Analyzing global research trends in urban resilience and its nexus with renewable energy and climate change: a bibliometric study (2000–2025)

Review Article

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Shahriar Rezaee[1], Maryam Torkaman[2], Mostafa Behzadfar[3*]

1. M.Sc. Student in Urban Planning, Department of Urban Studies, Faculty of Architecture and Art, University of Guilan, Rasht, Iran
2. PH. D Candidate, Department of Urban Planning, School of Architecture and Environmental Design, Iran University of Science and Technology, Tehran, Iran
3. Professor, Department of Urban Planning, School of Architecture and Environmental Design, Iran University of Science and Technology, Tehran, Iran

Abstract

Urban resilience has emerged in the twenty-first century as a key paradigm for confronting climate-change–induced stresses and associated hazards. Its linkage with renewable energy is fundamental, as clean-energy infrastructure facilitates decarbonization. This study aimed to chart the scientific evolution of the “urban resilience–renewable energy–climate change” nexus from 2000 to 2025. Records were retrieved from Scopus using TITLE-ABS-KEY queries centered on urban resilience, renewable energy, and climate change, then harmonized by consolidating synonyms and near-terms (e.g., PV/photovoltaic; NBS/green infrastructure) and deduplicating entries. The final dataset comprises 460 records; the subject-area distribution indicates environmental sciences (> 400), social sciences (~280), and energy (~150). Output has grown more than threefold since 2015, peaking at ~80 publications in 2024 and > 110 in 2025. Geographically, China and the United States lead, with India and Iran emerging as growing contributors. Keyword co-occurrence analysis in VOS viewer (Association Strength normalization; complete counting) reveals three dominant clusters: (1) resilience–climate change and risk management; (2) governance, justice, and energy policy; and (3) urban microclimate, remote sensing, and urban morphology. Journal outlets are led by Sustainability (Switzerland) (~80 papers) and Sustainable Cities and Society (~25 papers). The field is shifting from purely conceptual debates toward applied agendas, such as green infrastructure, urban hydrological risk management, and data-driven urban climatology. Key gaps persist, including the absence of integrated “resilience–energy–ecosystem” metrics, cross-scale disconnects between building and city scales, and the under-representation of spatial/energy justice. The study provides a reproducible quantitative map of this triad and, at the policy level, highlights three priorities: integrating nature-based solutions with renewable energy systems, deploying an urban microclimate monitoring network, and institutionalizing energy justice within urban planning.

Keywords

Climate Change
Co-occurrence
Flood Risk Management
Renewable Energy
Urban Resilience

* Corresponding Author: behzadfar@iust.ac.ir

1. Introduction

The accelerating pace of urbanization, the rising demand for energy, and the intensifying impacts of climate change have positioned urban resilience as a central pillar in global policy and planning agendas (UN, 2019; IPCC, 2022). Over recent centuries, particularly in the twenty-first century, the expansion of human settlements and the growing trend of industrialization have served as indicators of economic and social progress in urban areas, generating substantial environmental consequences and pressures on natural resources (Torkaman & Jalilisadrabad, 2024). At the same time, the notion of valuing and protecting the environment has a long historical trajectory, yet its significance has become increasingly evident in the modern era. The human role in confronting environmental challenges and proposing practical solutions has consequently attracted growing attention from scholars and policymakers alike (Salaripour et al., 2025; Salaripour & Zareh, 2019). Within this context, the concept of urban resilience has evolved beyond the traditional notion of bouncing back toward a transformative framework aimed at reducing fossil-fuel dependency, advancing energy justice, and achieving long-term sustainability (Elmqvist et al., 2019; McPhearson et al., 2015; Romero-Lankao & Gnatz, 2022). Concurrently, the scientific literature has increasingly focused on examining the interconnections between resilience, climate change, and the energy transition. With the consolidation of nature-based frameworks and green infrastructure (GI) concepts at the urban scale, recent research has increasingly combined clean technologies with ecological solutions at the building and neighbourhood levels (Fleck et al., 2022). However, systematic reviews reveal that only a limited share of studies (approximately 11%) directly address the energy dimension, thereby constraining the integration of nature-based solutions (NBS) and urban governance with the energy-transition agenda (Schlör et al., 2018). Amid escalating scenarios of heatwaves and flooding, the linkage between resilience and energy, particularly at the network and microgrid levels, has gained strategic importance (Rafael et al., 2016; Ottenburger et al., 2024). From a policy perspective, climate-adaptive planning must integrate NBS/GI components with renewable urban energy technologies such as rooftop PV systems, biosolar roofs, and waste-to-bioenergy conversion in order to reinforce both climate and energy resilience (Yu et al., 2017; Tablada & Zhao, 2016; Fleck et al., 2022). Despite these advances, several critical gaps persist in the literature: limited attention to the systematic linkage between urban resilience and energy (Ahern et al., 2021; Romero-Lankao & Gnatz, 2022); a scale disconnect between the building–neighborhood–city levels (Güneralp et al., 2021; Hsu et al., 2023); the absence of integrated indicators that simultaneously measure resilience, energy efficiency, and ecosystem services (Sharifi et al., 2022; Meerow & Stults, 2021); challenges of justice and governance in distributed-energy systems (Anguelovski et al., 2023; Rice et al., 2022); and persistent gaps in science–policy translation despite the proliferation of big-data platforms and monitoring systems (McPhearson et al., 2023; Chu et al., 2022). Accordingly, the present study conducts a comprehensive bibliometric analysis covering the 2000–2025 period to trace conceptual and practical trajectories, thematic clusters, influential actors, and research gaps within the urban resilience–renewable energy–climate change nexus. This research contributes several innovations:

1. Comprehensive quantitative mapping: It provides, for the first time, a systematic and reproducible global map of the scientific evolution of the urban resilience–renewable energy–climate change interface, documenting the persistent underrepresentation of the energy dimension within resilience research.
2. Temporal and multi-scalar analysis: Through precise coding of energy-related terms and keyword co-occurrence analysis across multiple time slices, the study traces the conceptual evolution of the field from the building and neighborhood scales up to the urban and network levels.
3. Justice-centred network analysis: By incorporating keywords related to justice and equity alongside energy and NBS, the co-citation network identifies bridging scholars who act as intermediaries linking the subfields.
4. Framework development: The study proposes a preliminary set of integrated resilience–energy–ecosystem indicators grounded in recent critical reviews and, finally, aligns the findings with global policy frameworks such as the Sustainable Development Goals (SDGs) and the IPCC recommendations to suggest actionable strategies for transitioning toward low-carbon and resilient cities.

Methodologically, the use of bibliometric tools to analyze collaboration and co-citation networks, along with term evolution analysis, enables a fine-grained depiction of knowledge evolution pathways. By identifying conceptual trends and key actors, this approach reveals prospective trajectories for just energy transitions in cities, highlighting both research gaps and opportunities for interdisciplinary collaboration.

In line with these objectives, the study focuses on Scopus-indexed publications from 2000 to 2025 and pursues four main goals: (a) Quantifying publication and citation trends, and identifying journals and research domains related to the urban resilience–energy–climate change nexus; (b) Detecting and labelling thematic clusters and emerging hotspots including NBS and green infrastructure, the Food–Energy–Water (FEW) nexus, energy efficiency and microclimate, distributed-energy infrastructures and microgrids, and governance and justice and examining their dynamic evolution; (c) Identifying influential authors, institutions, and countries, and analyzing collaboration patterns; (d) Formulating knowledge gaps and future research pathways for multi-scalar integration of NBS with renewable systems, developing integrated resilience–energy indicators, and revealing underexplored areas.

2. Literature review

Over the past decade, the literature on urban resilience has evolved from reactive approaches toward transformative and integrated frameworks that align with climate policy and energy transition agendas. The growing stream of nature-based solutions (NBS), particularly in connection with flood resilience and risk management, has increasingly been embedded into assessment and decision-making frameworks. However, it still requires "integrative tools" capable of linking risk metrics, ecosystem services, and urban planning indicators. This conceptual shift clearly demonstrates that effective resilience cannot be achieved without coupling with policy-oriented and data-driven instruments such as earth observation, risk indicators, and evidence-based planning frameworks (de MacEdo et al., 2025; Pirrone et al., 2022).

Concurrently, recent studies emphasise justice as an inseparable dimension of resilience. Research from 2024 to 2025 shows that inequalities in heat exposure and access to green infrastructure benefits have significant socio-spatial implications, necessitating distribution-sensitive indicators for their assessment (Zhang et al., 2025; Gallez et al., 2024). Critical reviews also expose systematic gaps in equitable access to ecosystem services and highlight disparities based on class and location. Without embedding justice into resilience interventions, these measures may unintentionally reinforce inequality (Haque & Sharifi, 2024). In the domain of heat-resilience, emerging literature has increasingly linked urban design, microclimate, and energy demand. Studies from 2022 to 2025 demonstrate that fine-scale mapping of urban heat islands and heatwave patterns is crucial for estimating building thermal performance and managing peak electricity loads; otherwise, urban energy models remain prone to significant errors and poor generalizability (Karimi et al., 2025; Xu et al., 2022). These findings highlight the significance of utilizing local data, model calibration, and integrating microclimatic information into resilience assessments (Xu et al., 2022). Integrating renewable technologies with NBS at the building–neighbourhood scale has emerged as one of the most promising pathways. Empirical evidence on biosolar roofs, the co-location of green roofs and photovoltaic systems, shows that such designs can enhance electrical efficiency while simultaneously reducing surface temperatures and cooling loads.

However, the magnitude of these benefits depends on climate conditions, irrigation practices, and system configuration, necessitating context-specific design. These advances reinforce the link between building energy efficiency and ecological benefits, highlighting the need for multidimensional performance indicators (Fleck et al., 2022). At the network scale, the rising frequency of extreme events and infrastructure vulnerabilities has drawn attention to microgrids and distributed energy systems. Conceptual frameworks introduced in Nature Sustainability (2024) reveal that integrated microgrid design can enhance the resilience of essential services. However, without embedding spatial justice and participatory governance, there is a risk of creating energy enclaves that reproduce existing inequalities (Ottenburger et al., 2024). At the urban scale, aligning decarbonisation and resilience goals and identifying their co-benefit drivers has become a central research priority, particularly in large metropolitan contexts (Zhou et al., 2025). In the policy and implementation domains, two parallel lines of progress are converging: one focusing on the integration of NBS into vulnerable and informal neighborhoods (e.g., e-waste management), and the other on ranking green infrastructure priorities using equity-based and multi-criteria approaches (Asibey & Cobbinah, 2025; Dong et al., 2024). These trends suggest that the success of resilience initiatives depends not only on technical performance but also on social–institutional fit and justice-based metrics (Dong et al., 2024; Haque & Sharifi, 2024).

Despite considerable advances, several fundamental challenges persist. First, energy remains underexplored in a large portion of urban resilience studies compared to the more dominant themes of climate adaptation and nature-based strategies. Second, existing models and assessments still suffer from scale fragmentation, with weak integration between building-, neighbourhood-, and city-level analyses. Third, there is still no standardised set of composite indicators that jointly capture resilience, energy efficiency, and ecosystem performance. Fourth, spatial and social justice are often insufficiently incorporated into the design of distributed technologies and green interventions, limiting progress toward a just energy transition. The present bibliometric study (2000–2025) aims to address these gaps by tracking scientific trends, identifying thematic clusters and key actors, and mapping the pathways of convergence among nature-based solutions, renewable energy systems, microgrids, and climate–energy justice (de MacEdo et al., 2025; Ottenburger et al., 2024; Zhang et al., 2025).

This research addresses a significant gap in the current body of knowledge: the triadic interplay between urban resilience, renewable energy, and climate change has been examined mainly in fragmented or one-dimensional ways to date. By conducting a quantitative, reproducible bibliometric analysis of global publications from 2000 to 2025, this study systematically centers the energy dimension in the analytical framework, from the standardization of energy-related terms (e.g., energy efficiency, microgrids, photovoltaics) to multi-period co-occurrence analysis. The second innovation lies in tracing conceptual evolution across multiple scales, from buildings and neighborhoods to cities and energy networks, to overcome persistent scale gaps. Third, by linking energy with justice, governance, and nature-based approaches through co-authorship and co-citation network analyses, the study identifies bridging nodes that connect otherwise isolated research clusters. Beyond mapping the knowledge structure, the study also proposes a set of integrated resilience–energy–ecosystem indicators designed for measurement, comparison, and policy application, harmonised with international frameworks. Finally, by translating bibliometric data into actionable co-occurrence and collaboration maps, the research bridges the science–policy divide, identifies priority areas for investment and urban planning, and highlights emerging pathways for integrating nature-based solutions, distributed energy systems, and climate–energy justice. In sum, the innovation of this research is twofold: (1) Thematic innovation, through the purposeful integration of energy and justice dimensions into the core of urban resilience; and (2) Methodological innovation, through multi-scalar conceptual tracking and the delivery of policy-oriented indicators and maps that enhance the practical relevance of bibliometric findings.

