects of microgrid management: Operational aspects of microgrid management focuses on how to efficiently schedule and manage the load demand and supply in microgrids. [81,82] develop optimal load scheduling methods for microgrids that consider various factors, such as user preferences, load profiles, renewable generation, energy storage, and grid conditions. They also investigate the benefits of demand response programs for microgrids.

These studies collectively contribute to a deeper understanding of microgrid management and its challenges, providing valuable insights for the development of more efficient and reliable microgrids. Fig. 13 illustrates the different aspects of this theme.

Fig. 13(a) shows the citation network for Theme 4. We have chosen to highlight the most cited article within the network: Lokeshgupta B.'s publication in 2018 proposes a combined model to investigate the benefits of demand side management on generation side [83], Tabar V.S.'s publication in 2017 presents a model for portable renewable energy sources and explores energy management and dispatch within microgrids [84].

Fig. 13(b) shows the publication count of articles within Theme 4 over time. We can see that Theme 4 emerged around 2010 and has since experienced a steady increase in the number of articles. This suggests that research on microgrid management and related systems is still in a developmental stage and has significant potential for further growth and exploration. The rising publication count also reflects the growing interest and attention that this topic has received from the research community. On the other hand, Fig. 13(c) presents the average number of citations for articles within Theme 4 over time. Interestingly, the trend is opposite to the publication count. The average number of citations indicates that the early articles within this theme have made substantial contributions and laid the groundwork for the subsequent development of the topic. This implies that the early research within Theme 4 has had a notable impact and continues to be influential in the field. Such as Palma-Behnke R.'s article in 2013 proposed a novel energy management system and introduces coherent forecast information and an economic comparison framework [85]. Figs. 13(d)

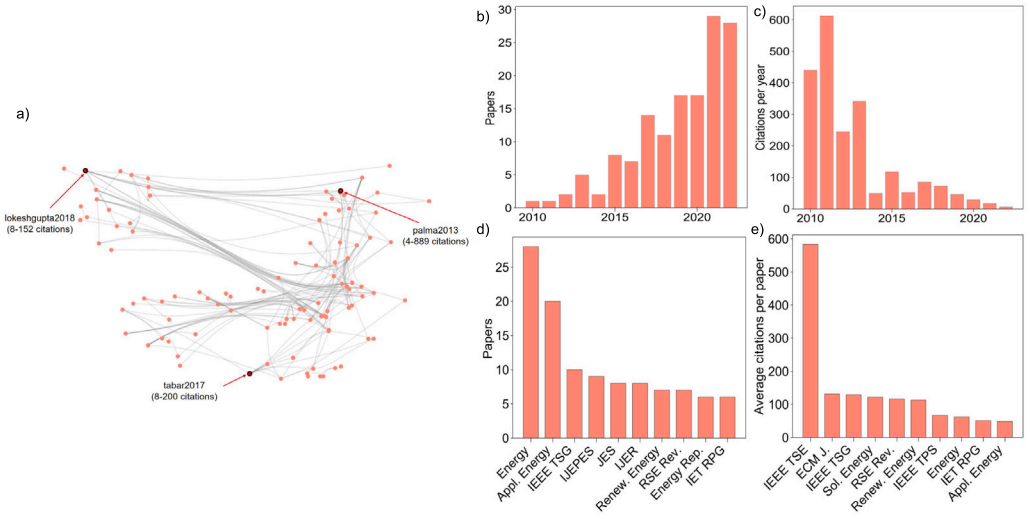

Fig. 13. The citation network and statistical analysis of Theme 4. It includes: (a) main view: citation network diagram for Theme 4; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

and 13(e) display the distribution of articles across journals within Theme 4. *Energy* and *Applied Energy* journals are the primary outlets for publishing research on this topic, indicating their prominence and specialization in microgrid management and related systems. These journals account for a significant proportion of articles within the theme, highlighting their importance as platforms for disseminating research findings. Moreover, *IEEE Transactions on Sustainable Energy* performs well in terms of the average number of citations. This is mainly due to [86]has a high number of citations. It proposes a novel distributed economic dispatch approach to power scheduling to solve the stochastic availability problem of renewable energy sources. It verifies the effectiveness of the method through numerical results.

5.5. Theme 5: demand-side management programs and utilities

Theme 5 deals with the topic of demand-side management programs and utilities, which are strategies and actions that aim to improve the efficiency and reduce the costs of energy consumption and supply. Demand-side management programs and utilities can involve various measures, such as using smart devices, dynamic pricing, renewable energy sources, and energy audits. They can also provide benefits, such as enhancing grid stability, reducing peak demand, lowering emissions, and saving money. This theme covers a broad range of research topics that address the challenges and opportunities of demand-side management in different contexts and applications.

One of the main research topics in this theme is residential demand response, which focuses on how to encourage and enable households to adjust their energy consumption according to the grid conditions and price signals. For example, [87] explored the use of advanced control strategies for smart appliances in residential demand response, while [88] highlighted the role of consumer behavior and preferences in demand response participation. Another research topic is the integration of renewable energy sources in demand-side management, which aims to increase the share of clean and sustainable energy in the power system. For example, [89,90] emphasized the role of utilities in facilitating this integration, proposing novel methods and models for optimal coordination of renewable generation and demand response. A third research topic is the economic aspects of demand-side management, which examines the effects of different pricing schemes and incentives on energy consumption and cost. For example, [91,92] addressed the economic aspects of demand-side management, discussing the impact of time-of-use pricing on consumer behavior and the role of utilities in promoting energy efficiency. These studies collectively contribute to the understanding of demand-side management programs and their impact on utilities and energy consumption. They also provide valuable insights for designing and implementing effective demand-side management strategies in various scenarios.

As shown in Fig. 14a, the citation network of Theme 5 (demand-side management programs and utilities, focusing on improving efficiency and reducing costs) resembles that of Theme 4. Both networks have nodes that cluster around highly cited articles. Themes 5 and 4 are closely related, as they deal with demand-side management projects and microgrid management, respectively. For example, Palma-Behnke R.'s 2013 article in Theme 4 builds on research about demand-side management [85]. The most cited papers in the network are: Warren, Peter's 2014 article, which provides a comprehensive definition of demand-side management and addresses the gap in demand-side management policy [22], and Paulus, Moritz's 2011 publication, which extends the existing European electricity market model and makes long-term projections for market prices, dispatch and investments in the electricity markets [93].

