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Bibliometric Analysis of the Zero Energy Neighborhood Concept: Developments and Key Trends in the Literature

Zero Energy Neighborhood Kavramının Bibliyometrik Analizi: Literatürdeki Gelişmeler ve Temel Eğilimler

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Abstract

This study presents the findings of a comprehensive literature review conducted in November 2024 using the Web of Science (WoS) database with the keyword "zero energy neighborhood," analyzing 596 documents through bibliometric methods. Vosviewer software was employed to identify trends, thematic focuses and research collaborations in the field. Two main thematic clusters emerged: Energy Efficiency and Monitoring Parameters and Building Energy Consumption and Carbon Reduction. The Energy Efficiency and Monitoring Parameters cluster explores tools and processes for measuring and optimizing the energy performance of zero energy neighborhoods. It emphasizes real-time monitoring, improving energy efficiency and process optimization. The Building Energy Consumption and Carbon Reduction cluster focuses on sustainable solutions, including reducing building energy use, minimizing energy demandand cutting carbon emissions. Key topics include renewable energy integration, energy storage systemsand energy efficiency standards in building designs. This study also delves into collaboration networks among authors, institutionsand countries, identifying influential researchers, leading organizationsand strong international partnerships. The keyword analysis highlights key themes driving the development of zero energy neighborhoods, such as innovative technologies and conceptual approaches. These include energy monitoring, renewable energy integrationand carbon reduction. The findings underscore that zero energy neighborhoods are not just about reducing energy consumption; they play a vital role in sustainable urban planning and energy policy implementation. The study stresses the importance of strategies to enhance the practical application of zero energy neighborhoods and encourages further research on emerging thematic areas and technological advancements. In conclusion, this research contributes to understanding the conceptual foundations of zero energy neighborhoods, promoting innovations to improve their feasibility. It provides valuable insights for both academics and practitioners, fostering the development of strategies to support sustainable urban planning and energy policies.

Keywords: *Zero energy neighborhood, zero energy, bibliometric analysis, Web of Science.*

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Öz

Bu çalışma, Kasım 2024'te Web of Science (WoS) veritabanında "zero energy neighborhood" kavramı ile yapılan kapsamlı bir literatür taramasının sonuçlarını ve elde edilen 596 belgenin bibliyometrik analizini detaylı bir şekilde sunmaktadır. Analiz, bilimsel literatürdeki ana eğilimleri, tematik odak noktalarını ve araştırma işbirliklerini incelemek için Vosviewer yazılımı kullanılarak gerçekleştirilmiştir. Çalışma kapsamında, iki ana tematik küme tespit edilmiştir: Enerji Verimliliği ve İzleme Parametreleri ile Bina Enerji Tüketimi ve Karbon Azaltımı. Enerji Verimliliği ve İzleme Parametreleri kümesi, sıfır enerji mahallelerinin enerji performansının ölçülmesi ve değerlendirilmesi ile ilgili temel konuları içermektedir. Bu küme, enerji verimliliğini artırmaya yönelik ölçüm araçlarının geliştirilmesi, enerji tüketiminin gerçek zamanlı olarak izlenmesi ve bu süreçlerin optimize edilmesi gibi konuları kapsamaktadır. Bina Enerji Tüketimi ve Karbon Azaltımı kümesi ise binalarda enerji tüketiminin düşürülmesi, enerji talebinin minimize edilmesi ve karbon emisyonlarının azaltılması gibi sürdürülebilir çözümleri vurgulamaktadır. Çalışma, yalnızca tematik analizle sınırlı kalmamış, aynı zamanda yazarlar, kurumlar ve ülkeler arasındaki işbirliği ağlarını da detaylı bir şekilde incelemiştir. Bu analiz, sıfır enerji mahalleleri konusundaki bilimsel araştırmalarda öne çıkan etkili yazarları, lider kurumları ve güçlü uluslararası işbirliği ağlarını ortaya koymaktadır. Çalışmada kullanılan anahtar kelime analizleri, sıfır enerji mahallelerinin gelişiminde yenilikçi teknolojiler ve kavramsal yaklaşımlar açısından ön planda olan temaları açığa çıkarmıştır. Araştırmanın bulguları, sıfır enerji mahallelerinin yalnızca enerji tüketimini azaltmayı hedefleyen bir yaklaşım olmadığını, aynı zamanda sürdürülebilir kentsel planlama ve enerji politikalarının geniş ölçekli uygulanabilirliğine katkıda bulunmayı amaçladığını göstermektedir. Sonuç olarak, bu çalışma, sıfır enerji mahalleleri konusundaki mevcut bilgi birikimini zenginleştirirken, sürdürülebilir kentsel planlama ve enerji politikaları bağlamında uygulanabilecek stratejilere dair önemli bulgular sunmaktadır. Çalışmanın literatüre katkısı, sıfır enerji mahallelerinin kavramsal temellerinin anlaşılmasını kolaylaştırmak ve bu kavramın uygulanabilirliğini artırmaya yönelik bilimsel ve teknolojik yeniliklerin geliştirilmesini teşvik etmektir. Bu bağlamda, sıfır enerji mahalleleri üzerine yapılan çalışmaların, hem akademik literatüre hem de politika yapıcılar ve uygulayıcılar için somut öneriler geliştirilmesine katkıda bulunacağı sonucuna ulaşılmıştır.

Anahtar Kelimeler: *Sıfır enerji mahalle, sıfır enerji, bibliyometrik analiz, Web of Science.*

Introduction

Today, zero energy neighborhoods play a key role in sustainable urban planning and combating climate change. Aimed at reducing the environmental impact of cities and increasing energy efficiency, these neighborhoods strive to minimize carbon emissions by effectively utilizing renewable energy sources. The widespread adoption of zero energy neighborhoods contributes not only to energy independence but also to social sustainability. In this context, the planning processes of zero energy neighborhoods have become a critical area of study for urban planners and energy experts.

However, in the literature, studies addressing the concept of zero energy neighborhoods from a bibliometric analysis perspective, such as the spread of the concept, influential authors, international collaborationsand key themes, are limited. This research aims to systematically examine the distribution of academic publications on zero energy neighborhoods, the key authors and institutions in the literatureand the fundamental research trends in this field. In this context, the following questions are being explored:

- How is the academic spread of the zero energy neighborhood concept taking place?

- Who are the most influential authors, institutionsand countries in this field?

- What are the prominent themes and key topics in the literature?

This study aims to systematically analyze the existing body of knowledge on Zero Energy Neighborhoods (ZEN) and to reveal the current state and research trends in this field. Specifically, the study focuses on the academic dissemination of the ZEN concept, leading authors, institutionsand countries in the literature, key research themesand international collaborations through a detailed bibliometric analysis.