3. Theoretical foundations

3.1. Conceptual frameworks linking urban resilience, renewable energy, and climate change

Contemporary literature clearly demonstrates that the resilience–energy–climate nexus gains its true analytical and practical meaning only when it transcends sectoral or issue-specific viewpoints and is examined through comprehensive frameworks that capture knowledge structures, key actors, and intellectual trajectories. A highly cited systematic review published in Sustainable Cities and Society documents this paradigm shift in urban resilience research from reactive and recovery-oriented models toward transformative, policy-relevant, and cross-sectoral approaches. This framework allows for the mapping of emerging research hotspots and the identification of underexplored domains. In this new perspective, resilience is no longer confined to infrastructure enhancement or crisis management; rather, its alignment with decarbonisation goals, energy efficiency, and spatial–social justice is considered a fundamental necessity. Conceptually, two main frameworks act as complementary “tracks” linking climate policy and energy transition in cities: (a) impact–risk-oriented frameworks and (b) co-development policy frameworks (Büyüközkan et al., 2022). The first type of damage- and system-based models assess urban resilience under extreme rainfall and systematically convert climate hazards into damage indices, ultimately leading to risk-reduction options (Zhang et al., 2023). The second, reflective co-production framework emphasizes stakeholder interaction among urban managers, local communities, and academic institutions, facilitating the integration of science and policy, as well as the translation of research into actionable strategies (Bixler et al., 2022). Both approaches establish a shared conceptual ground for connecting energy transition with climate resilience and developing integrated policy mechanisms.

Additionally, the role of distributed energy infrastructures and urban microgrids has gained increasing prominence in recent scholarship. Research published in Nature Sustainability focusing on integrated microgrid design demonstrates that technical indicators of energy service continuity can be integrated with social justice, participatory governance, and infrastructure resilience within a single conceptual model. However, it also warns that neglecting spatial justice considerations could lead to energy enclaves and reproduce urban inequalities (Ottenburger et al., 2024). Collectively, these frameworks provide a robust conceptual foundation for bibliometric analysis of the resilience–energy–climate domain. Mapping conceptual clusters, identifying bridging actors, and tracing the actual pathways of integration among resilience, energy, and climate provide a systematic understanding of the field's knowledge dynamics and an empirical basis for developing integrated and forward-looking urban policies.

3.2. Theoretical approaches to the convergence of nbs, energy transition, and climate resilience

In recent years, nature-based solutions (NBS) have expanded beyond the realm of "green actions" to become a theoretical and operational framework for convergence between climate risk management and energy transition. A framework synthesis published in the Journal of Environmental Management highlights three key enablers for NBS mainstreaming: (1) quantitative evidence of climate–energy performance, (2) context-specific design and financing mechanisms, and (3) policy co-production processes involving diverse stakeholders (Adu Boateng et al., 2023). Empirical case studies have demonstrated that the drivers and barriers to NBS implementation are contingent upon institutional and social contexts, as well as the executive capacities of cities. A study in Land analyzing the "boundaries and drivers of NBS implementation" in Seville emphasizes the importance of aligning NBS with land-use planning, legal instruments, and local consensus-building (Hidalgo-García et al., 2022). Simultaneously, distributive justice literature reveals that the benefits of NBS are not evenly distributed across urban spaces; hence, equity metrics should accompany climatic and ecological indicators in evaluation frameworks (Gallez et al., 2024). A full-scale biosolar study demonstrates that integrating green roofs with photovoltaic panels can cool rooftop microclimates, enhance PV electrical yield, and reduce cooling loads; however, these effects are contingent upon climatic conditions, maintenance regimes, and system layout, underscoring the necessity of context-based design (Fleck et al., 2022).

3.3. The socio–ecological–technical systems (SETS) framework for energy-oriented resilience assessment

The SETS framework posits that urban resilience emerges from the interaction among three interdependent subsystems: social–governance structures, ecological/microclimatic processes, and technical and energy infrastructures. In the technical–climatic dimension, fine-scale modelling of urban heat islands (UHIs) and heat risk reveals that vulnerability patterns are highly heterogeneous and that "one-size-fits-all" policies are insufficient (Pappalardo et al., 2023). At broader scales, comparative analyses of statistical and machine-learning models in Science of the Total Environment indicate that accurate UHI estimation requires explicit incorporation of local data and contextual variables (Oukawa et al., 2022). The SETS–energy linkage becomes complete when microclimate and building/network energy performance are simultaneously evaluated. A study in Sustainable Cities and Society finds that incorporating local microclimatic data into building energy models reduces demand-estimation errors, particularly during heat peaks, and is vital for grid peak-load management (Xu et al., 2022). At the indicator level, the Comprehensive Resilience Index framework, proposed in Ecological Indicators, integrates physical, social, and ecological metrics to assess regional resilience (as applied to Madrid) and can be adapted for energy-focused assessments (Suárez et al., 2024). Ultimately, the SETS framework achieves practical completeness through distributed energy infrastructures, where urban microgrids serve as technical mechanisms to ensure the continuity of critical services during extreme events. However, they are truly resilient only when participatory governance and spatial justice dimensions are embedded in their design (Ottenburger et al., 2024). From a bibliometric standpoint, this implies that co-occurrence and co-citation maps should reveal bridging clusters linking "UHI–microclimate", "building/network energy", and "governance/justice," and that intermediary authors or institutions with high interdisciplinary centrality can be identified as key nodes within the resilience–energy–climate knowledge network.

4. Methodology

This research adopts a bibliometric approach to provide a comprehensive overview of global scientific evolution within the urban resilience–renewable energy–climate change nexus. The bibliometric method was selected due to the interdisciplinary and policy-driven nature of the topic, as well as its ability to identify scientific patterns, thematic trends, and international collaboration networks.

The methodological design adhered to the principles of transparency, reproducibility, and analytical precision, ensuring that all stages, from data retrieval to network analysis, can be evaluated and replicated by other researchers.

The data source for this study is the Scopus database, chosen for its extensive coverage of international journals, standardized metadata structure, and high compatibility with bibliometric analysis software, such as VOSviewer. Data were retrieved for the 2000–2025 period to capture two and a half decades of scientific progress, coinciding with the global rise of urban resilience and climate policy discourses.

The search strategy was designed to be systematic and reproducible. The query terms were defined to capture the three main dimensions of the study simultaneously: "urban resilience", "renewable energy", and "climate change. "To ensure comprehensive coverage of relevant studies, logical operators AND- OR were combined so that the dataset included articles addressing: (a) the relationship between urban resilience and renewable energy, or (b) the role of urban resilience within the context of climate change. The final search string was defined as:

("urban resilience" AND "renewable energy" OR "climate change")

Following the initial search, refinement filters were applied to enhance the precision of results. Only peer-reviewed research and review articles written in English, and classified under environmental sciences, energy, earth sciences, and social sciences, were retained. Conference papers, technical reports, book chapters, and non-English documents were excluded to ensure consistency of the dataset.

Data extraction and preprocessing were conducted through a multi-stage cleaning process. Duplicate records were removed, and author names and institutional affiliations were standardized to eliminate inconsistencies in spelling and institutional references. Keywords were unified using a controlled thesaurus file within VOS viewer to avoid term dispersion and synonym fragmentation. Equivalent terms and variations in spelling were merged into unified forms, such as photovoltaic (PV), nature-based solutions (NBS), and green infrastructure (GI).

Additionally, stop words and analytically insignificant terms were removed, while multi-word expressions, such as "urban heat island" and "renewable energy system," were standardized to minimize lexical bias. After this rigorous process, the final dataset consisted of 460 valid records, representing the global scientific production at the intersection of urban resilience, renewable energy, and climate change.

All data analyses were performed using VOSviewer (version 1.6.20), which allows for the visualization and quantification of co-occurrence and co-authorship networks. The analysis was structured around three principal axes:

- Keyword Co-occurrence Analysis: To identify conceptual clusters and thematic trends within the field.
- Country-Level Co-authorship Analysis: To uncover patterns of scientific collaboration and highlight leading knowledge-producing centres.
- Temporal Trend Analysis: To examine quantitative and qualitative changes in publication outputs over the selected time period.

To ensure the scientific validity and reproducibility of the research findings, all stages of the search process, including inclusion and exclusion criteria, vocabulary files, and software configurations, were meticulously documented to facilitate future scholarly replication. The temporal scope of 2000–2025 was deliberately selected to encompass three pivotal phases in the evolution of this field: the conceptual emergence of urban resilience in the 2000s, the proliferation of renewable energy technologies in the 2010s, and the acceleration of global climate policies following the Paris Agreement. Drawing upon verified data from the Scopus database, a systematic data-cleaning procedure, and network analyses conducted using VOSviewer, this study provides a comprehensive and reliable depiction of the scientific and policy dynamics at the intersection of urban resilience, renewable energy, and climate change. By integrating quantitative and qualitative analytical approaches, this research establishes a robust academic framework for elucidating research trajectories, identifying knowledge gaps, and outlining prospective directions toward the development of resilient, low-carbon, and equity-oriented cities.

4.1.Basic indicators

The retrieved bibliographic information encompassed key indicators, including institutional affiliation, authors, country of origin, source of publication, subject area, and year of publication. These data were directly extracted from the Scopus database and presented descriptively to illustrate the geographical, institutional, and temporal distribution of research within the field. This section provides a foundational overview of the growth of scientific output, active publication sources, and the spatial and thematic dispersion of studies, offering a baseline understanding of the field's structural and developmental dynamics.

4.2.Network analysis

To uncover the structural and conceptual relationships within the field, the VOS viewer was used to conduct two primary analyses:

1. Co-authorship analysis: Conducted at both the author and country levels to identify scientific collaboration networks and the strength of interlinkages. The output was presented as three distinct maps showing researcher clustering, collaboration density, and inter-country connectivity.

2. Co-occurrence analysis: Conducted using author keywords, indexed keywords, and title/abstract terms to detect thematic clusters and conceptual evolution. For each layer, an appropriate occurrence threshold was applied. After normalization using the Association Strength method, clustering was performed through the VOS viewer's internal algorithm. Overlay visualizations were generated to illustrate the temporal evolution of core research concepts.

4.3 Quality control and reproducibility

All steps of data cleaning, threshold setting, and software configuration were fully documented to ensure reproducibility. Potential limitations such as Scopus coverage bias, inconsistencies in keyword indexing, and reliance on metadata were acknowledged and discussed in the limitations section of the paper. This methodological framework integrates descriptive statistics with network-based analyses, providing a transparent and reproducible depiction of trends, collaboration structures, and conceptual transformations within the domains of urban resilience, renewable energy, and climate change.

5. Results

5.1.Trends in global scientific output on urban resilience, renewable energy, and climate change (2007–2025)

Figure 1 illustrates the annual distribution of articles retrieved from the Scopus database during the 2007–2025 period. In the early years (2007–approximately 2012), the volume of scholarly output was minimal, with fewer than five publications per year. This pattern indicates that during this initial phase, urban resilience had not yet become an established research axis interconnected with renewable energy and climate change; most works appeared as preliminary or fragmented studies. From 2013 onward, a gradual upward trend is observed, with the first central inflection point emerging in 2015, when approximately 15 articles were published per year. A slight decline is noticeable from 2016 to 2017, which may reflect temporary shifts in research priorities or the diversion of academic attention to adjacent topics. From 2018, however, the field appears to demonstrate an apparent acceleration. Between 2018 and 2021, publication growth was both consistent and pronounced, rising from fewer than 20 papers in 2018 to over 45 by 2021. This increase can be attributed to the strengthening of global discourse on climate change, particularly following the Paris Agreement (2015) and successive IPCC assessment reports, alongside the expansion of urban renewable-energy policies. The 2022–2023 period reveals a phase of relative stabilization, with publication counts remaining within the range of 50–55 papers per year. This stage can be interpreted as an early maturity phase, during which the core conceptual foundations of the field became consolidated, even though no dramatic breakthroughs occurred. A second surge is evident from 2024 onward. In 2024, the number of publications rose sharply to around 80, reaching more than 110 articles in 2025. This rapid increase likely reflects the growing integration of urban decarbonization policies, the expansion of renewable-energy deployment within distributed infrastructures, and the rising scholarly focus on climate-energy justice. Accordingly, 2025 can be identified as the peak year of scientific flourishing within this domain.