In Fig. 14(b), we notice that Theme 5 has the highest number of articles around the years 1994 and 2017. These peaks indicate periods of high research activity and interest in the topic. It implies that research on demand-side management programs and utilities experienced significant growth and attention during those years. Fig. 14(c) highlights the most cited articles on average for Theme 5, with most of them published in 2008. This indicates that publications from 2008 have played a key role in shaping the subsequent development and understanding of the theme. These articles may have a significant impact on the topic. Such as Strbac, Goran's article in 2008 discusses the benefits and challenges of electricity demand-side management in the UK electricity system [94]. Looking at Fig. 14(d) and Fig. 14(e), we observe the distribution of articles across journals within Theme 5. *Energy Policy* and *Energy* journals emerge as the main outlets for publishing research on this topic, with a majority of articles appearing in these journals. This concentration of publications signifies the relevance and focus of these journals in the domain of demand-side management programs and utilities. Additionally, *Renewable and Sustainable Energy Reviews* is the journal with the highest average number of citations. This is because articles published in the journal are mainly of the review type and are cited more frequently.

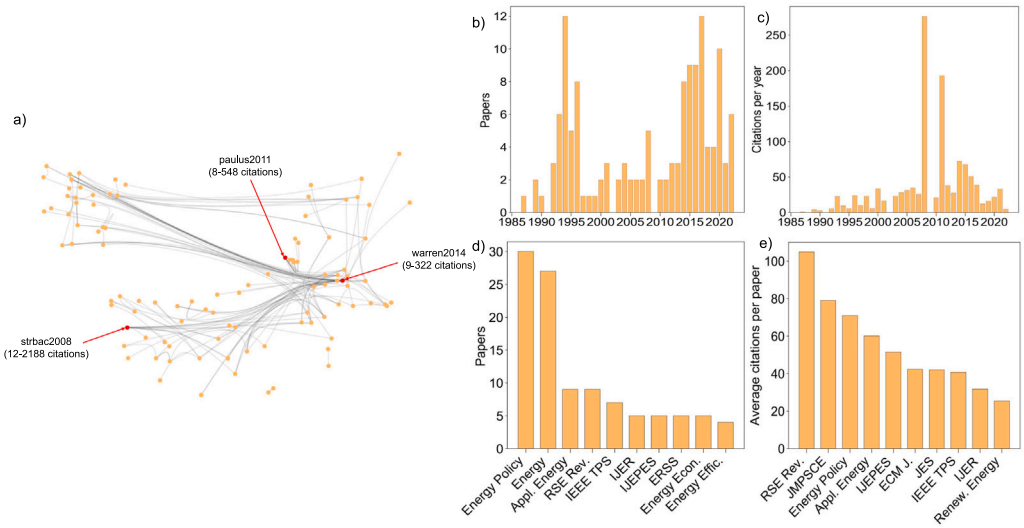

Fig. 14. The citation network and statistical analysis of Theme 5. It includes: (a) main view: citation network diagram for Theme 5; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

5.6. Theme 6: demand response programs and their impact

Theme 6 deals with the topic of demand response programs and their impact on the electricity market. Demand response programs are strategies and actions that aim to optimize grid load by encouraging customers to lower their electricity consumption during peak demand periods. This helps to balance the electricity market and reduce prices, as well as to enhance grid stability, reliability, and flexibility. Demand response programs can also facilitate the integration of renewable energy sources, such as wind and solar, which are variable and intermittent in nature. Moreover, demand response programs can provide benefits to customers, such as lower electricity bills, incentives, and participation in energy management.

To achieve these goals, various research works have emerged with different perspectives and methodologies. Some of them focus on the modeling of demand response programs, highlighting the potential of these programs in managing peak demand and reducing grid congestion [95,96]. Others emphasize the role of incentives in demand response, demonstrating their impact on consumer behavior and overall energy consumption [97,98]. The integration of renewable energy sources is a central theme in the works of [99,100], underscoring the need for effective demand response strategies in facilitating this integration and improving the grid flexibility and resilience. [101,102] investigate the potential of demand response programs in grid stability, emphasizing their role in ensuring reliable electricity supply and providing ancillary services. Lastly, [103,104] discuss the role of demand response programs in the context of smart grids, highlighting the potential of these programs in transforming the energy sector and empowering customers. These studies collectively contribute to the understanding of demand response programs and their impact on energy systems.

We present the main features and findings of Theme 6 as shown in Fig. 15. Fig. 15(a) shows the citation network for Theme 6. Theme 6 has a more compact network structure centered around a few critical articles. Key papers are: Gils H.C.'s publication in 2014 presents an assessment of the theoretical DR potential in Europe [105], Aalami H.A.'s publication in 2010 presents a demand response model that considers interruptible/curtailable loads and capacity market programs [32]. We examine the literature on this theme in more detail below.

Figs. 15(b) and 15(c) reveal that the peak year for publications related to Theme 6 was 2016. This indicates a period of high research activity and knowledge creation on demand response programs. Interestingly, despite having fewer articles, the years 2013 and 2014 stand out in terms of the average number of citations. This implies that some articles published during those years had a significant impact on Theme 6 and received considerable attention. For example, Aghaei and Jamshid's 2013 article [106] researches the latest definition and classification of demand response. And Siano, Pierluigi's 2014 article [107] describes the potential and benefits of demand response in the smart grid. Fig. 15(d) indicates that most articles on Theme 6 were published in *Energy*, *Energy Policy*, and *Applied Energy* journals. These journals play a key role as major outlets for disseminating research on demand response programs. Researchers interested in this theme can rely on these journals as useful sources for accessing relevant literature and keeping up with recent developments. Moreover, Fig. 15(e) highlights the impressive performance of *Renewable and Sustainable Energy Reviews* in terms of average citations. This journal's strong performance can be attributed to the influential articles mentioned earlier [107], which were published within its pages. The high average citation count in this journal reflects the recognition and impact of research within Theme 6, further confirming its importance in the field.

5.7. Theme 7: energy consumption patterns analysis and modeling

Theme 7 deals with the analysis and modeling of energy consumption patterns at different levels, such as individual, household, sectoral, regional, and national. Energy consumption patterns reflect the temporal and spatial variations of energy use by different consumers and factors that influence them, such as weather, economic activity, social behavior, and technological change. Analyzing and modeling these patterns can help understand the current and future energy demand and supply, as well as the potential for energy efficiency, conservation, and demand response.