The scientific contributions of this study can be summarized as follows:

- Addressing Gaps in the Literature: The study aims to fill knowledge gaps by shedding light on areas such as collaboration networks and international comparisons, which are limited in the current literature on zero energy neighborhoods. One of the most significant gaps in the literature is the insufficient exploration of cross-country comparisons and international collaboration networks. ZEN implementations vary significantly due to the diversity in energy infrastructures, climatic conditionsand policy approaches across different countries. However, existing studies mostly focus on individual countries or specific projects, limiting broader knowledge sharing and learning in the context of energy efficiency and sustainability goals.
- Providing a New Perspective: By deeply examining international collaborations and thematic analyses, this research facilitates the development of strategic and innovative approaches in the field of zero energy neighborhoods.

- Comprehensive Data Presentation: Findings related to prominent researchers, themesand collaboration networks provide urban planners, energy expertsand policymakers with strategic and guiding insights.
- Guidance for Applications and Future Research: The findings of this study are expected to guide future research on zero energy neighborhoods and offer valuable insights into the applicability of ZENs in the creation of sustainable cities.

In this context, the study not only contributes to the academic literature but also sheds light on practical applications in urban planning and energy policies aligned with sustainable urbanization goals.

Current studies on zero energy neighborhoods encompass various strategies aimed at achieving energy efficiency, integrating renewable energy sourcesand reducing building energy consumption. These studies propose numerous solutions for the development and implementation of zero-energy buildingsand the expansion of these practices to the neighborhood level. At the same time, these practices increase energy efficiency and reduce carbon emissions.

The study first conducted a literature review on the concept of zero energy neighborhoods, shedding light on the perspectives of publications related to the topic.

In this study, a bibliometric analysis was conducted as an ideal approach to identify key themes, widespread collaborationsand influential researchers in the literature, using the search results from the Web of Science database based on the keywords "zero energy neighborhoods" and "net-zero energy buildings," as of November 2024. The analysis was carried out using the Vosviewer software. The bibliometric analysis method, which focuses on neighborhoods and energy efficiency, was applied to assess the main themes and collaboration relationships in zero energy neighborhood research. The study aims to examine fundamental concepts related to zero energy neighborhoods, such as energy efficiency, renewable energy sources, building designand low carbon emissions, as well as the academic development of this field.

As part of the bibliometric analysis, publication trends, author, institutionand country analyses, as well as social network and collaboration analyses, were conducted. Additionally, thematic analyses, including keyword networks and cluster analysis, were performed to evaluate the key research themes, collaborations among researchersand developmental trends in the literature. Through these analyses, a systematic evaluation of the knowledge accumulation in the field of zero energy neighborhoods was presented, considering the prominent themes in the literature, partnerships between researchersand international collaborations.

This study provides a comprehensive perspective on the current state of academic research on zero energy neighborhoods and the key trends in the literature. The bibliometric analyses reveal the influential researchers, collaboration networksand key themes in the field, aiming to deepen the understanding of how zero energy neighborhoods contribute to sustainable urban development. The findings of the study are expected to guide urban planners, energy expertsand policymakersand also

highlight potential areas for future research. This will provide important strategic information on how zero energy neighborhoods can be applied on a larger scale in the pursuit of creating sustainable cities.

In recent years, especially in Europe, the concept of zero energy neighborhoods has developed in line with energy efficiency and sustainability goals, with the aim of expanding the zero energy buildings concept to a broader neighborhood scale, creating collective energy management systemsand fostering sustainable living spaces.

The transition from zero-energy buildings to zero-energy neighborhoods is a transformation process triggered by developments in sustainability and energy efficiency. Zero-energy buildings (ZEBs) are structures where energy efficiency strategies are tested on a small scale and successful results are achieved. These buildings aim to reach net-zero energy consumption by producing as much energy as they consume. The use of innovative materials to improve energy efficiency in building design, passive and active solar energy systems, energy storage solutionsand smart building technologies are key aspects in this field. The sustainable success of zero-energy buildings has given rise to the concept of applying this idea at the neighborhood scale. The reasons behind the shift from zero-energy buildings to zero-energy neighborhoods are explained as follows (Skaar et al., 2018):

- Expansion from Building Scale to Neighborhood Scale: While ZEB focuses on energy efficiency of individual buildings, ZEN (Zero-Energy Neighborhoods) takes this concept to the neighborhood level. This transition requires a better understanding of the interactions between buildings and the flow of energy between them. At the neighborhood scale, buildings, energy systems, transportationand infrastructure are considered as a whole.

- Carbon Footprint and Energy Management: ZEN aims to balance the total energy consumption of a neighborhood with the renewable energy produced. This requires the calculation and management of the carbon footprint not only of the buildings but also of transportation and other infrastructure elements, ensuring sustainability at the neighborhood level.

- Life Cycle Assessment (LCA): While LCA is typically used in later stages of ZEB applications, ZEN aims to integrate this assessment into early design phases. This is important to better understand and optimize the environmental impacts of design decisions.

- Social and Community Aspects: ZEN also considers the social dimensions of neighborhoods. Through consultations with local stakeholders, the needs and characteristics of a specific neighborhood are understood. This ensures that sustainability goals align with the needs of local communities.

- Interconnectedness and Systems: At the neighborhood scale, interactions between buildings and infrastructure systems become more complex. Therefore, a more comprehensive decision-making process is needed during the design phase. ZEN proposes the use of parameter-based approaches and algorithms to manage this complexity.

Zero-Energy Neighborhoods (ZENs) are seen as a significant step toward reducing energy consumption in cities, combating climate changeand creating more livable environments. These neighborhoods integrate high-energy-efficiency buildings and renewable energy sources, achieving nearly zero total energy consumption while minimizing carbon emissions in the process. The concept has emerged as part of sustainable urbanization and efforts to combat climate change (Skaar et al., 2018; Kazmi et al., 2022; Edwards et al., 2024; Everitt et al., 2024). Zero-Energy Neighborhoods are designed with energy-efficient buildings (Kazmi et al., 2022), renewable energy sources such as solar panels, wind turbinesand energy storage systems (Everitt et al., 2024). Some key features of zero-energy neighborhoods, designed in alignment with sustainability and energy efficiency goals, are as follows (Verbruggen et al., 2020):

- Renewable Energy Sources: Zero-energy neighborhoods meet their energy needs by using renewable energy sources like solar panels and wind turbines.

- Energy Efficiency: Buildings are constructed using high-energy-efficiency materials, including proper insulation and energy-efficient lighting and appliances.

- Sustainable Design: Neighborhoods are optimized using passive design strategies such as natural light and ventilation, which reduce energy consumption.

- Public Transport and Walkability: Zero-energy neighborhoods are designed to be near public transportation systems and walkable areas, reducing the need for car use.

- Water Management: These neighborhoods incorporate sustainable water management practices, including water conservation and rainwater management.

- Community and Social Interaction: Zero-energy neighborhoods are designed with common areas and community activities that promote social interaction.

- Smart Technologies: Smart technologies and systems are used to monitor and manage energy consumption.

Zero-energy neighborhoods aim to reduce environmental impacts and increase energy independence, offering both economic and ecological benefits.

Backe et al. (2023) define zero-energy neighborhoods as communities consisting of interconnected buildings and distributed energy resourcesand they highlight their importance in local energy management, the use of smart energy management systems to balance energy demand and supplyand the adoption of circular economy principles such as efficient resource use and waste reduction.