Overall, the trajectory depicted in Figure 1 shows a gradual evolution up to 2018, followed by strong acceleration from 2019 onward. This pattern closely aligns with global scientific and policy transformations, underscoring the increasing significance of the triadic nexus between urban resilience, renewable energy, and climate change.

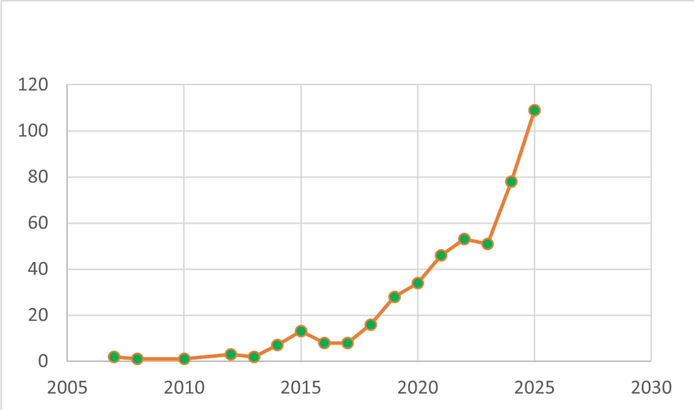

Figure 1. Annual publication trend of studies related to "urban resilience, renewable energy, and climate change" in the scopus database during the period 2007–2025.

5.2.Trend of annual publications by leading journals in the field of urban resilience, renewable energy, and climate change (2000–2025)

Figure 2 presents the distribution of selected publications across leading journals and scientific sources during the 2000–2025 period. As shown, the journal Sustainability (Switzerland) ranks decisively first, having published nearly 80 papers within this domain. This prominence reflects the journal's open-access and multidisciplinary orientation toward sustainability, energy, and urban resilience, indicating that a significant share of research on the resilience–energy–climate nexus has been disseminated through its interdisciplinary framework. In second place, Sustainable Cities and Society accounts for approximately 25 publications, with a focus on sustainable urban systems, resilient infrastructure, and related technologies. The proximity of its scope to the core themes of this study underscores its role as one of the key platforms for both theoretical and empirical development of the urban resilience concept. A subsequent group of journals, including Environmental Science & Policy, Land, Climate, Journal of Environmental Management, and Science of the Total Environment, each hosts between 20 and 25 papers. Their shared focus on environmental policy integration, resource management, and climate impacts indicates the strong policy dimension that connects urban resilience with climate governance in the academic discourse. In the middle and lower segments of the chart, journals such as Journal of Cleaner Production, Ecological Indicators, Frontiers in Sustainable Cities, and Water (Switzerland) appear with smaller shares (around 10 papers or fewer). Although their publication volumes are lower, their contributions tend to be more innovative, emphasizing quantitative assessment methods, performance indicators, and evaluation metrics. Overall, the distribution demonstrates that the resilience–energy–climate literature spans a broad array of interdisciplinary outlets, while maintaining its core concentration within journals devoted to urban sustainability and environmental policy. Notably, the large publication gap between Sustainability and other journals suggests a form of publication polarity, with one dominant outlet and moderate dispersion across others. This structural bias should be taken into account when interpreting bibliometric results.

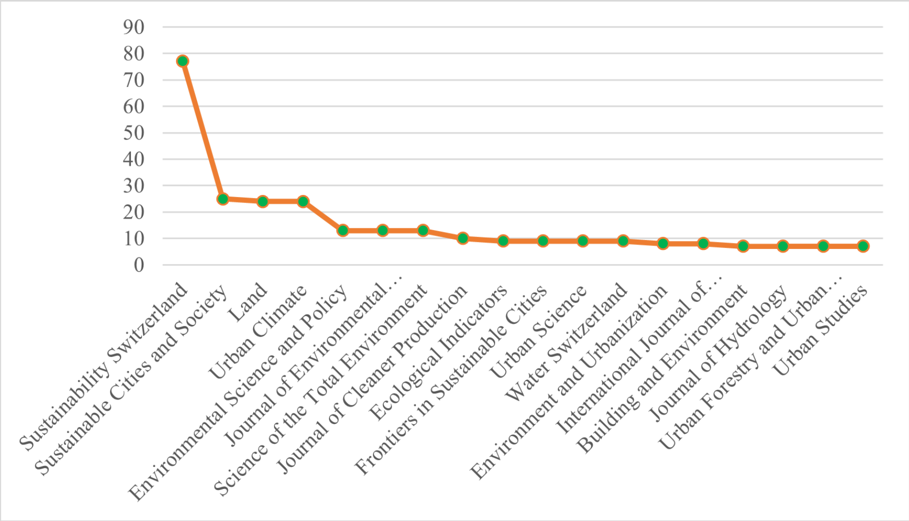

Figure 2. Distribution of publications by journals and sources in the field of "urban resilience, renewable energy, and climate change" (2000–2025).

5.3. Geographical distribution of scientific output in the field of urban resilience, renewable energy, and climate change (2000–2025)

Figure 3 illustrates the distribution of publications by country during the 2000–2025 period. The data show that China, with nearly 100 publications, ranks first and plays a leading role in global knowledge production within this domain. This dominance can be attributed to China's extensive investment in renewable energy, the expansion of sustainable urban policies, and its active participation in international research networks. In second place, the United States contributes around 70 publications. Although there is a noticeable gap compared to China, the U.S. remains one of the central hubs of research activity. American studies have primarily focused on the intersections between climate policy, energy justice, and urban infrastructure. Italy, the United Kingdom, and Australia occupy the third to fifth ranks, each with approximately 38 to 42 publications. Their significant presence, primarily through EU-funded projects and international collaborations, reflects the growing prominence of urban resilience in regional and municipal policy agendas. Among other European nations, Spain, Germany, and the Netherlands have made notable contributions (about 25–35 publications each), demonstrating that scholarly development in these countries closely parallels European energy and climate-policy frameworks. Japan and Canada, positioned in the middle tier with around 20 papers each, reflect an emphasis on technological innovation and sustainable urban strategies. In the lower segment of the chart, countries such as Poland, Sweden, Portugal, and South Korea (each with around 15 papers) are represented, along with South Africa, Brazil, and Iran (with fewer than 15 papers), as emerging contributors. Despite their smaller share, their participation highlights the expanding geographical scope of research on this topic. In particular, Iran's inclusion despite structural and resource limitations signals that the urban resilience–energy–climate nexus has begun to gain academic traction within the national research landscape. Overall, this geographical distribution reveals a highly multipolar structure in the global literature, characterized by a dominant hub in East Asia (China), a central pole in North America (the United States), and several active clusters across Europe and Oceania. This pattern underscores the need for broader international collaboration, enabling countries with lower publication output to play a more effective role in knowledge co-production and experience exchange within this rapidly evolving field.

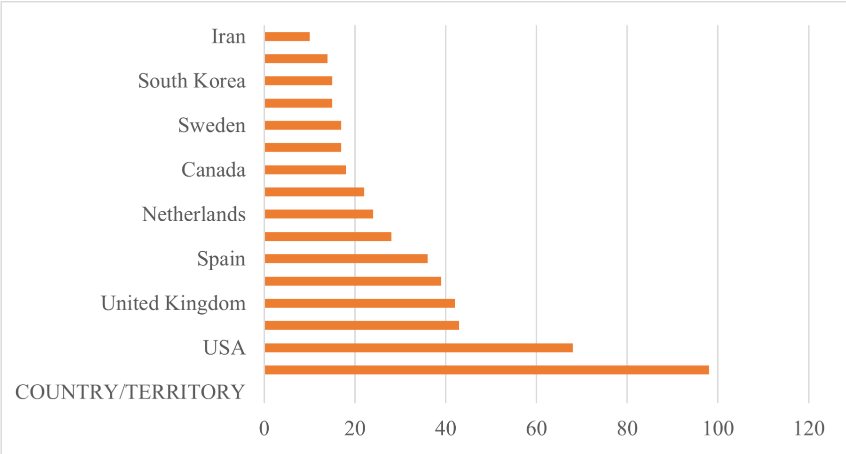

Figure 3. Distribution of publications related to "urban resilience, renewable energy, and climate change" by country during the period 2000–2025.

5.4.Thematic distribution of scientific publications in the field of urban resilience, renewable energy, and climate change (2000–2025)

Figure 4 presents the thematic distribution of publications across subject areas indexed in the Scopus database. As shown, the largest share of research belongs to Environmental Sciences, with over 400 records, ranking first. This dominance is expected, as both urban resilience and climate change are primarily examined within the frameworks of environmental assessment, ecosystem services, and climatic impact analysis. In second place, the Social Sciences account for approximately 280 publications. The strong presence of this domain highlights that urban resilience is not merely a technical or engineering topic. However, it is also a socio-political construct that requires analysis through the lenses of justice, governance, and human behavior. The energy category ranks third, comprising nearly 150 publications, which reflects the growing emphasis in the scientific literature on integrating urban resilience with energy transition and distributed infrastructure. Following these three dominant areas, disciplines such as Engineering, Computer Science, and Earth and Planetary Sciences show moderate contributions (around 50–80 papers). Their participation highlights the importance of technical and numerical modeling methods, as well as geospatial analyses, in advancing resilience and energy research. At lower levels, fields including Agricultural and Biological Sciences, Biochemistry and Genetics, Management and Accounting, Medicine, Decision Sciences, Economics, and Chemical Engineering each contribute fewer than 50 papers. Although their share is relatively small, their inclusion underscores the interdisciplinary nature of the domain. For instance, agriculture and biology are closely linked to food security and the FEW (Food–Energy–Water) nexus, while economics and management sciences play crucial roles in cost–benefit analysis and resilience investment assessment. Overall, this thematic distribution reveals that research on the urban resilience–energy–climate nexus is fundamentally interdisciplinary, with environmental sciences, social sciences, and energy studies forming the three primary poles of knowledge production. The presence of additional domains highlights the breadth and multidimensionality of both theoretical and applied aspects of this emerging field.

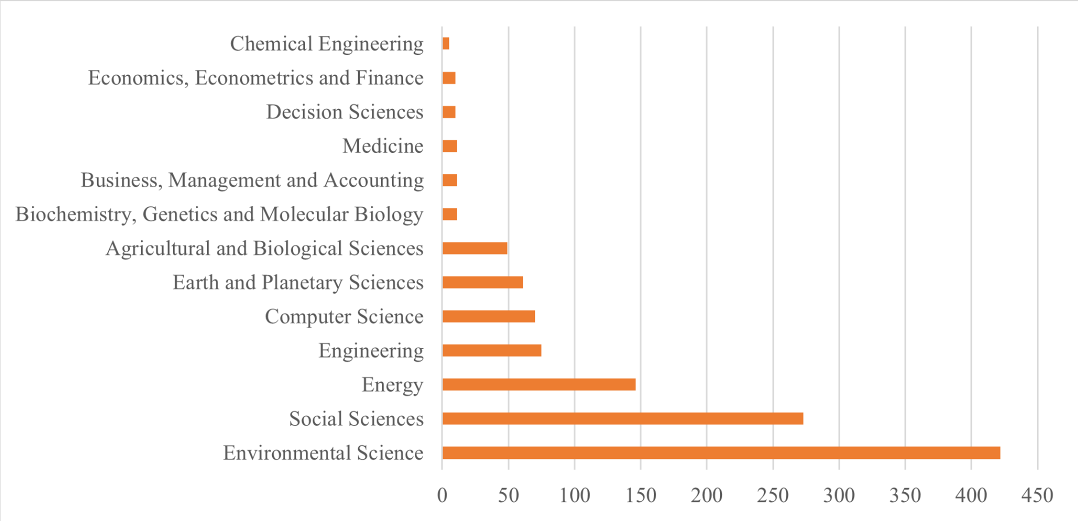

Figure 4. Distribution of publications related to "urban resilience, renewable energy, and climate change" by subject areas in the scopus database (2000–2025).