To achieve this goal, various research works have emerged with unique perspectives and methodologies. Some of them focus on the analysis of consumption patterns in residential areas, using intelligent systems and modeling techniques to capture the characteristics and preferences of households [108,109]. Others emphasize the importance of considering temporal and spatial variations in energy use, proposing advanced techniques to forecast energy consumption based on historical data and external factors [110,111]. Moreover, some studies explore the role of social behavior in energy consumption, shedding light on how household characteristics, such as size, income, and lifestyle, affect energy use patterns [112,113]. In addition, some research works develop energy consumption models that consider economic activity,

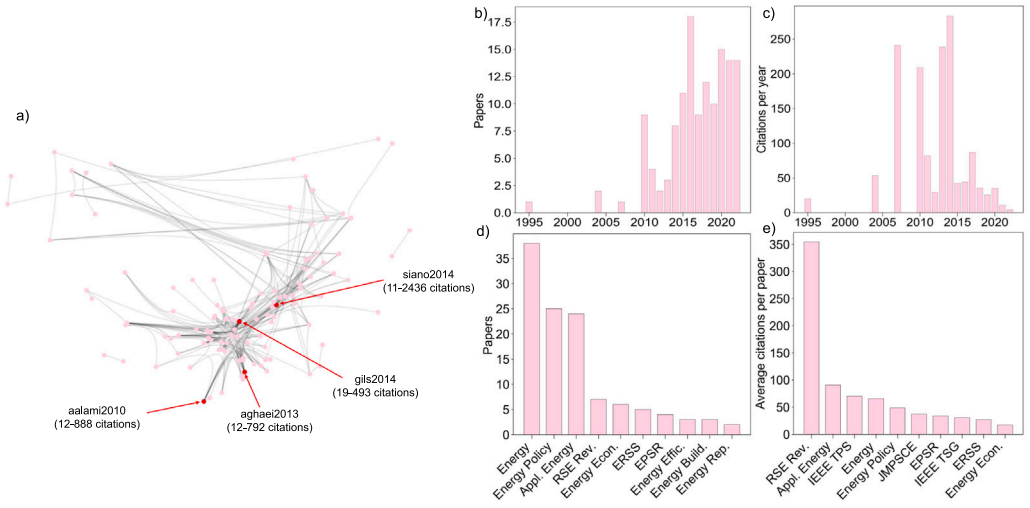

Fig. 15. The citation network and statistical analysis of Theme 6. It includes: (a) main view: citation network diagram for Theme 6; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

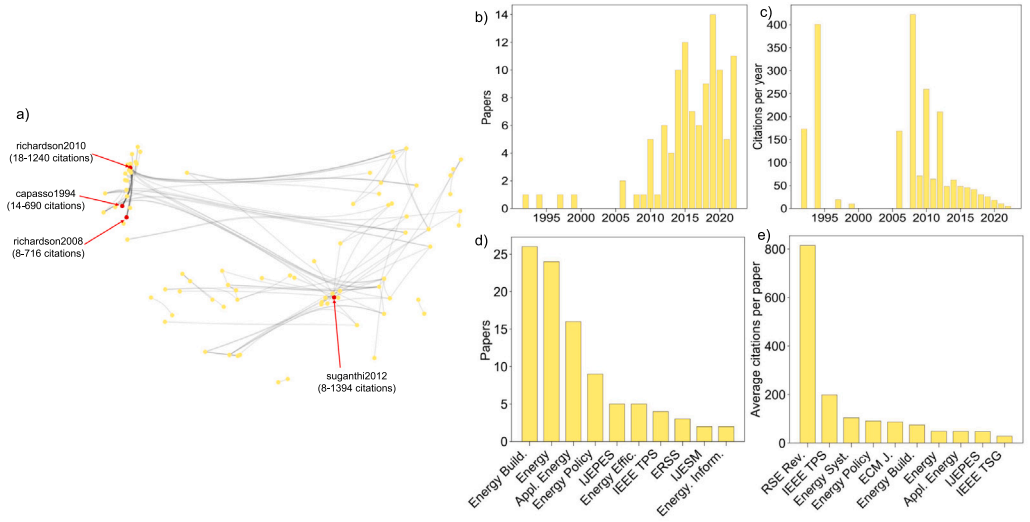

Fig. 16. The citation network and statistical analysis of Theme 7. It includes: (a) main view: citation network diagram for Theme 7; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

using data-driven and econometric models to analyze the relationship between energy demand and economic indicators [114,115]. Finally, some works discuss the potential of demand response programs in managing energy consumption, reinforcing the need for an understanding of consumption patterns to enhance demand response [116,117]. These works collectively contribute to a more comprehensive understanding of energy consumption patterns and provide valuable insights for the development of effective energy consumption models.

Fig. 16(a) shows the citation network for this theme, which differs from other themes by having more evident clusters. We found that some highly cited articles within dense clusters influenced these patterns, suggesting that they guided and shaped the research in this theme. These influential articles may have introduced some classical models or analysis methods that are still widely used in current research. The network's most cited papers are: Richardson, Ian's 2010 paper, which introduces a high-resolution model of domestic electricity [118], Capasso, A.'s 1994 paper, which proposes a model of electric residential end-use [119], Richardson, Ian's 2008 paper, which presents a high-temporal-resolution model of domestic demand profiles [120], and Suganthi L.'s 2012 paper, which reviews various energy demand forecasting models [121]. This hypothesis is supported by Figs. 16(b) and 16(c), which show that the early articles in this theme had a high average number of citations, despite being few in number. These foundational contributions likely remain relevant and impactful within the field. Figs. 16 (d) and 16(e) highlight the main publication venues for Theme 7. *Energy and Buildings* is the most frequent journal for publishing articles in this theme, followed by *Energy* and *Applied Energy*. These journals play a significant role in disseminating research on data analysis and modeling techniques. Moreover, *Renewable and sustainable energy reviews* is the journal with the highest average number of citations, Mainly due to [121] having high citation counts, it provides a comprehensive assessment of energy demand forecasting models,