Shaw-Williams et al. (2020) emphasize that zero-energy neighborhoods should have energy storage systems and smart grid technologies.

In a publication by Taveres-Cachat et al. (2019), zero-energy neighborhoods are discussed in the context of smart cities, highlighting the importance of integrating information and communication technologies (ICT) and the Internet of Things (IoT) in their design. These technologies can be used to manage the complex relationships between buildingsand responsive building facades are identified as having great potential for energy efficiency and reducing carbon emissions.

Salom et al. (2021) present a more comprehensive approach to the zero-energy neighborhood concept, considering not only energy efficiency and renewable energy production but also social sustainability, indoor environmental quality, flexibilityand life cycle costs. This concept, known as "sustainable plus energy neighborhoods," aims to achieve a local or regional surplus in energy production.

De Coninck et al. (2014) discuss zero-energy neighborhoods (ZEB) as residential areas built with low energy consumption goals, integrating renewable energy sources (especially photovoltaic systems and heat pumps). They emphasize the importance of these neighborhoods for energy efficiency and sustainability and detail the necessary strategies and management methods to achieve these goals.

Pinel et al. (2021) examine the impact of CO2 factors and external CO2 offset prices on the design of energy systems in zero-energy neighborhoods. They present a case study using an optimization model based on a neighborhood example in Norway, illustrating the role of different CO2 factors and offset mechanisms in ZEN design. This work contributes to the creation of sustainable living spaces by emphasizing the importance of local renewable energy investments and CO2 offset mechanisms.

Bilardo et al. (2021) emphasize the importance of fifth-generation, bidirectional, low-temperature regional heating and cooling networks for zero-energy neighborhoods. These networks aim to place entire communities at the center of the energy revolution, providing innovative solutions to meet community energy needs while enhancing energy efficiency and offering sustainable energy solution.

Zero-energy neighborhoods aim to establish a sustainable energy balance by considering not only the energy consumption of buildings but also the daily mobility of individuals. This approach emphasizes the importance of urban scale in solving environmental issues (Nematchoua et al., 2021). Isaac et al. (2020), in their study on the impacts of these neighborhoods on costs across different urban scales and densities, found that increasing the community scale reduces energy costs, though this effect is limited. They also observed that the impact of urban density on costs is more complex, varying depending on local climate conditions. They highlighted the importance of integrating energy system design in the early stages of urban planning and suggested that, under specific conditions, community-level solutions could be more cost-effective than building-level solutions.

Zero-energy neighborhoods play a critical role in combating climate change and building sustainable cities. These neighborhoods focus on issues such as energy efficiency, renewable energy

useand carbon emission reduction (Brozovsky et al., 2021). Zero-energy neighborhoods propose strategies to reduce greenhouse gas emissions, one of the primary causes of climate change. These strategies include (Lausselet et al., 2021):

- Passive House Technologies and Renewable Energy: ZENs aim to contribute to a low-carbon society by replacing energy produced from fossil fuels with locally generated renewable energy, combining passive house technologies with local renewable energy production to meet internal energy demand and export surplus energy to the external grid.

- Life Cycle Assessment (LCA): ZENs use life cycle assessment (LCA) methods to evaluate the climate change mitigation performance of a system, considering the environmental impacts and their causes at all stages of the life cycle, from material production to energy use.

- Emission Sources: It is observed that embedded emissions in materials play a greater role in buildings with high energy efficiency.

- Mobility and Energy Dynamics: The impact of mobility on emissions is emphasized.

- Policy Recommendations: It is emphasized that local governments should develop laws and guidelines to increase the potential for material recycling.

The role of zero-energy neighborhoods in combating climate change and their environmental impacts have been intensively studied. These neighborhoods are frequently highlighted for their ability to locally produce renewable energy, meet energy needsand send surplus energy to the grid. In this context, Lausselet and Brattebo (2021) stated that material efficiency, which involves using fewer materials to provide the same services, is crucial. They also noted that this process, resulting in reduced material production and processing during construction, could reduce overall greenhouse gas emissions. Furthermore, they suggested that the construction of new neighborhoods might affect local carbon storage balancesand land use changes should be carefully assessed for their environmental impacts.

The realization of zero-energy neighborhoods relies on the successful integration of a range of key concepts and technological applications. These neighborhoods are heavily dependent on technologies such as energy efficiency, renewable energy sources, energy storage, microgridsand digital energy management systems, forming sustainable, self-sufficient communities that produce and consume their own energy.

Urban planning plays a critical role in the integration and optimization of energy sources, providing a suitable framework for the development of energy infrastructure and the integration of renewable energy sources. Urban planning is a key factor in the creation of sustainable cities and the enhancement of energy independence by supporting the design and implementation of energy systems necessary for the success of zero-energy neighborhoods (Hachem-Vermette & Singh, 2021). The

design and planning of zero-energy neighborhoods (ZENs) must consider various elements. The key points to be considered in this process are outlined as follows (Skaar et al., 2022):

- Energy Efficiency: Energy efficiency should be a priority in the design of buildings and infrastructure. This can be achieved through the construction of high-energy-efficient buildings, good insulation, energy-saving systemsand lighting.

- Renewable Energy Sources: The integration of solar energy systems, wind turbinesand other renewable energy sources within the neighborhood is essential. These sources should be used to meet the neighborhood's energy needs.

- Smart Energy Management: The management of energy flows between buildings and interactions with the environment should be done in a smart and flexible way. This can be achieved through energy storage systems and smart grids.

- Sustainable Transportation: Sustainable transportation systems should be promoted within the neighborhood. This can be achieved through the integration of bicycle lanes, pedestrian pathwaysand public transportation systems. Additionally, charging stations for electric vehicles should also be planned.

- Economic Sustainability: Economic sustainability should also be considered in the design process. This involves minimizing total life cycle costs and supporting the local economy.

- Social and Spatial Quality: Well-planned public spaces, green areasand social services should be provided to enhance social interactions and improve quality of life within the neighborhood. This encourages sustainable behaviors.

- Databases and Tools: The use of tools such as Life Cycle Assessment (LCA) in the design of zero-energy neighborhoodsand the provision of the necessary data for these tools, is crucial for evaluating environmental impacts.

The design of zero-energy neighborhoods, which requires careful planning to achieve energy efficiency and sustainability goals, should consider the following elements (Pinel, 2020):

- Energy Production and Consumption: ZENs should increase energy production using local renewable energy sources (e.g., solar, wind, biomass), ensuring that energy consumption is locally met and reducing dependence on external sources.

- Clustering Methods: Different clustering methods should be used in the design of the energy system. For instance, the k-means algorithm stands out as an effective method for grouping energy consumption data. This method can be used to better understand and optimize energy demand.

- Optimization Models: Optimization models should be used in the design of the energy system. These models aim to minimize investment and operational costs while ensuring a balance between energy production and consumption. Properly structuring these models is crucial for ZENs to meet their zero-emission targets.