5.5. Leading institutions and universities publishing research on urban resilience, renewable energy, and climate change (2000–2025)

Figure 5 presents the distribution of scientific output based on the institutional affiliations of contributing researchers. As shown, the Chinese Academy of Sciences (CAS) ranks first with 14 publications, followed by related entities such as the University of the Chinese Academy of Sciences and the Ministry of Education of the People's Republic of China. This concentration reflects China's institutionalized and centralized approach to research in this field, demonstrating a strong alignment between national policy agendas and academic activity. Such alignment indicates that research in China is supported not only through universities but also at the state policy-making level, enabling the country to emerge as a global hub of knowledge production in the resilience–energy–climate nexus in recent years. In second place, Arizona State University (ASU) appears with 10 publications, recognized internationally for its interdisciplinary research on climate justice, sustainable cities, and energy policy. Its prominent position reflects the U.S. model of innovation-driven academia, where conceptual development and cross-disciplinary work are led primarily by universities rather than central governmental institutions. Among European universities, Politecnico di Milano, Sapienza University of Rome, University of Naples Federico II, Politecnico di Torino, and Polytechnic University of Catalonia all appear among the top contributors. This geographical dispersion across Europe mirrors the European Union's policy emphasis on sustainable cities and clean energy programmes. Unlike China's centralized structure, Europe exhibits a multi-nodal and networked system, heavily based on transnational collaborations and joint projects under initiatives such as Horizon Europe. In addition, institutions such as the University of Melbourne (Australia), the National University of Singapore (Asia), and the American University of Beirut (Middle East) signify the global diffusion of research in this domain. Although these institutions contribute fewer publications than China or the U.S., their participation highlights the regional contextualization of resilience and renewable-energy concepts adapted to distinct climatic and urban conditions. Overall, the findings from the institutional-affiliation analysis indicate that research in this area is not confined to a single geographic region, but rather emerges from the convergence of multiple scientific poles worldwide. China leads quantitatively, the United States excels in interdisciplinary innovation, and Europe strengthens conceptual diversity and collaborative sustainability through its distributed research networks.

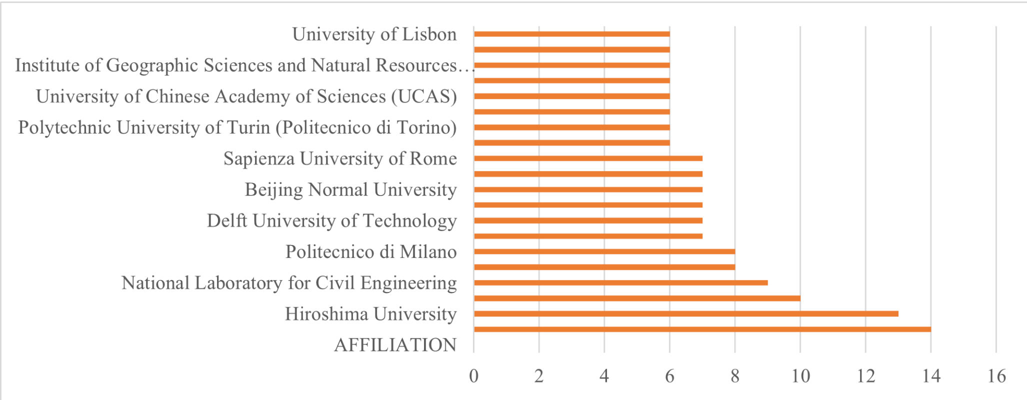

Figure 5. Distribution of scientific publications by researchers' institutional affiliations in the field of "urban resilience, renewable energy, and climate change" (2000–2025).

5.6. Role of co-authorship networks among influential authors in the urban resilience–renewable energy–climate change nexus

Figure 6 presents the co-authorship network generated in VOS viewer, visualizing the structure of collaboration among the most influential authors in the field. The size of each node represents the author's publication weight or link strength, while the thickness of connecting lines (edges) indicates the intensity of collaboration. Colours distinguish different communities of collaboration, and central positions highlight authors with high betweenness centrality who act as conceptual and structural bridges across clusters.

Central bridging core: At the center of the map, Timon P. McPhearson, Niki Frantzeskaki, and Erik Andersson occupy pivotal bridging positions that connect trans-Atlantic research communities (Europe and North America). Their multiple linkages across both sides of the network reveal their role as intermediary nodes that facilitate the flow of ideas between the "ecosystem/green-infrastructure", "urban resilience", and "policy/governance" clusters. Their proximity and dense interconnections confirm their status as authors with high network brokerage capacity, enabling cross-fertilization from ecological-theoretical to policy-applied domains.

Urban ecology – social-ecological systems theory cluster (upper left): Scholars such as Thomas Elmqvist and Carl Folke dominate this classical cluster, representing the foundations of urban ecology and ecosystem-service frameworks. The location of this group near the central hub suggests that ecological theory remains a conceptual pillar of the literature and maintains active interconnections with other clusters.

Green infrastructure (GI) / nature-based solutions (NBS) and landscape planning cluster (left): Dagmar Haase and Stephan Pauleit form a cohesive sub-network representing the green infrastructure and NBS planning stream. The strong ties between this cluster and the central hub (Frantzeskaki–Andersson–McPhearson) suggest that the NBS literature has become structurally integrated with urban resilience and policy-making research.

Justice, governance, and urban resilience cluster (mid-right): Sara A. Meerow appears as the central node in this cluster, closely linked to Nancy B. Grimm and collaborators. The thematic focus lies on urban governance, environmental justice, and policy frameworks for resilience and climate adaptation. The interlinkages between this group, the central hub, and the technical-applied cluster (discussed next) show that justice-oriented studies have evolved into key bridging nodes connecting conceptual and applied subfields.

Technical–applied and climate-risk cluster (right): Robert Hobbins emerges as a bridging node between the policy/justice cluster (Meerow–Grimm) and the central network (McPhearson–Chang–Kim). This cluster typically encompasses studies on heat-risk indexing, critical infrastructure resilience, and the interface between microclimate and energy demand. It represents the methodological link that connects theory and governance with quantifiable assessment approaches. Collectively, the co-authorship map highlights a densely interconnected but multi-clustered network, where ecological, policy, and technical strands converge through a small number of high-centrality mediators. These structural linkages underscore the maturity of the urban resilience–

renewable energy–climate change field, characterised by increasing collaboration, interdisciplinary integration, and conceptual bridging between theory, policy, and application.

Emerging peripheral clusters (lower left): Smaller, newly formed clusters comprising authors such as Xinyu Dong, Runjia Yang, and Angela Lausch represent relatively new or specialized research teams. These groups are primarily engaged in data-driven, remote-sensing, and urban microclimate modelling studies, which, as their publication output grows, are gradually becoming integrated into the leading network. Their peripheral yet connected positions on the map indicate promising potential for growth and future consolidation within the core of the field. Overall, the co-authorship map depicts a multi-clustered and interconnected structure: the Ecology and NBS cluster is positioned on the left, the Justice and Governance cluster on the right, and a transnational bridging core occupies the centre. The presence of several nodes with high betweenness centrality signifies a strong capacity for cross-domain synergy, enabling faster transfer of knowledge from urban ecology and nature-based solutions toward resilience policymaking, risk assessment metrics, and even urban energy systems.

At the same time, the existence of small, data-oriented peripheral clusters reflects the emergence of technological pathways including microclimate analytics, thermal mapping, and urban data systems that are likely to reinforce future linkages with distributed energy networks and peak-load management strategies.

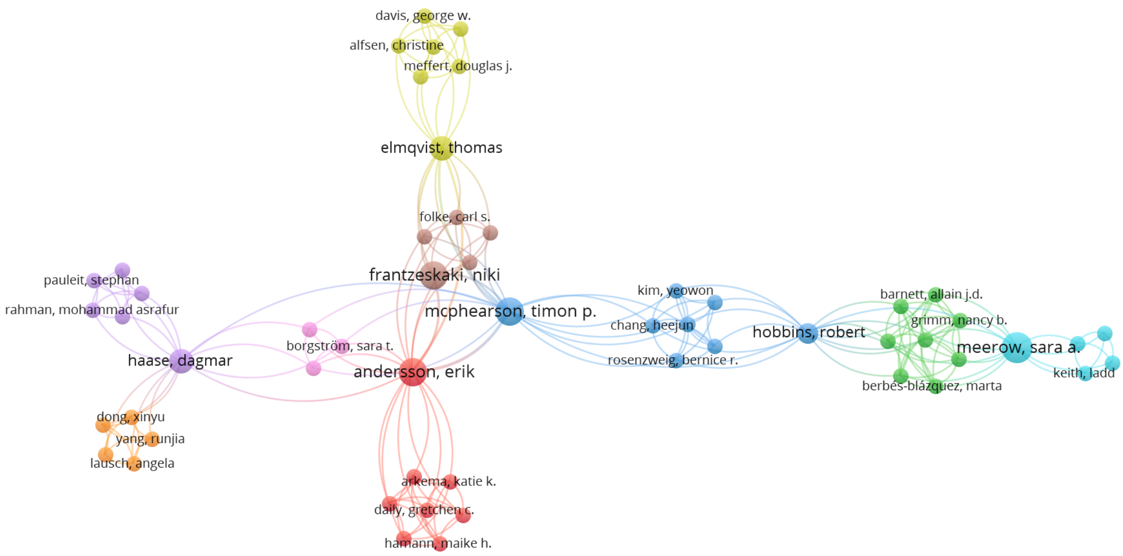

Figure 6. Co-authorship map of influential authors in the field of urban resilience–renewable energy–climate change.

5.7. Temporal co-authorship network (overlay visualization): evolution of influential author collaboration in the urban resilience–renewable energy–climate change nexus (2010–2025)

Figure 7 presents the co-authorship network overlay map, displaying the temporal evolution of author collaborations through colour coding based on the average year of publication for each author. The colour gradient ranges from dark blue/purple (earlier years: 2010–2015) to yellow (recent years: 2023–2025). Node size represents publication and collaboration weight, while the thickness of the connecting lines (edges) indicates link strength between authors.

Phase 1 – foundation stage (2010–2015, dark blue/purple): In the upper-central region of the map, nodes such as George W. Davis, Christine Alfsen, and Douglas J. Meffert are represented in darker shades, indicating early pioneers in establishing the foundational urban resilience networks. Their collaborations primarily focused on urban ecology, ecosystem services, and the initial urban resilience agendas, forming the conceptual groundwork for subsequent interdisciplinary partnerships.

Phase 2 – convergence and consolidation (2016–2020, green): At the centre of the network, Timon P. McPhearson, Niki Frantzeskaki, and Erik Andersson appear in medium-green hues and relatively larger nodes, signifying their central and bridging roles among subclusters. Their dense cross-network connections to Thomas Elmqvist and Carl Folke on the ecology–SES side, and to policy and metric-oriented clusters on the opposite side, reflect high betweenness centrality. In other words, these authors functioned as key conduits transferring ideas from NBS/ecological systems to policy and planning for resilience, marking the 2016–2020 period as one of conceptual and institutional consolidation within the field.

Phase 3 – expansion and emerging directions (2021–2025, light green to yellow): On the right-hand side of the map, a cluster centred on Sara A. Meerow and linked with Nancy B. Grimm appears in lighter tones, representing the new wave of research focusing on governance, energy justice, and urban policy, which has intensified since 2021. The presence of Robert Hobbins as a connecting node between this cluster and the central hub indicates the translation of justice and governance frameworks into quantifiable risk and resilience assessment tools. On the left edge of the map, a small subcluster, composed of Xinyu Dong, Runjia Yang, and Angela Lausch, is highlighted in bright yellow, indicating the emergence of data-driven research paths, including microclimate analytics, remote sensing, and heat-risk mapping. These recent trajectories show growing potential for integration with urban energy systems and peak-load management. Additionally, the Dagmar Haase – Stephan Pauleit cluster, appearing in light green, confirms the ongoing expansion of NBS and green infrastructure research, as well as its active interaction with the central network. In summary, the overlay visualization depicts a temporal evolution from ecological foundations to governance- and data-oriented innovation, demonstrating how the urban resilience–renewable energy–climate change research network has progressively diversified, expanded, and integrated new scientific and policy dimensions over the 2010–2025 period.