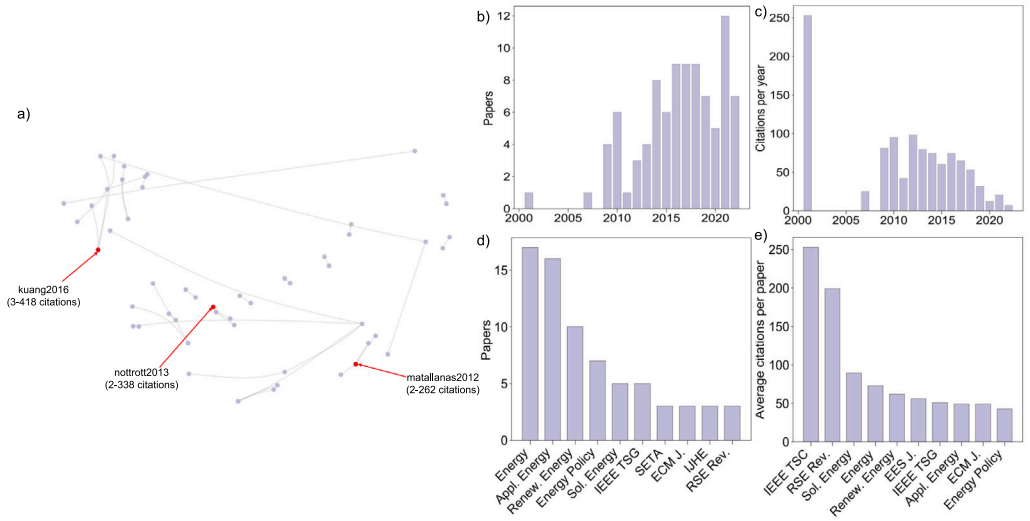

Fig. 17. The citation network and statistical analysis of Theme 8. It includes: (a) main view: citation network diagram for Theme 8; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

including time series, regression, and econometric models, providing helpful information for energy demand management and planning.

5.8. Theme 8: energy storage in various technologies

Theme 8 explores the topic of energy storage in various technologies, such as batteries, hydrogen, and photovoltaic systems. Energy storage is an essential component of renewable energy systems, as it can help overcome the intermittency and variability of renewable energy sources, such as wind and solar. Energy storage can also provide ancillary services, such as frequency regulation, voltage control, and peak shaving, to enhance the stability and reliability of the power grid.

This theme covers a wide range of research areas related to energy storage technologies and their applications in different energy systems. One of the main research areas is hybrid energy systems, which combine multiple energy sources and storage devices to optimize the system performance and efficiency. For example, [122,123] investigated the importance of optimal sizing and operation of hybrid energy systems, highlighting the essential role of energy storage in reducing the system cost and emissions. Another research area is advanced control strategies for energy storage systems, which aim to improve the system operation and performance by using intelligent algorithms and methods. For example, [124,125] proposed advanced control strategies for energy storage systems, emphasizing the critical role of these systems in grid stability and reliability. A third research area is hydrogen as an energy storage medium, which can store excess renewable energy and convert it back to electricity or heat when needed. For example, [126,127] demonstrated the potential of hydrogen in achieving sustainable energy systems, especially in remote areas and islands. A fourth research area is battery energy storage, which is one of the most widely used and versatile energy storage technologies. For example, [128,129] focused on battery energy storage, with the former proposing an optimal operation strategy for battery systems in microgrids, and the latter discussing the role of batteries in grid-connected photovoltaic systems. A fifth research area is the integration of renewable energy sources into the power grid, which poses various challenges and opportunities for energy storage technologies. For example, [130,131] addressed the integration of renewable energy sources, outlining the importance of energy storage in facilitating this integration and improving the grid flexibility and resilience. Collectively, these studies underscore the significance of various energy storage technologies in optimizing energy systems.

Fig. 17(a) displays the citation network for this theme. The literature within this field is relatively sparse, and the network structure is also decentralized, which suggests that this is an emerging topic with substantial opportunities for future research. The most highly cited publication within this network is Yonghong Kuang's 2016 paper, which discusses the utilization status and development potential of various renewable energy sources in island power grids, emphasizing the importance of developing grid integration technology and energy storage technology to ensure a continuous and stable power supply from renewable energy sources [132]. This is followed by Nottrott, A.'s 2013 publication, which models optimal energy storage dispatch schedules [133], and Matallanas E.'s 2012 paper, which discusses the development of a control system for demand-side management [134]. As shown in Fig. 17(b), the topic first appeared around 2001, with a peak in publications occurring in 2021. This reaffirms that Theme 8 is a developing topic with growing research interest. Fig. 17(c) demonstrates that the articles published in 2001 received the highest average number of citations, suggesting that these early works significantly influenced the development of the topic.

The prominent journals within Theme 8, as shown in Fig. 17(d) and Fig. 17(e), include Energy, Applied Energy, and Renewable Energy. These journals provide essential platforms for disseminating research findings within the field. Notably, IEEE Transactions on Energy Conversion has the highest average number of citations, this is mainly due to [135], it reports on the performance of a 4 kW residential wind energy complementary system with battery storage. The aim is to explore the implementation of wind–solar–volt systems to support future renewable energy applications. Additionally, *Renewable and Sustainable Energy Reviews* stands out as the second most cited journal, indicating its influence and relevance in the field.

5.9. Theme 9: electric vehicles and their charging infrastructure

Electric vehicles (EVs) are vehicles that use electric motors and batteries instead of internal combustion engines and fossil fuels. EVs offer many benefits, such as reducing greenhouse gas emissions, improving air quality, lowering fuel costs, and enhancing energy security. However, EVs also face many challenges, such as high initial costs, limited driving range, and insufficient charging infrastructure.

The literature on Electric Vehicles (EVs) and their charging infrastructure is replete with diverse yet interconnected research topics. Demand-side management of EVs in smart grids, for instance, seeks to seamlessly integrate EVs into existing power systems [136]. Concurrently, strategic development of infrastructure focuses on optimal

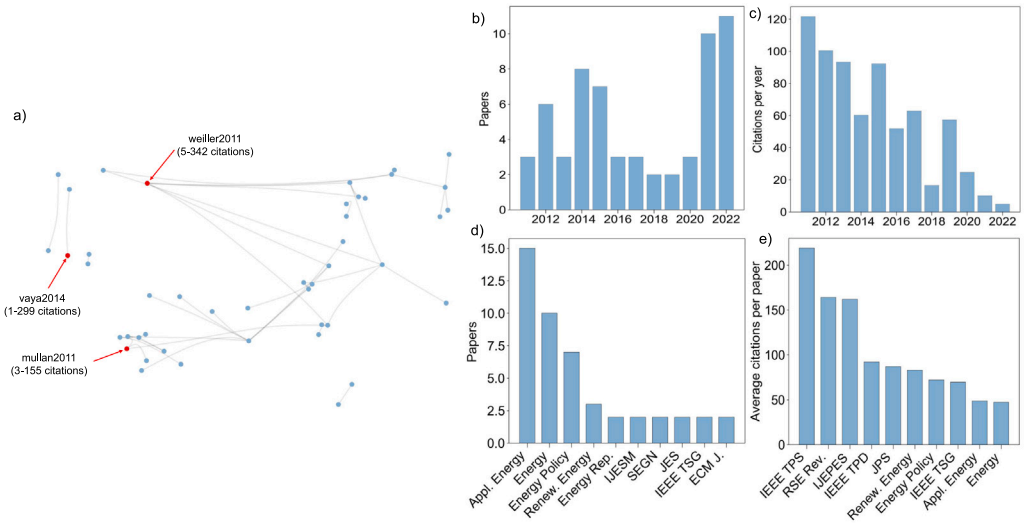

Fig. 18. The citation network and statistical analysis of Theme 9. It includes: (a) main view: citation network diagram for Theme 9; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