- Solar Irradiation Time Series: Solar energy plays a significant role in ZENs. Therefore, accurately modeling and analyzing solar irradiation time series is essential. High-quality data is critical to enhancing the performance of the energy system.

- Operation and Maintenance: During the design phase, the operational and maintenance costs of the energy system should also be considered. For long-term sustainability, the effective management of operation and maintenance processes is necessary.

- Community Participation: In ZEN design, it is important to consider the participation and needs of local communities. Community energy consumption habits and expectations should be integrated into the design process.

Public-private partnerships (PPP) play a critical role in creating sustainable and energy-efficient communities during the planning process of zero-energy neighborhoods. PPPs are an important factor in enhancing the success of the planning and implementation of ZENs. The elements that make this collaboration crucial for achieving sustainability goals are expressed as follows (Ekambaram et al., 2024):

- Resource Pooling: The public and private sectors can develop more effective projects by pooling financial, technicaland human resources. This enables faster and more efficient project implementation.

- Policy and Regulatory Support: The public sector can create the necessary supporting policies and laws for the development of zero-energy neighborhoods. This encourages the private sector's energy efficiency efforts and increases the feasibility of projects.

- Stakeholder Management: PPPs bring together various stakeholders (government, private sector, local communities, etc.), increasing the diversity and participation of stakeholders necessary for the success of the projects.

- Knowledge Sharing and Learning: Collaboration promotes knowledge sharing and learning. The public and private sectors can share their experiences and best practices to develop more effective strategies.

- Uncertainty Management: Zero-energy projects often involve uncertainties. PPPs can help develop better strategies to manage these uncertainties.

Literature studies focus on the design and operation of zero-energy neighborhoods, as well as the integration of distributed energy storage systems. Sameti & Haghighat (2018) highlight that the main points in this context are energy production and consumption, energy storage systems, economic and environmental benefitsand optimization of energy system performance under different scenarios. As a result, zero-energy neighborhoods offer an important model for sustainable energy management, providing economic benefits while reducing environmental impacts.

Although research on zero-energy neighborhoods makes significant contributions to sustainable urban planning and low-carbon emission targets, there are some gaps and research needs in the literature. Particularly, the literature is limited in terms of collaboration networks and international comparisons. Comparisons between countries are crucial for zero-energy neighborhoods due to the unique energy infrastructures, climatesand urban policies in each country. However, existing studies are often limited to single countries or specific projectsand broader, comparative analyses are lacking. These gaps restrict the global exchange of knowledge and learning.

Similarly, there is a need for further investigation into collaboration networks in research on zero-energy neighborhoods. Limited information in the literature fails to fully capture the connections between key actors (researchers, institutionsand countries) that could play a crucial role in the spread and adoption of zero-energy neighborhoods. This study aims to address these gaps and strengthen collaborations, offering a new perspective in the literature.

In conclusion, this study contributes to the literature by analyzing key themes related to zero-energy neighborhoods, as well as the levels of collaboration among countries, institutionsand researchers. Such comprehensive bibliometric analyses are crucial for guiding the development of international strategies to expand the implementation of zero-energy neighborhoods on a broader scale.

Methodology

Bibliometric Analysis Method

Bibliometric analysis is a research method that evaluates the impact and spread of scientific literature using quantitative data, providing an objective perspective on the examination of scientific knowledge production and academic contributions. This method, frequently used to assess the scientific productivity of researchers, institutionsand countries, relies on detailed analysis of bibliographic indicators such as citation counts, h-index and publication trends. Bibliometric analysis contributes to decision-making processes by offering objective measurements, especially in areas like funding allocation, resource distribution and research strategy development. This method provides a broad perspective for detecting research trends, collaboration networksand emerging topics, while also highlighting the most influential researchers and institutions in specific fields, making their contributions to the scientific world visible. The data obtained from bibliometric analysis not only evaluates scientific production but also shows which areas are open to development and which actors

are leading this growth. Therefore, when combined with interdisciplinary data mining, bibliometric analysis becomes a powerful tool that offers deep insights into the research world. Commonly used bibliometric analysis tools are as follows (Zengin Gengoru, 2024):

- Web of Science: A frequently used source for bibliometric analysis, covering a vast database of scientific literature, citationsand journal interactions.

- Scopus: A robust database of academic publications and citations, widely used for bibliometric analysis.

- Google Scholar: A source that scans academic publications and shows citations, frequently used for bibliometric analysis.

- Vosviewer: A tool used to visualize relationships and networks between articles.

- CiteSpace: A tool used for analyzing and visualizing scientific publications, revealing relationships between keywords, authorsand citations.

- BibExcel: An Excel-based tool containing a range of statistics and visualizations for bibliometric analysis.

- SciMAT: Another bibliometric analysis tool used to track and visualize the development of scientific literature.

For this study, Vosviewer software was used in the bibliometric analysis process.

Data Collection

The data for this study were collected in November 2024 using the Web of Science (WoS) database, one of the most comprehensive and widely used bibliographic databases in academic research. This database was chosen due to its extensive coverage of peer-reviewed journals and its robust bibliometric analysis capabilities. The primary objective of the data collection was to identify significant trends, research collaborations, focal areas, and emerging directions in zero-energy neighborhoods research.

To ensure the inclusion of relevant and comprehensive data, a keyword search strategy was employed. The keywords "zero energy neighborhoods" and "net-zero energy neighborhoods" were selected based on their frequent usage in the literature and their alignment with the study's focus. The search included all publication types (articles, conference papers, reviews, etc.) and covered a time span up to November 2024.

The results from the WoS database were exported in tab-delimited format, which preserves all bibliographic information, including titles, abstracts, authors, affiliations, keywords, and citations. These exported files were pre-processed to remove duplicates and irrelevant records, ensuring the

data's reliability and accuracy. The cleaned dataset was then formatted for bibliometric analysis using the VOSviewer software, a specialized tool for constructing and visualizing bibliometric networks.

VOSviewer was chosen for its capability to create network maps and identify patterns in large datasets. The software's "Create a map based on bibliographic data" and "Read data from bibliographic database files" options were used to generate visualizations and analyze co-authorship, keyword co-occurrence, and citation networks. These features enabled the identification of research trends and collaboration structures.

Analysis Criteria

Two primary bibliometric analysis methods were applied in this study to thoroughly examine the academic literature on zero-energy neighborhoods: social network and collaboration analysisand thematic analysis. The social network and collaboration analysis includes collaboration between authors, countriesand institutions. Thematic analysis focuses on analyzing the clusters formed by keywords. These analyses are crucial for identifying research trends, collaboration networksand key themes in the literature.

Author Collaboration: Analysis of Most Frequent Collaborating Authors

Author collaboration analysis identifies the most frequent researchers working together in a particular field and the network structure of these collaborations. This analysis, conducted using VOSviewer, examined the collaborative efforts of authors in articles related to zero-energy neighborhoods. The results revealed the leading researchers in the field and the institutions they collaborate with most intensively. Additionally, the clustering structure of author collaborations helped in understanding research groups and interdisciplinary interactions. This analysis provided valuable insights into how information sharing and joint projects have developed in the field of zero-energy neighborhoods.