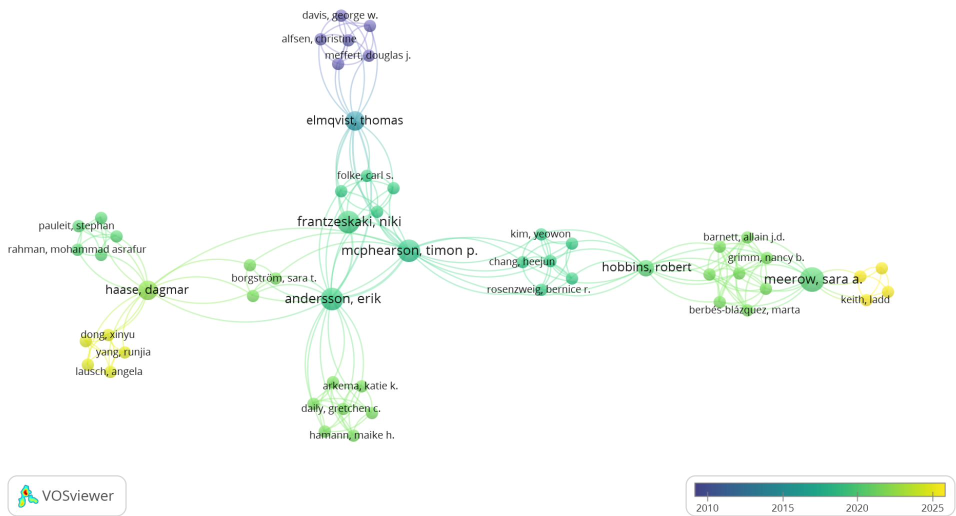

Figure 7. Temporal (overlay) co-authorship map in the field of urban resilience–renewable energy–climate change, showing the colour spectrum by authors' average year of publication (2010–2025).

5.8. International co-authorship network in the field of urban resilience, renewable energy, and climate change

Figure 8 depicts the country-level co-authorship network, illustrating the architecture of global scientific collaboration as a multi-polar yet interconnected system. The font size of each country label represents its collaborative weight (number of international co-authorships), while the thickness of the connecting lines (edges) reflects the strength of collaboration. Distinct colours differentiate clusters of cooperation. At the core of the network, the United States serves as a global hub, maintaining dense connections with Europe (the United Kingdom, Germany, the Netherlands, Italy, and Spain), Oceania (Australia), and Asia (Japan, South Korea, and India). This extensive web positions the U.S. as a trans-regional bridge, facilitating the exchange of ideas and cross-pollination between thematic and geographic clusters. China emerges as the second central hub, maintaining strong bilateral ties with the United Kingdom, Germany, Australia, and several Asian nodes such as Hong Kong, Pakistan, and Indonesia. This pattern highlights China's broad strategic collaboration across the Europe–Oceania–Asia corridor, reflecting its dual emphasis on technological innovation and policy-oriented research. Within Europe, a cohesive cluster of intercontinental mediators, including the United Kingdom and Germany, maintains high-density linkages to both global hubs (the U.S. and China) and to neighboring European countries (Italy, Spain, the Netherlands, and Portugal). This configuration forms a tightly connected European network, anchored through the U.K. and Denmark, which acts as a gateway to transatlantic collaborations. Finland and Denmark, located at the network's periphery, remain connected to both sides of the Atlantic. The Oceania–Asia hubs, particularly Australia, occupy a bridging position that extends beyond links with China, Ukraine, and the United States, also connecting to New Zealand, South Africa, and Cyprus, functioning as a cross-regional conduit across the Pacific–Indian Ocean–Africa arc. In East Asia, Japan and South Korea maintain joint linkages with both China and the United States, while Hong Kong serves as a specific bridge between China and Southeast Asia (Indonesia). In the Middle East, Africa, and Latin America, emerging peripheral but expanding collaborations are observed. Countries such as Lebanon and Iran appear as smaller nodes connected to Japan, the U.S., and regional partners, indicating growing but still limited integration into the global collaboration network. In Africa, South Africa appears as a more connected node, while Uganda, Malawi, and Egypt maintain fewer ties. In Latin America, Brazil and Mexico are embedded within the European and U.S. clusters, although a noticeable structural distance remains between them and the major global hubs.

Overall, the map reflects a fragmented yet synergistic global research landscape anchored by two dominant poles (China and the United States) and multiple regional clusters in Europe, Oceania, and Asia, interconnected through bridging countries. This structure highlights the increasing importance of international cooperation, encouraging emerging nations to expand participation in the co-production of knowledge and exchange of best practices in the urban resilience–renewable energy–climate change nexus.

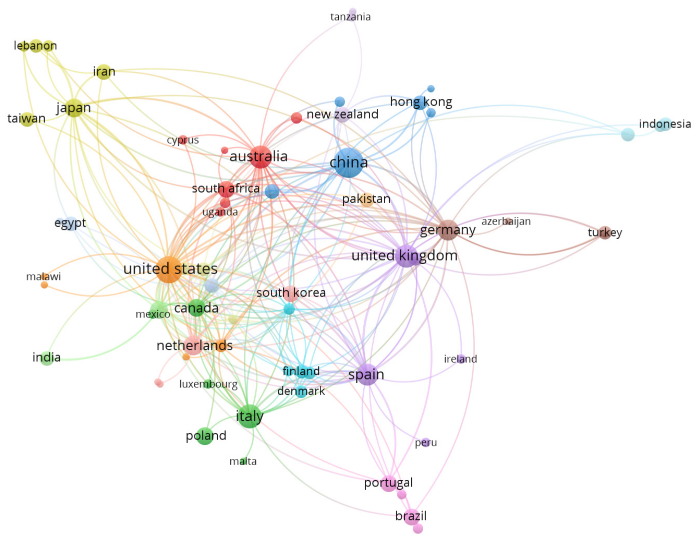

Figure 8. International co-authorship network of countries in the fields of urban resilience, renewable energy, and climate change.

5.9. Temporal (overlay) co-authorship network of countries: dynamics of international collaboration in urban resilience–renewable energy–climate change (2020–2024)

Figure 9 visualizes the temporal evolution of international co-authorship among countries, as generated in VOSviewer. The colour spectrum, ranging from blue/purple to green and yellow, represents the average publication year of each country's contributions, with darker shades indicating earlier activity (2020–2021) and lighter shades marking more recent collaborations (2023–2024). The size of each node denotes the country's collaborative weight (number of co-authored publications). At the same time, the thickness of the connecting lines (edges) reflects the strength and intensity of scientific collaboration.

Historical core and established drivers (2020–2021, blue/purple)

At the centre of the network topology, countries such as the United States, the United Kingdom, the Netherlands, and Canada appear in darker tones. The high density of connections surrounding these nodes indicates their enduring role as global hubs forming the foundational backbone of knowledge exchange and data flow. Their extensive interlinkages with Europe, Oceania, and East Asia confirm the persistence of a multi-continental collaboration model that has shaped the intellectual infrastructure of the field since its early stages.

Asian–european convergence wave (2021–2022, green)

Countries such as China, Germany, Italy, Spain, and Finland are primarily represented in green, indicating a newer but rapidly consolidating wave of collaboration. China, in particular, exhibits strong bilateral links not only with Germany and the United Kingdom, but also with Australia, Pakistan, and Hong Kong, reflecting an increasingly mature Asia–Europe Oceania axis of research partnerships. Within Europe, the southern cluster (Spain, Italy, and Portugal) connects through Germany and the U.K. to global hubs, while also extending southward to Latin America (Brazil and Peru), highlighting emerging north–south scientific linkages.

Emerging entrants and expanding periphery (2023–2024, light green to yellow)

Newly active countries, including Lebanon, Iran, Turkey, Tanzania, and Hong Kong, are displayed in lighter yellowish tones, representing recent entrants into the global collaboration network. Positioned at the outer edges of the map but maintaining multiple links to major hubs (e.g., Lebanon and Iran connected to Japan and the U.S.; Turkey to Germany and Azerbaijan; Tanzania to New Zealand and China), these countries illustrate a progressive geographical diffusion of research activity from the core to the periphery. Similarly, Indonesia, marked in turquoise-green, demonstrates rapid integration into the East and Southeast Asian collaboration corridor through strong ties with Hong Kong and China.

Overall, this overlay map demonstrates that between 2020 and 2024, the field of urban resilience, renewable energy, and climate change has evolved from a transatlantic concentration to a globally distributed network, with increasing participation from Asian, Middle Eastern, and African countries. The expansion of these newer connections suggests a shift toward a more inclusive and geographically diversified scientific ecosystem, bridging established knowledge hubs with emerging research regions.

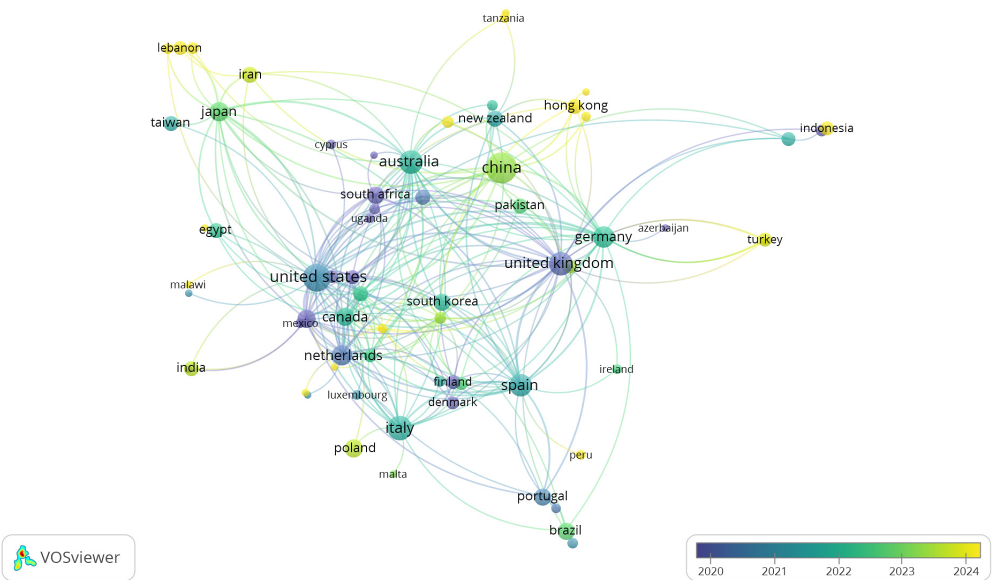

Figure 9. Temporal (overlay) co-authorship network of countries in the field of “urban resilience–renewable energy–climate change” (2020–2024).

5.10. Keyword co-occurrence network: conceptual structure of the urban resilience–climate change–renewable energy field

Figure 10 presents the keyword co-occurrence network, where the size of nodes represents the frequency of keyword usage, and the thickness of connecting lines (edges) reflects the strength of co-occurrence. At the core of the network, the two dominant nodes "urban resilience" and "climate change" form the conceptual nucleus with the highest connectivity, reaffirming the resilience–climate duality as the structural backbone of the field's literature.

Urban policy and planning cluster (blue): This cluster includes terms such as urban planning, sustainability, climate change adaptation, policy-making, urban governance, and stakeholder engagement. The dense interlinkages indicate that urban resilience discourse is deeply embedded within planning and governance processes. "Climate adaptation" is thus operationalized primarily through policy instruments and urban management frameworks. The cluster's direct connections to both "urban resilience" and "climate change" highlight its bridging policy role, translating climate knowledge into actionable strategies at the city level.

Hydro-risk and flood management Cluster (green): Comprising terms like flood, urban flooding, flood control, surface runoff, risk assessment, and disaster management, this cluster captures the dominant hydrological dimension of resilience studies. The frequent co-occurrence of climate change and flood-related terms highlights the prevalence of water-related hazards in the resilience literature. Linkages with water management and risk management further demonstrate that hydro-risk mitigation constitutes a principal operational domain of urban resilience research.

Microclimate, land use, and remote sensing cluster (red): Keywords such as urban heat island (UHI), air temperature, remote sensing, spatial analysis, land use, and urban morphology define this group. Its close proximity to the climate–resilience core indicates the growing importance of microclimate analysis and data-driven approaches, particularly remote sensing, in understanding patterns of urban vulnerability. The frequent connections between urban heat islands and urban planning/design highlight the critical role of urban form and morphology in managing heat-related risks.

Intermediate linkages and conceptual bridges (yellow/central): Terms such as urban ecosystem, ecosystem services, urban green spaces, and urban sustainability are positioned between the policy and microclimate clusters. Their intermediary location reflects the bridging function of nature-based solutions (NBS) and green infrastructure (GI), linking ecological metrics with urban planning and risk reduction. The proximity of climate resilience and strategic approaches to the central hub suggests a gradual conceptual shift toward integrative, strategy-oriented frameworks in recent years.