sizing and siting of various types of charging stations [137,138]. The field also benefits from the application of advanced computational techniques like deep reinforcement learning, which manages EV charging loads [139], exemplifying the influence of artificial intelligence. Furthermore, understanding user patterns and requirements plays a crucial role in the design and implementation of EV charging infrastructure [140,141]. The economic implications of EVs and their charging infrastructure are also studied extensively, examining the effects of electricity pricing and tariff design on EV charging behavior [142,143]. Lastly, the computational challenges arising from the growing scale of EV charging infrastructure have been addressed using meta-heuristic methods to solve large-scale EV charging problems [144]. Collectively, these topics provide a comprehensive picture of the current research landscape and potential future directions for EVs and their charging infrastructure.

Fig. 18(a) shows the citation network for this topic, which resembles Theme 8 in having fewer articles and no clear clusters or citation patterns. The network's most cited article is: Weiller, Claire's 2011 publication, which develops a simulation algorithm to estimate the Plug-in hybrid electric vehicle charging profiles of electricity demand [145], and Mullan, Jonathan's 2011 paper, which investigates the potential impacts of electric vehicles on the Western Australian electricity grid [146]. Fig. 18(b) confirms that this topic is relatively new and emerged around 2011, with a surge in publications after 2021. This implies that this theme has ample opportunities for further research and development. Fig. 18(c) presents the average number of citations to articles in Theme 9. The downward trend from past to present reflects the evolution of the literature, suggesting that earlier works have established the basis for the topic's advancement. This indicates that the initial literature has been influential in advancing the knowledge of electric vehicles and their charging infrastructure.

Fig. 18(d) and Fig. 18(e) reveal the main journals that publish articles on this theme. *Applied Energy*, *Energy*, and *Energy Policy* are the leading journals for disseminating research findings in this area. These journals provide key platforms for researchers to exchange their insights and innovations related to electric vehicles and charging infrastructure. Notably, the *IEEE Transactions on Power Systems* ranks as the top journal in terms of the highest average number of citations. This recognition is due to the 2015 publication [147] by Gonzalez Vaya M. This paper presents an optimal bidding strategy for a plug-in electric vehicle aggregator in day-ahead electricity markets under uncertainty.

5.10. Theme 10: optimizing energy consumption and cost management through distributed scheduling algorithms

Theme 10 focuses on optimizing energy consumption and cost management through distributed scheduling algorithms. Distributed scheduling algorithms are methods that coordinate the operation and control of multiple distributed energy resources (DERs), such as renewable generation, energy storage, and flexible loads, in a decentralized manner. These algorithms can help achieve various objectives, such as minimizing the total energy cost, maximizing the renewable energy utilization, balancing the supply and demand, and enhancing the grid reliability and resilience.

This theme spans a broad scope of research areas in energy management. For example, [148,149] explored the importance of smart homes in energy consumption and cost reduction, with the former focusing on a multi-objective unit and load commitment approach and the latter delving into intelligent algorithms for demand response optimization. Similarly, [150,151] proposed novel scheduling methods for load management, underlining the potential of optimal load scheduling in energy conservation. [152,153] addressed the need for effective demand response programs, with emphasis on appliance-level operation models. The transition towards Smart Grids was addressed by [154], illustrating the impact of advanced load scheduling methods on energy optimization. Lastly, [155,156] employed a game-theoretic approach to manage demand-side energy, underscoring the potential of intelligent algorithms in managing energy consumption efficiently. These research works collectively contribute to the optimization of energy consumption and cost management, highlighting the crucial role of advanced scheduling algorithms in the era of smart grids and homes.

The citation network of this theme as shown in Fig. 19a has a sparse structure due to the smaller number of articles in this theme. However, some articles stand out as highly cited and influential within the network, such as Mohsenian-Rad A.-H.'s 2010 publication [31], which presents an autonomous and distributed DSM system among users; Atzeni I., et al.'s 2013 publication [157], which presents a distributed algorithm to be run on the users' smart meters; and Samadi P., et al.'s 2012 article [143], which proposes an efficient pricing method to address future smart grid problems. These articles have played a key role in shaping the subsequent development and understanding of the topic. They have also had a significant impact and influence in the field.

The publication count of articles within this theme as shown in Fig. 19b indicates that the topic has grown mainly within the last

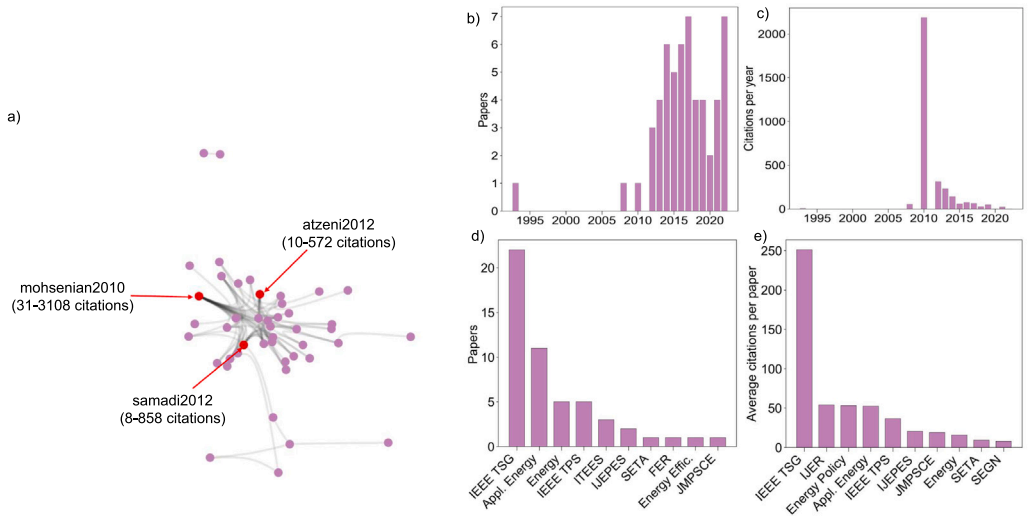

Fig. 19. The citation network and statistical analysis of Theme 10. It includes: (a) main view: citation network diagram for Theme 10; (b) number of articles published over the years; (c) average number of citations per year of publication; (d) top ten journals in terms of number of publications; and (e) top ten journals in terms of average number of citations.

decade, highlighting its emerging nature and signaling ample opportunities for further research and exploration. The rising publication count also reflects the growing interest and attention that this topic has received from the research community. The average number of citations for articles within this theme peaked in 2010, largely due to the impact of Mohsenian-Rad A.-H.'s aforementioned article [31], which has received more than 3,000 citations to date. The distribution of articles across journals within this theme as shown in Fig. 19d and Fig. 19e indicates that the *IEEE Transactions on Smart Grid* is a primary platform for publishing research on distributed scheduling algorithms. The journal's focus on smart grid technologies aligns well with the topic of optimizing energy consumption and cost management through distributed scheduling algorithms. The journal also establishes its relevance and significance within the theme. The journal has both the highest number of publications and the highest average number of citations within this theme.