Country and Institution Collaboration: Collaboration Among Countries and Institutions Contributing the Most to the Literature

Country and institution collaboration analysis evaluates the partnerships between countries and institutions that produce and support the most research in zero-energy neighborhoods. This analysis investigated the countries that have made the greatest contributions to the literature and their collaborative efforts, as well as the most influential institutions and their international collaborations. The findings highlighted the leadership roles of specific countries and institutions in this areaand the intensity of their collaborations with other countries. Particularly, countries and universities at the forefront of energy efficiency and sustainable urban planning were observed to make significant contributions, along with research centers in these countries. Furthermore, it was determined that international collaborations enable the spread of knowledge and technology and facilitate the execution of research projects on a larger scale.

Keyword and Thematic Analysis: Keyword Networks and Clustering Analysis

Keyword and thematic analysis aims to identify the prominent topics in the zero-energy neighborhoods literature and the relationships between these topics. Using VOSviewer, this analysis examined the most frequently used keywords in publications on zero-energy neighborhoods and visualized the relationships between these keywords in network maps. Through clustering analysis, key themes such as energy efficiency, renewable energy sources, building designand carbon footprint reduction were identified. Each cluster represents sub-themes related to different aspects of zero-energy neighborhoodsand these themes reveal the research trends and focal points in the literature. For example, the energy efficiency cluster includes studies focused on developing technologies and methods for energy savings in buildings, while the renewable energy sources cluster encompasses research on the use of solar and wind energy at the neighborhood level. This thematic analysis offers a structural assessment of the zero-energy neighborhoods literature, identifying areas for future research and highlighting research gaps.

These three bibliometric analysis methods provide a comprehensive evaluation of the academic literature on zero-energy neighborhoods and allow for a deep understanding of research trends, collaboration networksand key themes in the field. Author collaboration analysis reveals the leading researchers and their collaborations, while country and institution collaboration analysis helps identify international collaborations and contributing countries. Keyword and thematic analysis visualizes the main research topics and their interrelationships, contributing to the identification of future directions for the field. These comprehensive analyses offer valuable insights for developing sustainable urban planning and energy efficiency strategies for zero-energy neighborhoods and facilitate more effective guidance of future research in this area.

Findings

In this research, the concept of "zero energy neighborhood" was searched in the Web of Science database in November 2024 and subjected to analysis. The distribution of the total number of publications related to "zero energy neighborhood" by year is presented with relevant visuals.

Publication Years	Count
2024	51
2023	46
2022	43
2021	60
2020	42
2019	42
2018	36
2017	22
2016	21
2015	25

2014	26
2013	16
2012	22
2011	11
2010	12
2009	14
2008	15
2007	8
2006	9
2005	6
2004	5
2003	8
2002	4
2001	2
2000	10
1999	4
1998	5
1997	1
1996	8
1995	2
1994	4
1993	3
1992	3
1991	6
1989	1
1986	2

Table 1. Distribution of Publication Numbers by Year (Web of Sciences, 2024)

Looking at the distribution of publications, it is observed that research on "zero energy neighborhoods" began in 1986 with 2 publications, experienced a rapid increase in 2008and reached 51 publications by 2024. The significant rise in the number of publications, particularly in the last 10 years, indicates a growing trend in the literature on this topic in recent years.

Regarding the types of publications, it is evident that publications from every category are represented, with a particularly high number of 484 research articles included.

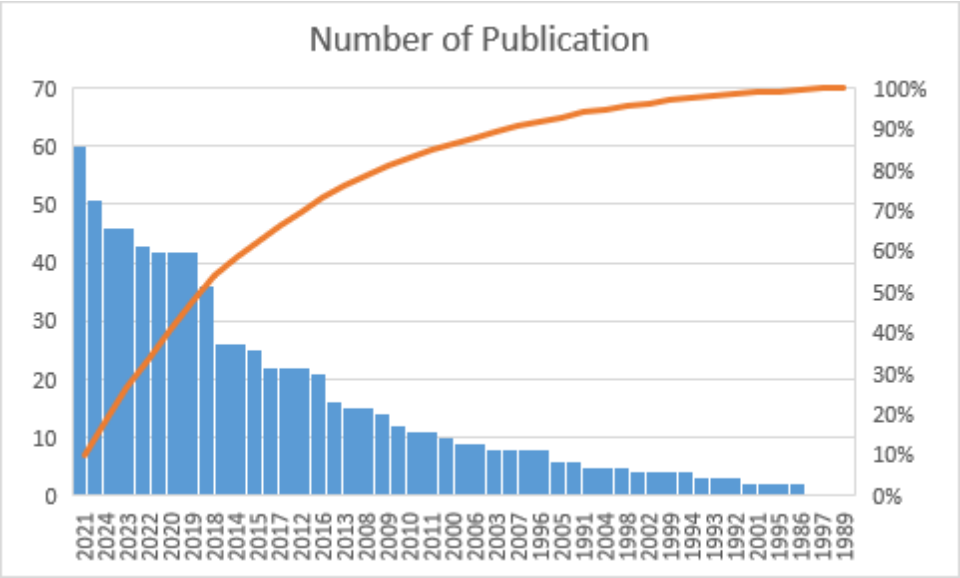

Figure 1. Distribution Graphic of Publication Numbers by Year (Web of Sciences, 2024)

Document Types	Count
Article	484
Proceedings Paper	80
Review	27
Early Access	9
Editorial Material	7
Book Chapter	5
Book Review	1
Letter	1
Meeting Abstract	1

Table 2. Distribution of Publication Types (Web of Sciences, 2024)

The table presents the types and numbers of documents related to zero energy neighborhoods in the literature. This data helps us understand the research trends and publication formats in the field:

- Articles: The most prevalent publication type (484 articles), indicating that the majority of research is presented as original scientific papers published in peer-reviewed journals. This reflects a broad research base and strong academic interest in zero energy neighborhoods.

- Proceedings Papers: In second place with 80 papers, conference proceedings are frequently published, highlighting that the topic is actively discussed at academic conferences where new ideas, developmentsand techniques are shared.

- Reviews: With 27 articles, review papers contribute by summarizing research, providing critical analysesand identifying gaps in the literature. These publications offer a general overview, enhancing the collective knowledge in the field.

- Early Access and Editorial Materials: These types of publications reflect the current state of the literature, including studies that have been recently published or are forthcoming, contributing to ongoing discussions.

- Book Chapters and Other Publication Types: Book chapters contribute to detailed analyses of broader topics, while fewer publications like book reviews, lettersand meeting abstracts represent more specific or interpretive aspects of the discussions.

This table shows that original articles are the most prominent in academic research on zero energy neighborhoods. The topic is addressed intensively through both scientific articles and conference proceedings, suggesting that various publication formats complement each other in the field's development.