Despite the cohesion of these three main clusters, energy-related and renewable technology terms (e.g., microgrid, energy efficiency, photovoltaics/PV) appear weakly connected or nearly absent within the co-occurrence layer. This gap highlights a conceptual distinction between the "energy" dimension and the resilience–climate discourse, indicating a notable research void. Strengthening the co-occurrence between distributed energy terms and microclimate/risk assessment keywords could accelerate the transition from purely climate-focused resilience toward energy-integrated urban resilience.

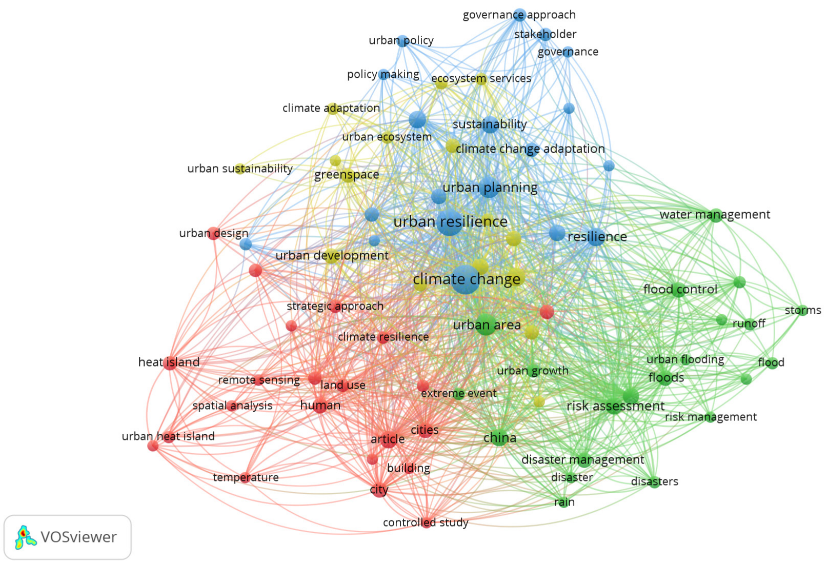

Figure 10. Keyword co-occurrence map in the field of urban resilience, climate change, and renewable energy.

5.11. Keyword co-occurrence network with temporal layer (overlay): conceptual evolution of "urban resilience–climate change" (2021–2023)

Figure 11 visualizes the temporal overlay of the keyword co-occurrence network, showing how the conceptual structure of research on urban resilience and climate change has evolved from 2021 to 2023. The colour gradient ranges from purple/blue (earlier average publication years, around 2021) to green/yellow (more recent years, 2022–2023). The size of nodes represents keyword frequency, while edge thickness denotes the strength of co-occurrence between terms.

At the core of the network, the two dominant nodes "climate change" and "resilience" form the spine of the conceptual structure, anchoring the surrounding thematic clusters.

Policy and urban planning cluster (upper zone, cooler colours): Keywords such as policy-making, governance systems, stakeholders, urban policy, and urban planning appear in darker blue and purple tones, densely connected to climate change adaptation. The cooler hues indicate that this cluster dominated the early phase (2021) of the studied period, laying the normative and institutional foundations of the field. In other words, the initial entry of resilience into the urban agenda primarily occurred through the pathway of governance and policy frameworks.

Hydro-risk and crisis management cluster (right, green–yellow): Comprising keywords such as urban flooding, surface runoff, flood control, extreme weather events, risk assessment, and disaster management, this cluster appears in warmer tones, indicating an acceleration in research intensity since 2022. Its strong connections with water-resource management and risk management demonstrate a conceptual shift from policy frameworks toward quantifiable risk-assessment tools and operational interventions.

Microclimate, remote sensing, and urban morphology cluster (left, green–yellow): This group includes urban heat island, temperature, remote sensing, spatial analysis, land use, and urban design/development. The recent colour range suggests that data-driven and multi-scalar approaches, particularly those utilizing remote sensing and spatial modeling, have become increasingly prominent. These methods are instrumental in linking urban form and microclimate dynamics to vulnerability assessment and adaptation planning.

Ecological bridging terms (central connectors): Positioned between the policy and risk/microclimate clusters, intermediary keywords such as nature-based solutions (NBS) and green infrastructure (GI) act as conceptual bridges. They translate resilience objectives into ecosystem-based interventions, mediating between ecological functions and urban planning tools. This middle layer highlights the increasing importance of ecological pathways in achieving resilience, adaptation, and sustainability objectives.

Overall, the temporal overlay map demonstrates a progressive conceptual evolution:

- Early dominance of policy and governance frameworks (2021),

• Transition toward risk-based and technical applications (2022), and
• Recent prominence of data-driven, ecological, and design-oriented approaches (2023).

This trajectory reflects the maturation of the urban resilience–climate change discourse from institutional foundations to integrated, evidence-based, and multi-scalar frameworks.

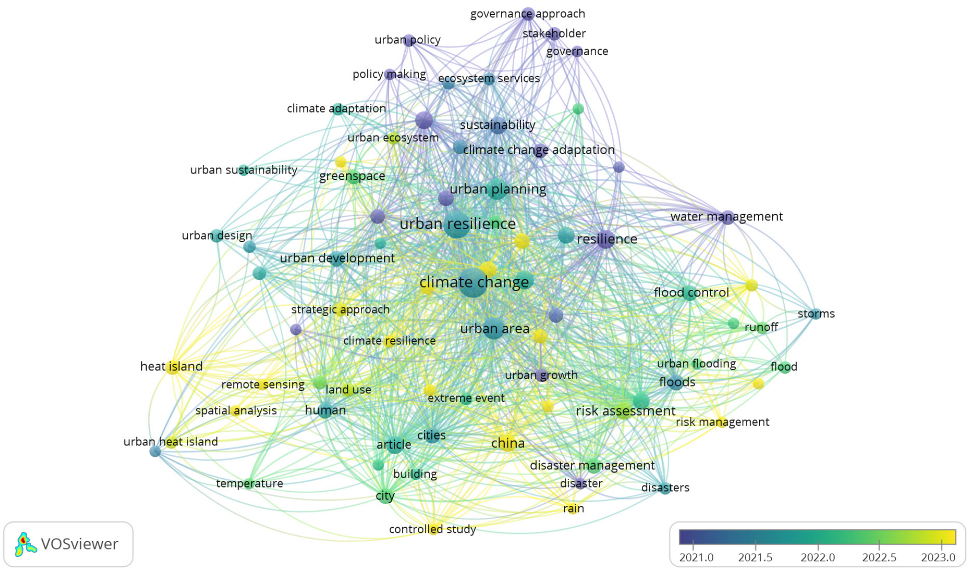

Figure 11. Temporal (overlay) keyword co-occurrence map in the field of urban resilience–climate change–renewable energy (2021–2023).

5.12. Author keyword co-occurrence network: conceptual architecture of "urban resilience–climate change–renewable energy"

Figure 12 illustrates the author keyword co-occurrence network, derived directly from the keywords chosen by authors in their publications. This layer provides the most accurate representation of research priorities and thematic trends within the literature on urban resilience, climate change, and renewable energy. The map reveals three main conceptual clusters, reflecting the multidimensional structure of the field.

Blue cluster – urban resilience and climate change (core cluster)

At the centre of this cluster lie the two dominant keywords "urban resilience" and "climate change", which exhibit the highest density and connectivity with other terms. Their prominence underscores the enduring thematic interdependence between urban resilience and climate adaptation. Surrounding them are closely related concepts, including urban planning, sustainability, climate change adaptation, and urban governance. This composition highlights that research in this domain remains heavily oriented toward policy integration, governance mechanisms, and strategic urban planning frameworks designed to manage climate-induced challenges. The presence of these governance-related terms indicates a strong institutional and planning focus within the resilience discourse.

Green cluster – risk and disaster management

This cluster primarily includes keywords such as flood control, disaster management, risk assessment, and urban runoff management. It represents the operational and managerial dimension of urban resilience, focusing on practical interventions against natural hazards. The frequent co-occurrence of these terms with urban resilience demonstrates that risk management and adaptation measures are at the core of the applied research agenda.

This cluster bridges policy intentions and practical actions, showing that many studies seek to operationalize resilience through tools and frameworks for risk reduction, emergency response, and adaptive urban infrastructure.

Red cluster – spatial analysis and urban heat island

Characterised by keywords such as urban heat island (UHI), land use, remote sensing, urban design, and surface temperature, this cluster reflects the technological and analytical frontier of the field. It focuses on spatial modelling, GIS-based analysis, and multi-scale simulations to assess how land-use changes and urban form influence thermal stress and microclimate patterns.

The increasing frequency of GIS and remote-sensing terms indicates recent methodological advancements and the integration of data-driven approaches into resilience and climate-change research.

Cross-cluster connections and integration

The map shows significant overlaps and intersections among clusters. For example, urban planning acts as a cross-cutting bridge between the blue cluster (policy/ governance) and the red cluster (spatial and thermal analysis). This dual presence highlights that urban planning serves as a conceptual and operational nexus, connecting climate adaptation with land-use and spatial design strategies.

Overall, the network in Figure 12 demonstrates that the literature is evolving toward multidimensional integration:

- A strategic policy layer (blue) defining governance and adaptation goals,
- A managerial–operational layer (green) addressing practical risk and disaster management, and
- An analytical–technological layer (red) focused on spatial modelling and environmental metrics.

This three-tiered configuration reveals the field's movement toward bridging policy frameworks, management actions, and analytical tools, forming a coherent yet interdisciplinary research architecture for urban resilience, climate change, and renewable energy.

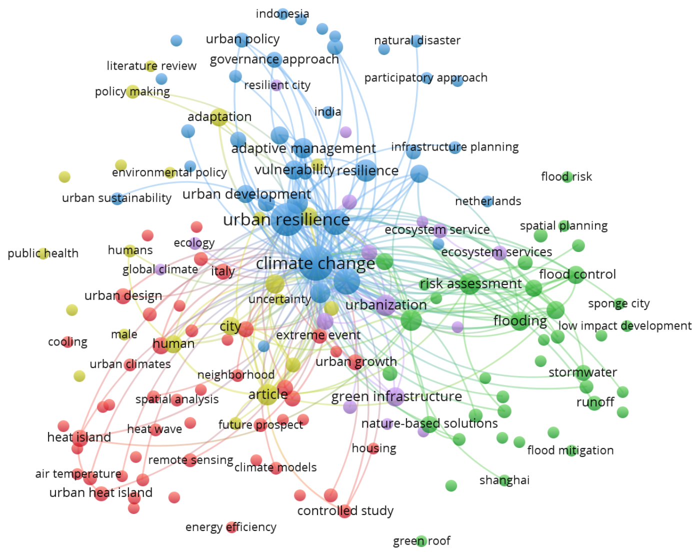

Figure 12. Author keyword co-occurrence map in the field of "urban resilience, climate change, and renewable energy" (2000–2025). the node size represents the frequency of keyword usage, while the link thickness indicates the strength of co-occurrence between terms.

5.13. Temporal (overlay) author keyword co-occurrence network (2021–2024): conceptual evolution of urban resilience in relation to policy, hydrological risk, and microclimate

Figure 13 displays the temporal co-occurrence map of author keywords, illustrating the conceptual evolution of urban resilience research between 2021 and 2024. The colour gradient ranges from purple/blue (earlier average publication years, around 2021) to green/ yellow (more recent years, 2023–2024). The node size represents the frequency of keyword usage, and the edge thickness reflects the strength of co-occurrence among terms. At the centre of the map, the two key nodes "urban resilience" and "climate change" form the backbone of the conceptual structure, around which other thematic clusters are organized.

Governance and planning axis (institutional dimension – cooler colours, upper zone)

Keywords such as governance approach, policy-making, urban policy, participatory planning, and adaptive management appear in blue to purple hues, indicating their dominance in the early period (2021–2022). This phase represents the normative–institutional foundation of the field, where scholarship primarily focuses on multi-level governance, stakeholder participation, and strategic infrastructure planning. The proximity of vulnerability and resilience in this cluster shows a discursive transition from vulnerability assessment to adaptive capacity and resilience-based management. Strong linkages between this set and climate change adaptation confirm the mediating role of urban policy in translating resilience goals into urban governance frameworks.