6. Discussion

Our bibliometric analysis offers a detailed understanding of the evolution and current state of DSM research. It reveals the key themes that have shaped the field and suggests future directions for researchers. However, we acknowledge that the trends and patterns identified in this study are subject to the dynamism and complexity of the research landscape. Therefore, they should be interpreted with an awareness of the broader context and changing realities of the field. The citation network analysis of the ten themes in DSM research provides a comprehensive view of the research landscape. Each theme revealed unique characteristics and trends, highlighting the diversity of research in this field. In this section, we compare and contrast the research in different themes, especially regarding the integration of renewable energy sources and the challenges.

The themes within Group 1 all have a relatively large amount of literature, and their citation networks were well connected. This indicates that these areas have a relatively mature body of literature and provide a solid foundation for future research. They all deal with optimizing and controlling energy systems but from different perspectives. Theme 1 focuses on innovative management and optimization techniques to improve the performance and sustainability of power systems through new technologies. Theme 2 focuses on the building level, through thermal management and control, to reduce energy consumption and greenhouse gas emissions and improve occupant health and well-being. Theme 3 focuses on the complexity and dynamics of various forms of energy in terms of energy consumption and supply, which are crucial to influencing socio-economic and environmental well-being. Integrating renewable energy within these themes also poses some special challenges that have not been well addressed in the existing literature. Some of these challenges include dealing with the uncertainty and variability of renewable energy sources in power system management and optimization, ensuring cybersecurity and data privacy in smart grid technologies, and coordinating multiple agents and devices in complex networks. Future research could address these challenges by exploring new technologies and techniques to improve the efficiency and effectiveness of power systems, such as artificial intelligence, blockchain, or quantum computing. Future research could also explore new models and methods for thermal management and control of buildings, such as smart thermostats, adaptive ventilation, or occupant behavior modeling.

Themes within Group 2 are all concerned with energy management. Theme 4 focuses on the management of microgrids. Theme 5 focuses on demand management program design. Theme 6 focuses on the implementation and impact of demand response programs. Theme 7 focuses on the analysis and modeling of energy consumption patterns. The number of articles on these themes has grown rapidly in recent years. Integrating renewable energy sources in these themes also presents some particular challenges that have not been well addressed in the existing literature. Some of these challenges include how to segment and target consumers based on their preferences and behaviors, balance consumer satisfaction and grid reliability in demand response programs, and evaluate the long-term effects and benefits of demand response programs. Future research can address these challenges by developing more sophisticated models and methods, conducting more empirical studies, and applying more rigorous evaluation techniques.

Themes within Group 3 have all emerged in recent years. Theme 8 focuses on energy storage with various technologies that can help overcome renewable energy sources' intermittent and variable nature. Theme 9 looks at electric vehicles and their charging infrastructure. Theme 10 looks at optimizing energy consumption and cost management through distributed scheduling algorithms. The integration of renewable energy sources also poses some particular challenges. Some of these challenges are how to evaluate the costs and benefits of energy storage technologies for consumers and grid operators, how to integrate electric vehicles into demand side management schemes, how to assess the costs and benefits of electric vehicles for consumers and grid operators, and how to compare and combine different optimization

methods such as linear programming, genetic algorithms or artificial neural networks, Future research can be done by developing more advanced models and methods, conducting more empirical studies, and applying more rigorous evaluation techniques to address these challenges.

In conclusion, our study provides a comprehensive overview of the development and current state of DSM research. It uncovers the key themes that have shaped the field and compares and contrasts them, especially regarding the integration of renewable energy sources and challenges. We hope that our study can serve as a useful reference and guide for researchers who are interested in this field.

7. Dataset and code

We have developed a web-based bibliometric analysis platform to support our study of DSM literature. This platform is a software tool that enables us to collect, process, analyze, and visualize bibliometric data of different research fields and topics. It provides more accurate, comprehensive, and interactive results and visualizations than the existing platforms. The platform can be accessed at https://tinyurl.com/4sa3u7js. The platform consists of four main components: (1) A data collection module that uses OpenAlex API to crawl citations from various databases, such as Scopus, Web of Science, PubMed, and Google Scholar. We select the publications that match our search criteria based on title, abstract, keywords, and subject areas. (2) A data processing module that uses GPT Embeddings API to transform the texts of the publications into high-dimensional vectors that capture their semantic meaning. We apply this technique to the titles, abstracts, keywords, and full texts of the publications. (3) A data analysis module that uses BERTopic to identify the main themes that represent the research areas in DSM literature. We also use BERTopic to create citation networks for each theme based on the citation relations among the publications. (4) A data visualization module that uses WizMap, a web-based tool that we developed, to map the publications based on their semantic similarity and diversity. It also shows the time series of the publications by year and how the topics changed over time. Users can search, filter, and zoom in on the data points and see more information such as labels, contours, grids, and time series.

Our bibliometric analysis platform can also be used for other fields and topics, as long as there is enough literature data available for the chosen topic. The platform is flexible and customizable, allowing users to adjust the search query, the data sources, the analysis methods, and the visualization options according to their needs and preferences. The platform can provide valuable insights and guidance for researchers who want to explore and understand the evolution and current state of their research field or topic.