Findings of Social Network and Collaboration Analysis

Author Citation Analysis

A citation analysis was conducted to identify the most cited authors in zero energy neighborhood research. The analysis revealed that the authors with the highest number of citations are Helge Brattebo and Carine Lausselet, whose publication titled "Environmental co-benefits and trade-offs of climate mitigation strategies applied to net-zero-emission neighbourhoods (2021)" received the most citations. This indicates their significant contributions to the field of zero energy neighborhoods, particularly in the context of climate mitigation strategies.

Author	Documents	Citations
Brattebo, Helge	6	152
Lausselet, Carine	6	152
Andresen, Inger	5	105
Hachem-Vermette, Caroline	8	105
Pinel, Dimitri	5	47
Singh, Kuljeet	5	35
Cavalcanti, Marcelo M.	6	33
Sartori, Igor	5	14

Table 3. Most cited authors and citation counts (Web of Science, 2024)

When examining the network graph of the author citation analysis, it is evident that Helge Brattebo and Carine Lausselet are directly connected to each other. Additionally, Inger Andresen and Dimitri Pinel are also part of this citation network, albeit indirectly. This indicates that while Brattebo and Lausselet have a direct collaborative or citation relationshipandresen and Pinel are part of the

broader academic discourse surrounding zero energy neighborhoods, contributing to the network through indirect connections.

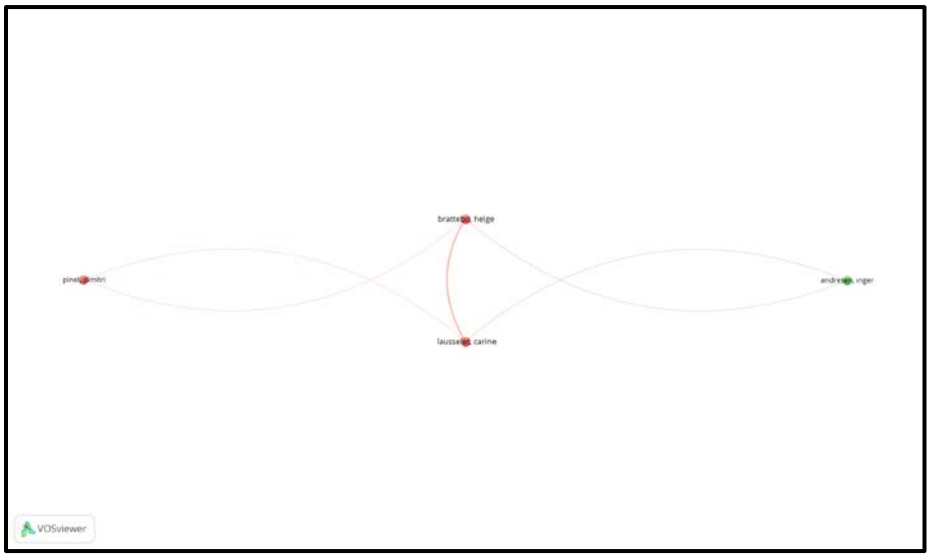

Figure 2. Author citation analysis graph.

Organization Citation Analysis

To showcase the research institutions that have made the greatest contributions to the literature and the number of citations they have received, an institution citation analysis was conducted. The institution citation analysis graph can be found in Figure 3.

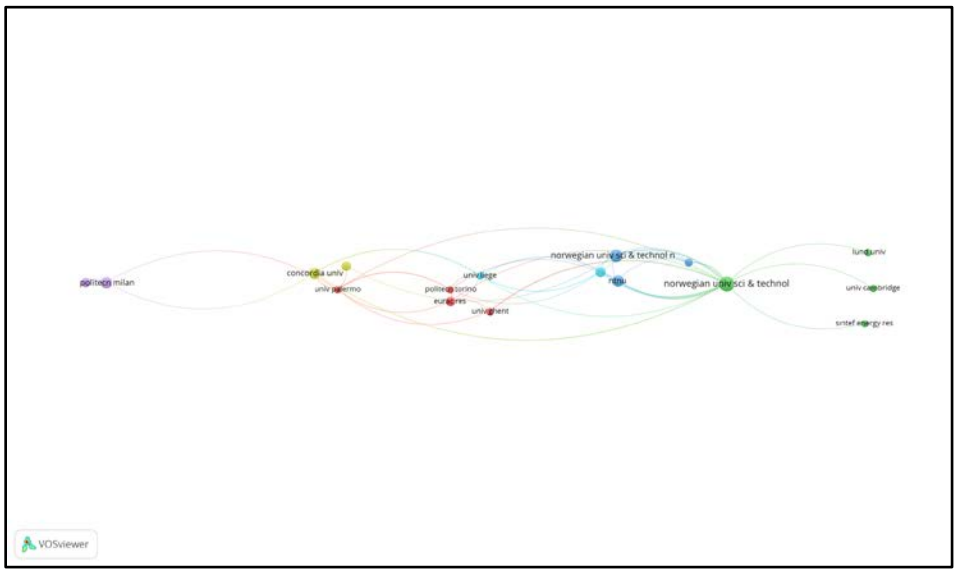

Figure 3. Organization citation analysis graph

The analysis shows that the institution with the highest number of publications, totaling 19, is the Norwegian University of Science and Technology. The total citation count for the publications from this institution is 522.

Organization	Document number	Citation
Norwegian University Science & Technology	19	522
Norwegian University Science & Technology, NTNU	13	150
Concordia University	11	361
Polytechnic University of Milan	11	210
State University of Maringá	11	54

Table 4. Organizations with the most publications and citation numbers (Web of Science, 2024)

Country Citation Analysis

A country citation analysis was conducted to identify the countries with the most research activity and to explore the relationships between them.