Hydrological risk and nature-based solutions axis (applied dimension – green to yellow, mid-right zone)

A rapidly expanding stream of applied research emerges here, centred around terms such as urban flooding, flood control, runoff management, and risk assessment, often co-occurring with ecosystem services, green infrastructure, nature-based solutions (NBS), sponge city, and low-impact development (LID). These nodes appear mostly in green to yellow, indicating intensification after 2022, which reflects the field's shift toward operationalizing resilience through water-based risk reduction and ecological design. This suggests that the practical implementation of resilience is increasingly relying on hydrological risk management integrated with nature-based and ecosystem approaches.

Microclimate, remote sensing, and urban morphology axis (analytical dimension – green to yellow, left zone)

This cluster includes keywords such as urban heat island (UHI), remote sensing, spatial analysis, urban climate, land use, and urban design. These terms form a technical–analytical subnetwork, primarily appearing in green–yellow tones, which signals the recent rise (2022–2024) of data-driven research utilizing GIS, spatial modeling, and climatic simulations. Their linkages with urban development and design strategies suggest that urban morphology is increasingly recognised as a key variable in understanding heat intensity, microclimate regulation, and urban cooling interventions.

5.14. Emerging trends and research gaps

Peripheral keywords, such as public health and energy efficiency, remain weakly connected, indicating that the systematic integration of health–justice dimensions and energy-centered resilience remains underdeveloped, presenting a critical opportunity for future research. The temporal distribution also reveals a paradigm shift: from institutional frameworks and governance models (2021) toward risk-assessment tools and nature-based interventions (2023–2024). Meanwhile, the absence or weak presence of terms like photovoltaic technology, microgrid, and distributed energy generation confirms that renewable energy integration within the urban resilience discourse remains underrepresented in author-level conceptual vocabularies.

Overall, Figure 13 illustrates a dynamic conceptual evolution:

- 2021–2022: Dominance of governance, institutional, and participatory frameworks.
- 2022–2023: Expansion of hydrological-risk management and nature-based approaches.
- 2023–2024: Consolidation of data-driven, climate–morphological analysis as the analytical frontier.

This trajectory marks a shift from governance and vulnerability paradigms toward ecological, spatial, and data-integrated models of urban resilience.

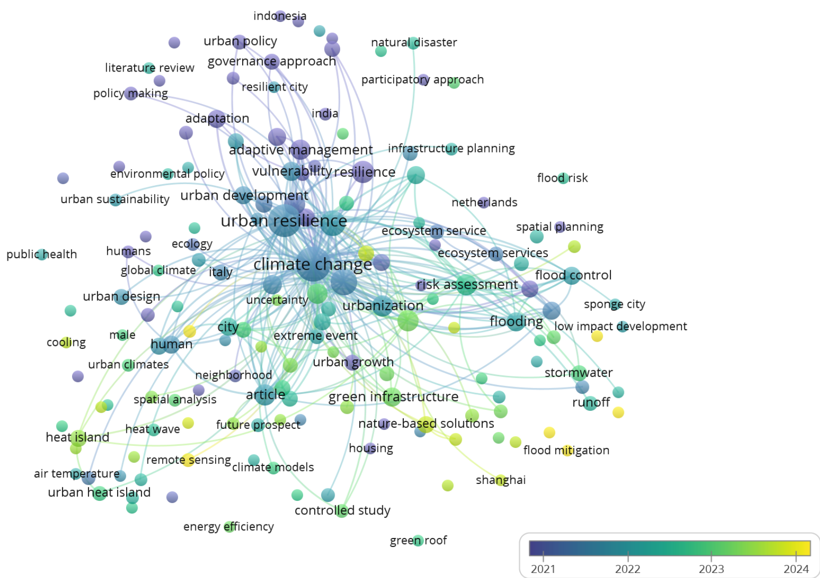

Figure 13. Temporal (overlay) author keyword co-occurrence map in the field of urban resilience and climate change (2021–2024).

In Figure 14. Indexed keyword co-occurrence map illustrating the standardized conceptual architecture and thematic linkages across policy pathways, hydrological risk, and urban microclimate in the field of urban resilience, climate change, and renewable energy. The map visualises the network of indexed keyword terms systematically assigned by database indexers to publications, which therefore provides a more consistent and less ambiguous conceptual structure than author keywords. The node size represents the frequency of keywords, while the edge thickness indicates the strength of co-occurrence among terms.

5.15. Core structure and dominant linkages

At the centre of the network, the three nodes "climate change," "urban planning," and "urban space" form the conceptual backbone, connecting the peripheral clusters.

The proximity between vulnerability and adaptive management within urban planning indicates that, in indexed records, resilience is predominantly framed through the lens of adaptive governance and vulnerability reduction in urban systems.

Cluster 1 policy, governance, and urban policy-making (blue)

Terms such as state, urban policy, governance approach, and policy-making are tightly linked to urban planning. This configuration indicates that, within the indexed taxonomy, policy–institutional frameworks and urban planning tools are the dominant pathways for translating resilience into practice. The appearance of public health at the periphery of this cluster highlights a growing yet still peripheral connection between urban resilience and health-oriented governance.

Cluster 2 hydrological risk and management tools (green)

This cluster encompasses terms such as urban flooding, flood control, stormwater drainage, storms, surface runoff, flood risk assessment and management, low-impact development (LID), and urban water resource management. The high co-occurrence intensity within this cluster shows that hydrological hazards remain a central operational focus of the resilience literature.

Notably, the inclusion of artificial intelligence (AI) adjacent to flood risk assessment reflects the emergence of machine learning applications in hazard prediction and resilience evaluation.

Cluster 3 urban climate, microclimate, and morphology (red)

This cluster is structured around urban climate, microclimate, urban heat island (UHI), air temperature/land surface temperature (LST), remote sensing, and spatial analysis.

Connections among land use, surface cover, climate modeling, and simulation demonstrate a multi-scale, data-driven modeling trajectory supported by GIS, remote sensing, and spatiotemporal simulations for understanding urban warming mechanisms and the impacts of land use.

Cluster 4 urban ecology and nature-based solutions (yellow / yellow-green)

Bridge terms, such as ecosystem services, urban ecosystems, green space, green roof, and spatio-temporal analysis, occupy an intermediate position between the microclimate (red) and hydrological risk (green) clusters. This positioning confirms their translational role serving as conceptual bridges between ecological–climatic processes and risk management frameworks.

The presence of GIS and spatio-temporal analysis alongside these terms underscores that spatial–temporal analytical approaches primarily support ecosystem service assessment and nature-based solutions (NBS).

Overall, Figure 14 depicts a standardized and interconnected conceptual architecture, in which:

- Urban planning and governance act as the institutional foundation,
- Hydrological risk management serves as the applied core,
- Urban climate and morphology represent the analytical front, and
- NBS and ecosystem approaches bridge the ecological and infrastructural dimensions.

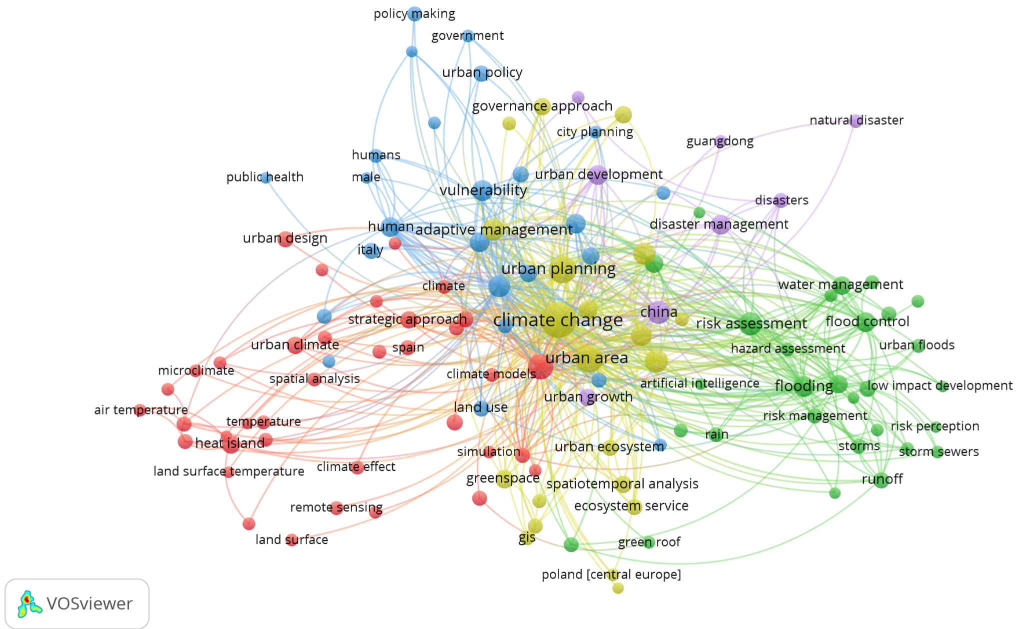

Figure 14. Indexed keyword co-occurrence map in the field of urban resilience, climate change, and renewable energy.

5.16. Temporal (overlay) co-occurrence map of indexed keywords in the field of urban resilience, climate change, and renewable energy (2021–2023)

The map illustrates the temporal evolution of indexed terms, with the color gradient ranging from blue/purple (earlier years, ~2021) to green/yellow (more recent years, 2022–2023). Node size represents the frequency of keyword usage, and link thickness indicates the strength of co-occurrence among terms. In the early phase (2021, blue–purple region), a conceptual cluster formed around "policy-making" and "governance." Terms such as policy-making, governance, urban policy, and governance approach are directly linked to urban planning. This configuration reveals that the early literature primarily focused on institutional structures, decision-making mechanisms, and participatory governance frameworks, essentially addressing who makes decisions, how they are made, and how these decisions are reflected in urban policy and planning. The proximity of vulnerability and adaptive management suggests an early shift in policy discourse toward adaptive management and vulnerability reduction. From 2022 onward (green–yellow region), the thematic focus shifts toward hydroclimatic risks and water-related resilience. Keywords such as floods, urban flooding, flood control, stormwater drainage systems, storms, runoff, risk assessment, risk management, and flood hazard become increasingly dominant, alongside urban water management and low-impact development (LID). This indicates a maturation of the field, where previously theoretical policy frameworks have evolved into operational and intervention-oriented approaches, including drainage network design, runoff management, and quantitative flood-risk modeling. The introduction of risk perception as a co-occurring term also reveals growing attention to social and behavioral dimensions of risk management, acknowledging how citizens and stakeholders perceive and respond to climate-related hazards. In the lower-left region (yellow–green cluster), the most recent wave of studies has concentrated on urban climate and microclimate dynamics. Prominent terms include urban climate, microclimate, urban heat island (UHI), air temperature, land surface temperature (LST), remote sensing, spatial analysis, simulation, climate models, geographic information systems (GIS), and spatio-temporal analysis. This trend highlights a technological and data-driven shift in the literature, reflecting the advancement of urban-scale climate monitoring, modeling, and visualization infrastructures. The strong co-occurrence between land use and climate modelling highlights the increasing recognition of urban morphology and land-use patterns as critical determinants in explaining urban heat mechanisms and assessing the efficacy of climate adaptation strategies. Overall, Figure 15 captures a temporal transition in the conceptual focus of global research from institutional and governance frameworks (2021) to operational risk management and hydrological resilience (2022) and finally to microclimate modelling and data-intensive analysis (2023), reflecting a deepening integration between urban governance, environmental risk, and climate-informed planning.

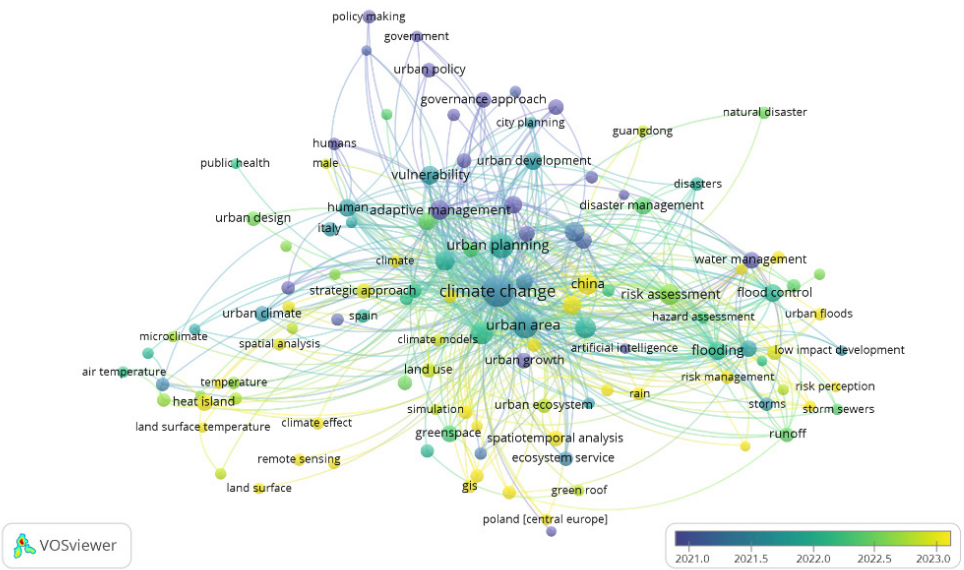

Figure 15. Temporal (overlay) indexed keyword co-occurrence map in the field of urban resilience–climate change–renewable energy (2021–2023).