We provide the operations and time required for each stage of the data for the reader's reference as follows:

- Data retrieval and crawling. Determine the search keywords based on the research content and crawl the citation information using the OpenAlex API. (related link: https://docs.openalex.org/)
- Data Cleaning. Delete incomplete data, ineligible journals. (related link: https://github.com/pandas-dev/pandas)
- Basic data statistics. Visualization and analysis of fundamental statistical indicators of the overall data, histograms, river diagrams, etc. (related link: https://github.com/matplotlib/matplotlib)
- GPT Embedding. GPT embedding using abstract and title text. (related link: https://github.com/openai/openai-cookbook/)
- Semantic Analysis. GPT embedding is used for Bertopic modeling and the resulting themes are analyzed. (related link: https://github.com/MaartenGr/BERTopic)
- Dimensionalensional visual analytics. Downscaling semantic information to the 2D plane and visual analysis using T-SNE and UMAP. (related link: https://github.com/scikit-learn/scikit-learn)
- Building the citation network. Construct network data based on citation information, including edge and node tables. (related link: https://github.com/networkx/networkx)
- Citation network analysis. Visual analysis of the overall citation network, using edge-binding algorithms to reduce visual distractions. (related link: https://github.com/upphiminn/d3.ForceBundle)

We demonstrate the applicability and utility of our bibliometric analysis platform by applying it to a case study on DSM, which is a key research area in energy systems. Fig. B.20 shows an example of the user interface for the DSM dataset. We collect and analyze 2,118 publications on this topic from 1987 to 2022, using OpenAlex API, GPT Embeddings API, BERTopic, and WizMap. We identify ten main themes that represent the DSM literature and examine their citation patterns and trends over time. We also visualize the results using interactive maps and graphs that show the semantic similarity and diversity of the publications. We are still developing this platform and plan to add more functionalities in the future. Some of the possible features are:

- A citation network that shows how the publications in a research field or topic cite each other. The nodes are the publications and the links are the citations. The size and color of the nodes show the number and type of citations. Users can zoom in and out, drag and drop, filter and highlight the nodes and links.
- A co-authorship network that shows how the authors in a research field or topic collaborate with each other. The nodes are the authors and the links are the co-authorship relations. The size and color of the nodes show the number and impact of publications. Users can zoom in and out, drag and drop, filter and highlight the nodes and links.
- A co-word map that shows how often and strongly the keywords in a research field or topic co-occur with each other. The words are the keywords and the links are the co-occurrence relations. The size and color of the words show the frequency and strength of co-occurrence.

8. Conclusions and future work

This paper presents a comprehensive bibliometric analysis of the DSM literature, covering 2,118 publications from 1987 to 2022. We used different analytic methods and tools to examine the citation patterns and topic evolution of the literature. We collected a large dataset of relevant papers and clean the data for further processing. We used the GPT embedding API to extract features from the abstracts and titles of the papers and apply the BERTopic model to classify them into ten key themes that represent the main research areas in the field. We analyzed the semantic meaning of each theme and its evolution over time using river diagrams. We also reviewed the research topics for each theme, constructed its citation network and conducted statistical analysis of the publications in terms of the number of articles published over the years, average number of citations per year of publications, top ten journals with respect to the number of publications, and top ten journals with respect to the average number of citations. We identified the most influential and impactful papers for each theme and discussed their contributions and implications. We also discussed the role and impact of interdisciplinary research in DSM, and we provided insights and recommendations for future research directions. Moreover, we presented the design and implementation of a bibliometric analysis platform, which is a software tool that enables us to collect, process, analyze, and visualize bibliometric data of different research fields and topics. Our study contributes to the existing literature by providing a comprehensive and systematic overview of the DSM field, revealing its structure, evolution, and diversity. Our study also highlights the opportunities and challenges for future research in this field, as well as the potential for interdisciplinary collaboration and innovation. We

hope that our study can serve as a valuable resource and guide for researchers, policymakers, and stakeholders who are interested in DSM.

For future work, we suggest several directions that can extend and improve our study. First, we plan to update our dataset regularly to capture the latest developments and trends in the field. Second, we intend to conduct a deeper analysis of the citation networks for each theme, using more advanced network metrics and algorithms. Third, we aim to explore the impact of DSM research on policy and practice, using indicators such as policy citations or media mentions. Fourth, we aspire to conduct a comparative analysis of DSM research across different regions and sectors, using geographic and thematic filters. Fifth, we envisage to conduct a qualitative analysis of the literature, using methods such as content analysis or discourse analysis. Sixth, we propose to improve the visual interaction of citation networks so that researchers can have a more user-friendly visualization system to navigate and explore the articles that interest them. Seventh, we plan to enhance our bibliometric analysis platform by adding more features and functionalities, such as allowing users to customize their own queries, filters, analyses, and visualizations. These directions can help us gain a more nuanced and holistic understanding of the DSM field.

CRediT authorship contribution statement

Fanyue Meng: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Zhaoyuan Lu:** Data curation, Methodology, Software, Writing – original draft, Writing – review & editing. **Xiang Li:** Conceptualization, Writing – review & editing. **Wei Han:** Conceptualization, Software, Writing – original draft. **Jieyang Peng:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Xiufeng Liu:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Zhibin Niu:** Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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Appendix A. List of statistical results

A.1. Number of DSM publications top-30 institutions

1. Aalborg University - 33 publications
2. North China Electric Power University - 31 publications
3. Imperial College London - 30 publications
4. Islamic Azad University - 28 publications
5. Tsinghua University - 28 publications
6. University of California - 25 publications
7. Zhejiang University - 20 publications
8. University of Pretoria - 19 publications
9. The Hong Kong Polytechnic University - 19 publications
10. Technical University of Denmark - 18 publications
11. University of Oxford - 17 publications
12. University of New South Wales - 16 publications
13. Indian Institute of Technology - 16 publications
14. University of Coimbra - 15 publications
15. Aalto University - 15 publications
16. Shanghai Jiao Tong University - 14 publications
17. National Institute of Technology (India) - 14 publications
18. National Technical University of Athens - 14 publications
19. Lawrence Berkeley National Laboratory - 14 publications
20. University College Dublin - 13 publications
21. University of Cambridge - 13 publications
22. Cardiff University - 13 publications
23. University of Strathclyde - 13 publications
24. Tianjin University - 12 publications
25. University of Tabriz - 12 publications
26. University of Bath - 12 publications
27. University of Salerno - 11 publications
28. Southeast University - 11 publications
29. University of Sydney - 11 publications
30. Norwegian University of Science and Technology - 11 publications

A.2. Number of publications top-10 authors on DSM

1. Shengwei Wang - The Hong Kong Polytechnic University - 13 publications
2. Xiaohua Xia - Renmin University of China - 13 publications
3. Jacopo Torriti - University of Reading - 12 publications
4. Strbac,Goran - Imperial College London - 11 publications
5. Siano, Pierluigi - University of Salerno - 11 publications
6. Woo, Chi-Keung - Education University of Hong Kong - 10 publications
7. Catalao, Joao P.S. - Imperial College London & University of Beira Interior - 10 publications
8. Guerrero, Josep M. - Aalborg University - 9 publications
9. Aghaei, Jamshid - University of Salerno - 9 publications
10. Lund, Peter D. - Aalto University School of Science - 9 publications