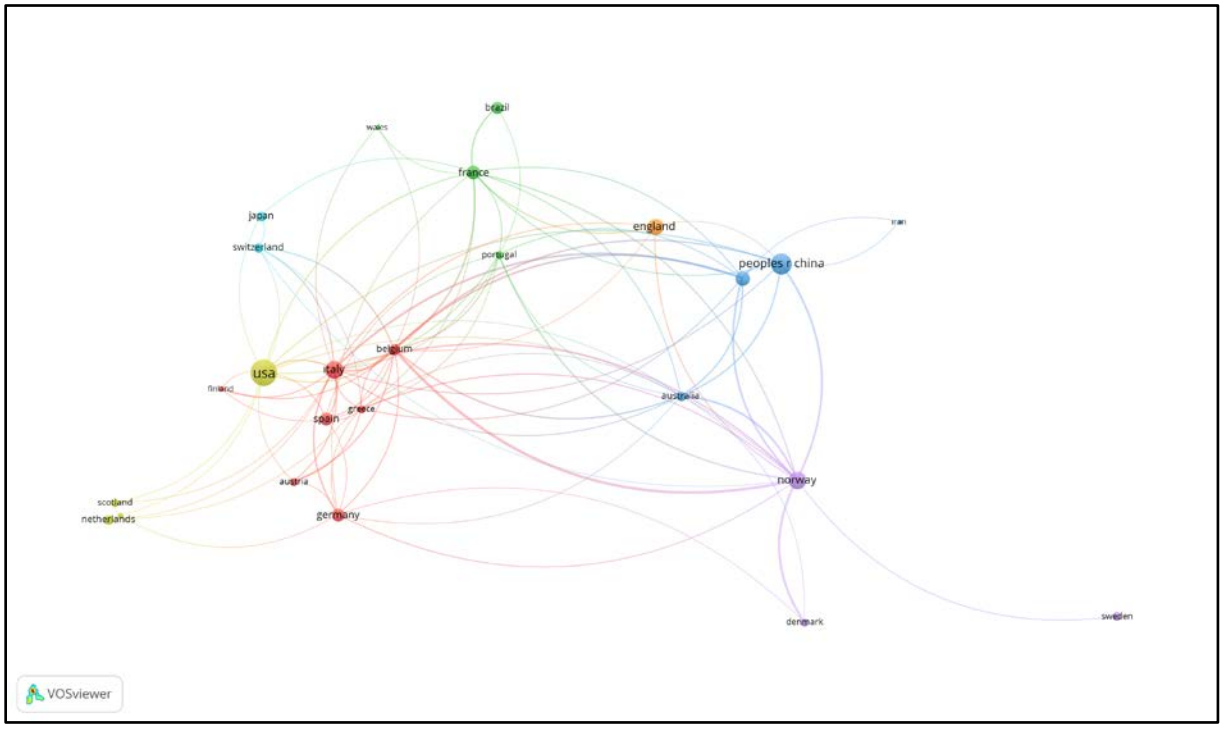

Figure 4. Country citation analysis graph

As a result of the country citation analysis, the countries with the most citations are led by the USA with 121 publications. Germany ranks second with 1,600 citations, France is third with 1,520 citationsand Australia ranks fourth with 1,180 citations (see Table 5).

Country	Document Number	Citation
The USA	121	3781
Germany	31	1600
France	32	1520
Australia	18	1180
Japan	18	1145
China	74	1122
Norway	55	1112
England	44	1044
Denmark	11	1036
Sweden	14	909

Table 5. Most cited countries and citation numbers (Web of Science, 2024)

Thematic Analysis

Keyword Networks

To highlight the prominent keywords related to "zero energy neighborhood" and their interrelationships, keyword networks have been prepared (see Figure5).

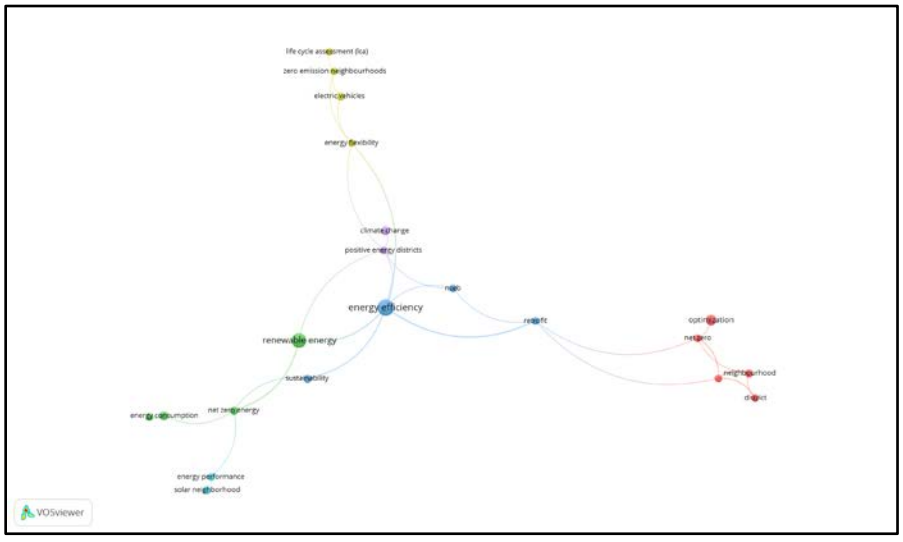

Figure 5. Keyword relationship analysis chart

The keyword analysis reveals that terms such as "energy efficiency," "renewable energy," "climate change," and "sustainability" are prominent in the field.

Cluster Analysis and Themes

A cluster analysis was performed on the keywords related to the publications on the topicand the analysis resulted in the identification of two clusters (see Figure 6).

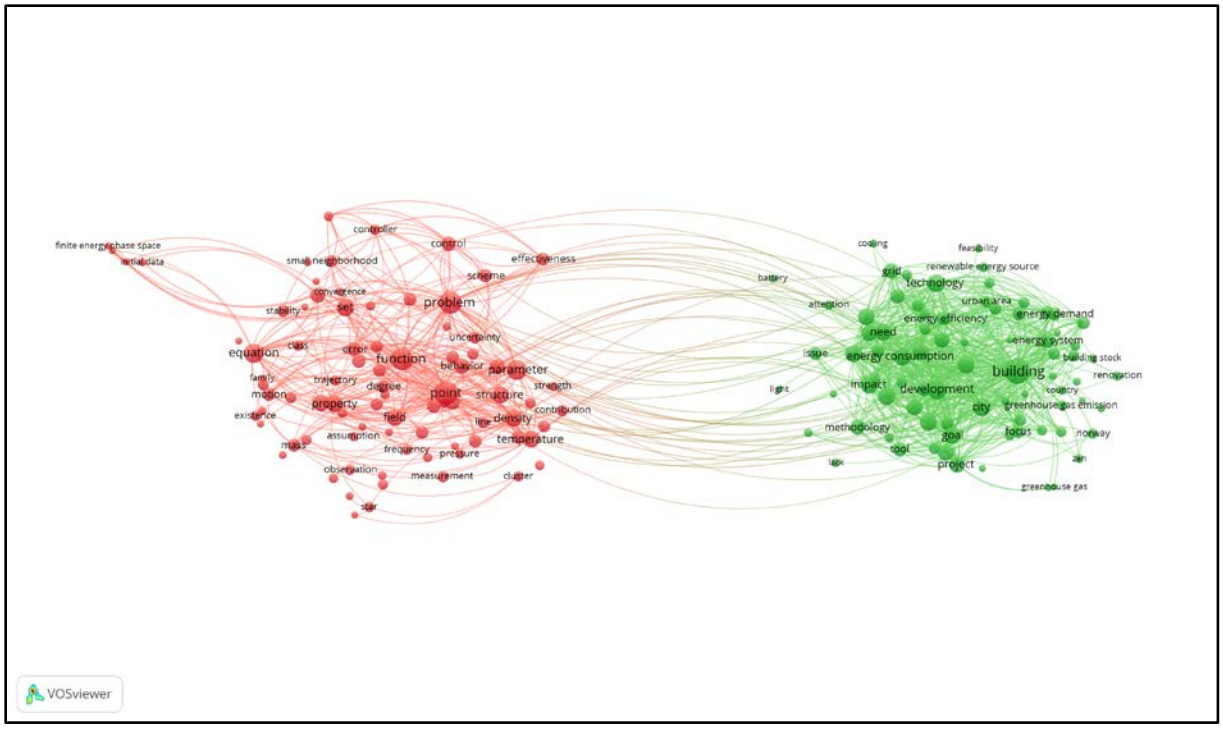

Figure 6. Cluster analysis graph

The keywords in the two clusters identified are as follows:

- Cluster 1: point, parameter, function, property, small neighborhood, problem, density, effectiveness, control, observation, temperature

- Cluster 2: buildings, energy consumption, heating, energy demand, renewable energy source, emission, greenhouse, gas emission, renovation

In this study, the clusters are interpreted within the context of urban planning and energy efficiency and are named as follows:

- Energy Efficiency and Monitoring Parameters: This cluster focuses on the fundamental measurements and monitoring parameters related to energy efficiency. In the context of urban

planning, this heading aims to understand which parameters are important for effectively managing energy consumption and how energy efficiency can be evaluated. This concept includes techniques used to monitor and control energy efficiency, as well as the necessary analyses to ensure energy conservation. Monitoring energy use is a critical step in ensuring the sustainability of a city or neighborhood. Such monitoring and control points can assist urban planners in developing more efficient energy management strategies.

- Building Energy Consumption and Carbon Reduction: The second cluster focuses on energy consumption in buildings and the reduction of greenhouse gas emissions. The energy efficiency of buildings plays a significant role in both reducing energy demand and minimizing carbon emissions. This cluster discusses sustainable solutions such as the use of renewable energy sources, reducing energy demandand cutting greenhouse gas emissions. These elements are vital when creating zero-energy neighborhoods because these solutions contribute to reducing environmental impacts and ensuring the sustainability of urban areas.

In conclusion, this study emphasizes the importance of key concepts such as energy efficiency and carbon reduction in the development of zero-energy neighborhoods. The relationship between energy efficiency, monitoring parameters, building energy consumptionand carbon reduction plays a crucial role in developing strategies for creating sustainable cities. These clusters identify the essential elements needed to minimize energy consumption and environmental impacts in urban planning processes and offer practical solutions. Ultimately, this study provides an in-depth analysis of zero-energy neighborhoods and sustainable energy solutions, offering significant guidance for urban planners, energy expertsand policymakers.

Discussion

The bibliometric development of the concept of Zero Energy Neighborhood (ZEN) has been shaped by increasing interest in recent years. Literature reviews have revealed that this concept has become a significant research area, particularly in the context of energy efficiency, sustainable urban planningand combating climate change. The growing number of studies and the expanding geographical distribution indicate that ZEN is not only an academic concept but also a practically applicable research field that has garnered worldwide attention. Moreover, the prominence of research conducted particularly in Europe and North America highlights the role of regional energy policies in shaping this concept. Trends in the literature show that various technological innovations and sustainable strategies related to ZEN practices have become a focal point.

One of the key factors influencing the development of the Zero Energy Neighborhood concept is academic collaboration. Multidisciplinary approaches, particularly those combining energy efficiency, urban planning, environmental engineeringand socio-economic factors, have created new research opportunities. It can be said that international energy policies have played a role in the spread of this concept. The European Union's sustainability and energy efficiency policies have contributed to the rapid development of ZENand the incorporation of innovative technologies into research literature

has accelerated this process. Additionally, international collaborations and innovations have encouraged the implementation of ZEN projects in cities around the world with similar goals. These interactions have had a significant impact on the evolution of the concept.

There are notable gaps in the literature, particularly concerning the challenges faced by ZEN practices in different geographies and how these practices can be aligned with local energy policies, which require further research. Furthermore, the lack of comparative studies between countries prevents us from understanding how ZEN differs on a global scale. Future research should focus on how ZEN practices can be adapted in developing countries and develop strategies to overcome the barriers in this process. Additionally, more emphasis should be placed on academic collaboration and innovative technologies for the development of new thematic areas. In this context, ZEN should be supported by more in-depth analyses and applied studies related to energy efficiency, sustainable urban planningand environmental impacts.

Conclusion

Bibliometric analysis in the field of Zero Energy Neighborhood (ZEN) has revealed significant academic development in recent years. Literature reviews show that most research in this area is concentrated around key themes such as energy efficiency, sustainable urban planning, renewable energy sourcesand carbon emission reduction. Additionally, the number of studies on ZEN has been steadily increasing, with a particularly higher number of case studies found in Europe and North America. Collaboration analyses highlight the strong network formed by influential authors and institutions in the ZEN field, emphasizing the role of this network in the global spread of the concept. Keyword analysis illustrates how key themes in this field have evolved over time and which research areas have gained prominence.

This study has generally assessed the significant research areas and themes in the zero energy neighborhood literature. Key topics in the studies include energy efficiency, renewable energy systems, microgridsand low-carbon buildings. Influential works in the literature demonstrate that ZEN has the potential to serve as a model for sustainable cities, providing both energy efficiency and carbon reduction simultaneously. Furthermore, it has been determined that academic collaborations and international relations have enhanced the quality and effectiveness of research in this area. In this context, the main themes in the literature shed light on the important factors that will ensure the applicability and spread of ZEN.

The findings of this study provide significant strategic insights for policymakers and practitioners. The data obtained serves as a guide for the widespread applicability of the zero energy neighborhood (ZEN) concept. The following recommendations have been developed for use in policy development processes:

- Development of Energy Policies: The thematic and collaboration network analyses presented in this study can guide the creation of national and local energy policies related to zero energy

neighborhoods. In particular, mechanisms and standards that promote cross-country collaboration are recommended.

- Public-Private Sector Collaboration: Collaboration between the public and private sectors plays a critical role in the implementation of zero energy neighborhoods. In this context, public-private partnerships that encourage innovative financing models and technology transfer processes should be established.
- Innovative Energy Management Models: Smart energy management systems should be developed to optimize energy production, storageand consumption at the neighborhood scale. This study lays the groundwork for the development of innovative models that can enhance energy efficiency and reduce carbon emissions.
- Local Government Strategies: The findings indicate that local governments should place greater emphasis on areas such as sustainable transportation, renewable energy sourcesand green infrastructure during the planning and implementation of zero energy neighborhoods.
- Community Engagement and Awareness: Community participation and awareness are crucial for the sustainable success of zero energy neighborhoods. Participatory processes that consider the needs and expectations of local residents are recommended in this context.

From a practical perspective, this study demonstrates that zero energy neighborhoods are not merely a theoretical concept but also offer concrete policy and implementation solutions. The findings provide a roadmap for energy planning, urban designand sustainable urbanization strategies.

For the deepening of the zero energy neighborhood literature, future research should focus on several key areas. First, it is important to conduct more research on how ZEN can be adapted and implemented in different geographies. Specifically, studies on the barriers and opportunities of ZEN applications in developing countries should be prioritized. Additionally, an increase in comparative research between countries could help us better understand the different global impacts of ZEN. It is also believed that studies should provide more insight into how energy policies, local governmentsand public-private sector collaborations can be integrated into ZEN projects. Moreover, understanding the role of innovative technologies and digitalization in ZEN applications is an important area for future research.

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