A.3. Average citations top-10 authors on DSM

1. Mohsenian-Rad, Hamed - University of California - 437.4 citations
2. Lund, Henrik - Leibniz Institute for Catalysis - 334.3 citations
3. Habib allah aalami - University of Eyvanekey - 309 citations
4. Richardson, Ian - University of Leeds - 220 citations
5. Siano, Pierluigi - University of Salerno - 211 citations
6. Cheng Fan - Shenzhen University - 195.5 citations
7. Samadi, Pedram - University of British Columbia - 190.5 citations
8. Cappers, Peter M. - Lawrence Berkeley National Laboratory - 148.5 citations
9. Logenthiran, Thillainathan - Newcastle University - 133.5 citations
10. Hug, Gabriela - AETH Zurich - 128.5 citations

A.4. Abbreviations of journals

1. Applied Energy - Appl. Energy
2. Energy - Energy
3. Energy Policy - Energy Policy

4. Renewable and Sustainable Energy Reviews - RSE Rev.
5. IEEE Transactions on Smart Grid - IEEE TSG
6. Energy and Buildings - Energy Build.
7. Renewable Energy - Renew. Energy
8. International Journal of Electrical Power and Energy Systems - IJEPES
9. Energy Economics - Energy Econ.
10. IEEE Transactions on Power Systems - IEEE TPS
11. Energy and Environmental Science - EES J.
12. IEEE Transactions on Sustainable Energy - IEEE TSE
13. Solar Energy - Sol. Energy
14. Energy Conversion and Management - ECM J.
15. Journal of Energy Storage - JES
16. Energy Reports - Energy Rep.
17. Sustainable Energy Technologies and Assessments - SETA J.
18. Energy Efficiency - Energy Effic.
19. Frontiers in Energy Research - FER
20. International Journal of Energy Sector Management - IJESM
21. International Journal of Green Energy - IJGE
22. Energy, Sustainability and Society - ESS J.
23. International Journal of Energy Research - IJER
24. IET Renewable Power Generation - IET RPG
25. Energy Research and Social Science - ERSS
26. Journal of Modern Power Systems and Clean Energy - JMPSCE
27. Electric Power Systems Research - EPSR
28. Energy Informatics - Energy. Inform.
29. Energy Systems - Energy Syst.
30. International Journal of Hydrogen Energy - IJHE
31. IEEE Transactions on Energy Conversion - IEEE TEC
32. Sustainable Energy, Grids and Networks - SEGN
33. IEEE Trans Power Delivery - IEEE TPD
34. Journal of Power Sources - JPS
35. International Transactions on Electrical Energy Systems - ITEES

A.5. Remained journals

1. Applied Energy - 405
2. Energy - 383
3. Energy Policy - 253
4. Energy and Building - 106
5. Renewable and Sustainable Energy Reviews - 105
6. IEEE Transactions on Smart Grid - 104
7. Renewable Energy - 72
8. Energy Economics - 71
9. International Journal of Electrical Power and Energy Systems - 58
10. IEEE Transactions on Power Systems - 52
11. Energy Conversion and Management - 42
12. Energy Research and Social Science - 42
13. Energy Efficiency - 41
14. Electric Power Systems Research - 35
15. Sustainable Energy Technologies and Assessments - 33
16. International Journal of Energy Research - 31
17. Energy Reports - 28
18. Journal of Energy Storage - 28
19. International Transactions on Electrical Energy Systems - 23
20. Solar Energy - 21
21. Sustainable Energy, Grids and Networks - 18
22. Energy for Sustainable Development - 16
23. International Journal of Energy Sector Management - 16
24. Frontiers in Energy Research - 14
25. IEEE Transactions on Sustainable Energy - 14
26. Journal of Modern Power Systems and Clean Energy - 13
27. Electric Power Components and Systems - 12

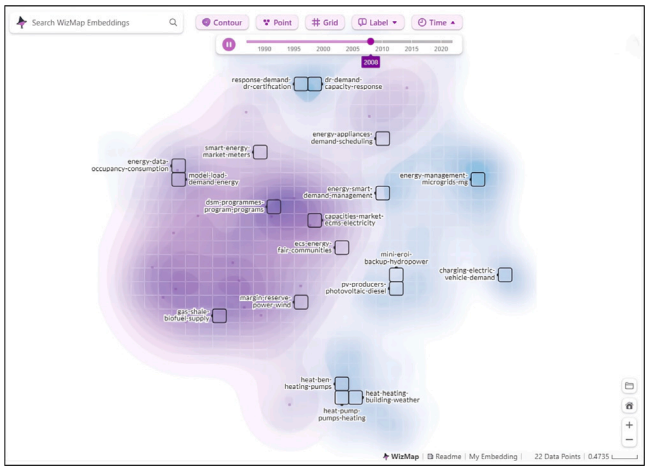

Fig. B.20. The user interface of the bibliometric analysis system (https://tinyurl.com/4sa3u7js).

28. IET Renewable Power Generation - 12
29. International Journal of Hydrogen Energy - 8
30. Energy and Environment - 7
31. Energy Informatics - 6
32. Energy Strategy Reviews - 5
33. Energy, Sustainability and Society - 4
34. IEEE Transactions on Energy Conversion - 4
35. International Journal of Green Energy - 4
36. Energy and Environmental Science - 3
37. Energy Journal - 2
38. Energy Sources - 2
39. Energy Sources, Part B: Economics, Planning and Policy - 2
40. IEEE Journal of Emerging and Selected Topics in Power Electronics - 2
41. International Journal of Energy Technology and Policy - 2
42. Nature Energy - 2
43. Renewable Energy and Power Quality Journal - 2
44. Advances in Building Energy Research - 1
45. Current Sustainable/Renewable Energy Reports - 1
46. Economics of Energy and Environmental Policy - 1
47. Energy Exploration and Exploitation - 1
48. Energy Systems - 1
49. Global Energy Interconnection - 1
50. IEEE Power and Energy Magazine - 1
51. IEEE Transactions on Power Delivery - 1
52. IET Energy Systems Integration - 1
53. International Journal of Emerging Electric Power Systems - 1
54. International Journal of Sustainable Energy - 1
55. Journal of Power Sources - 1
56. Journal of Solar Energy Engineering, Transactions of the ASME - 1
57. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy - 1
58. Resources and Energy - 1

Appendix B. Interface to visualize the DSM dataset

See Fig. B.20.

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