6. Discussion

The bibliometric and co-word analyses reveal that the literature on urban resilience, renewable energy, and climate change has undergone a notable paradigm shift since 2020 from institutional and policy framing toward measurable intervention packages and data-driven analytical integration. At the conceptual core, urban resilience and climate change remain central, closely interlinked with policy-making, governance, and urban planning. This configuration aligns with transformative governance frameworks and adaptive planning trajectories that emphasize iterative policy review in the face of climatic uncertainty (Chu et al., 2022; Meerow & Stults, 2021). At the intervention level, a clear thematic transition has emerged since 2022 toward hydroclimatic risk management. Terms such as flooding, urban flood control, runoff, risk assessment, and low-impact development dominate alongside urban water management, indicating that policy agendas have evolved into standardized operational and infrastructural practices (de MacEdo et al., 2025; Dong et al., 2024). This shift is consistent with the new wave of literature that integrates Nature-Based Solutions (NBS) and Green Infrastructure (GI) into flood-risk modeling and resilience-assessment frameworks such as Sendai and Bowtie (Ahern et al., 2021; de MacEdo et al., 2025), representing a move from physical adaptation toward ecosystem-service-oriented design. Methodologically, the field has also advanced rapidly. The microclimate cluster, comprising urban heat islands, air-land surface temperature, remote sensing, spatiotemporal analysis, simulation, and climate models, has strengthened and established tight linkages with land-use/land-cover. This evidences the growing recognition of urban morphology as a mediating variable in explaining heat dynamics and their implications for building and neighborhood-scale energy performance (Xu et al., 2022; Oukawa et al., 2022). This methodological transformation from basic UHI mapping to multi-scale, data-intensive modeling, incorporating machine learning, lays the groundwork for integrated strategies targeting simultaneous temperature reduction, energy demand mitigation, and risk minimization (Karimi et al., 2025; Hsu et al., 2023). Alongside this technical–spatial evolution, justice has become more central. Emerging research highlights inequities in access to green infrastructure and ecosystem service benefits, as well as the contradictions of energy democracy, warning that without distributive and procedural equity metrics, green or renewable interventions may reproduce existing urban inequalities (Haque & Sharifi, 2024; Rice et al., 2022). From an energy-transition perspective, the central research challenge lies in integrating multi-scalar aspects between climate adaptation and urban energy systems (from building to grid), which remains a key institutional and investment bottleneck (Romero-Lankao & Gnatz, 2022; Hsu et al., 2023). The co-authorship and geographical analyses reveal a multi-polar landscape of knowledge production: China leads quantitatively, followed by the United States, while Europe and East Asia (e.g., Guangdong) show strong growth through intercontinental collaborations. These networks reflect the transfer of policy experiments (e.g., Sponge Cities) into the academic domain, helping to develop transferable standards for risk assessment and NBS design (Zhou et al., 2025; de MacEdo et al., 2025). However, several structural gaps persist: 1. Systematic underrepresentation of the energy dimension within the resilience literature. Research directly addressing photovoltaics, microgrids, or energy efficiency alongside NBS remains sparse, despite the potential for distributed infrastructures to enhance both energy and ecological resilience (Ottenburger et al., 2024; Fleck et al., 2022).2. Scale disconnects between building, neighborhood, and city-level assessments. Microclimatic and morphological impacts are highly context-dependent and demand local calibration (Xu et al., 2022; Pappalardo et al., 2023).3. The absence of integrated “Resilience–Energy–Ecosystem” indices standardized for cross-comparison. Recent reviews emphasize the need for composite, indicator-based frameworks that jointly monitor equity, efficiency, and risk reduction (Suárez et al., 2024; Sharifi et al., 2022).4. A persistent science–policy gap in translating remote-sensing and Earth-observation data into actionable urban decision-support tools (Pirrone et al., 2022).

From these findings, several practical implications emerge: (a) Develop multi-benefit interventions that concurrently address microclimate cooling, runoff reduction, and energy-demand mitigation (e.g., biosolar roofs, solar-shaded greenery, and permeable drainage networks). (b) Transition from pilot projects to scalable urban programs using distributive justice and energy-performance benchmarks. (c) Embed adaptive pathways into urban policymaking to translate IPCC AR6 climate scenarios and UN SDGs into measurable urban indicators (IPCC, 2022; UN, 2019). The results align closely with the existing literature on energy transition and infrastructure resilience, which highlights the interconnection between energy, water, and ecosystems as a crucial foundation for systemic climate adaptation (Parker & Simpson, 2020; Ottenburger et al., 2024). Finally, the study acknowledges limitations inherent to Scopus coverage and the reliance on indexed keywords, which may introduce partial bias. Nonetheless, triangulation with author keywords and title/abstract vocabularies, along with sensitivity analyses, helped mitigate this issue. In Figure 16, the study presents a conceptual integrative model synthesizing global research trajectories on urban resilience. The model highlights the vital interlinkage between urban resilience, renewable energy, and climate change challenges, emphasizing that achieving resilience requires overcoming structural barriers—such as the science–policy divide and the underrepresentation of energy in climate analyses. Persistent challenges include the absence of unified metrics and scale integration (from building to city), which impede the implementation of holistic solutions to urban heat and water-related risks. The forward-looking framework positions Nature-Based and Energy-Integrated Solutions (NBS-Energy) at its core, promoting the simultaneous restoration of ecosystems, enhancement of energy systems, and the pursuit of spatial and social justice. This integrated approach ultimately aims to define and strengthen urban resilience indicators, thereby closing the loop between research, policy, and practice in the pursuit of building sustainable and climate-resilient cities.

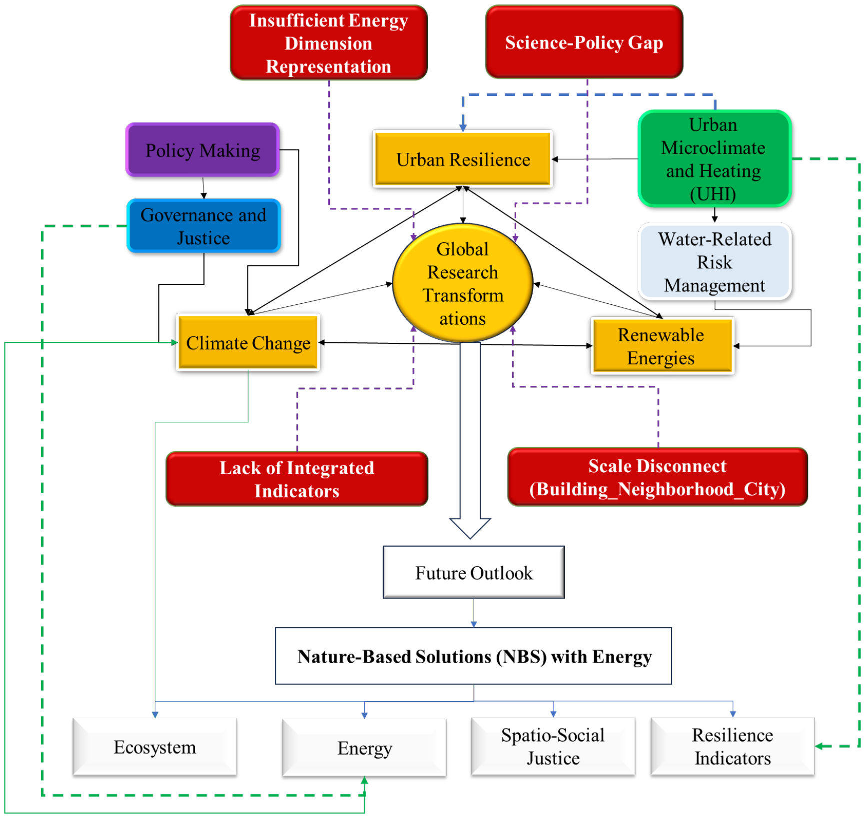

Figure 16: Conceptual research model

7. Conclusion

The present study was conducted to analyze global developments in the interconnection of urban resilience, renewable energy, and climate change from 2000 to 2025. The findings indicated that over the past two decades, this field has moved from a fragmented and conceptual stage toward a state of relative maturity and remarkable acceleration. Following the Paris Agreement in 2015 and the release of new IPCC reports, the volume of scientific output has more than tripled, with a shift in focus from theoretical discussions to applied approaches, such as green infrastructure, stormwater management, and data-driven urban climate modeling. The analysis of conceptual clusters revealed three main research streams:

• Policy-making, governance, and climate justice, which during the first decade focused on institutional framework development;

• Hydrological risks and green infrastructure, which since the 2020s has inclined toward Low Impact Development (LID) approaches;

• Microclimate and land use, which, through advances in remote sensing and spatiotemporal modeling, has established a new methodological foundation.

This pattern indicates that scientific transformation is shifting from macro-level governance to data-oriented tools for the simultaneous management of climate risks and energy demand. From a geographical and institutional perspective, countries such as China, the United States, India, Germany, and Iran have gained leading roles in recent years. This pattern reflects a shift from a Western-centric focus toward the polycentric production of knowledge and an increasing role of Asian research institutions. Furthermore, co-authorship analysis has shown that international collaboration networks have become gradually denser, and the role of developing countries as mediators in global scientific cooperation is increasing—a trend that could provide a foundation for strengthening climate justice in energy and resilience policies.

The results also reflected previous knowledge gaps: the systematic neglect of the energy dimension and its link with urban resilience, the scale disconnection among the building, neighborhood, and city levels, the absence of integrated indicators for simultaneously assessing resilience, energy, and ecosystem services, and deficiencies in justice and governance within distributed energy systems. Scientometric analyses revealed that, despite an increase in publication volume, the components of energy and justice still occupy a marginal position in citation networks, requiring integrative and policy-sensitive approaches. Accordingly, several key policy pathways are proposed to address the identified gaps. First, climate-adaptive planning must be practically linked to the energy transition, such that green urban interventions and nature-based solutions (GI/NBS) are designed and implemented simultaneously with localized renewable energy systems, including rooftop photovoltaics, biosolar roofs, and bioenergy production from urban waste. Such an approach enhances climate resilience against heatwaves and floods, as well as energy resilience. These actions should be defined as "intervention packages" at the building, neighborhood, and city levels to prevent project fragmentation and policy duplication. Second, bridging the scale disconnection requires standardization of data and modeling chains across urban levels. The establishment of urban microclimate observatories, the integration of thermal maps and remote-sensing data with building energy-demand models and distribution networks, and localized calibration for each city are prerequisites. These systems must be linked to climate scenarios and risk assessments, so that their results are reflected in building regulations, open-space design, and urban drainage systems. Third, the development of integrated "Resilience–Energy–Ecosystem" (SETS-informed) indicators is essential. These indicators should simultaneously measure energy performance, ecosystem services, and social equity, and be aligned with international frameworks such as the SDGs and IPCC. Applying these indicators in urban pilot projects enables a connection between performance evaluation and evidence-based budgeting, thereby preventing fragmented decision-making.

Fourth, energy transition policy-making must be formulated with a focus on justice and social inclusion. The development of microgrids and establishment of local resilience hubs in disadvantaged neighborhoods, combined with targeted subsidies and community energy participation, can prevent the formation of "energy boundaries" and reinforce spatial and social equity. Fifth, reducing the science–policy gap requires the creation of knowledge translation platforms. Scientometric data and analyses, including co-occurrence maps and collaboration networks, should be transformed into policy-research dashboards that identify the sequence of interventions, investment priorities, and underexplored domains. Each policy package should comprise a set of complementary interventions; for example, the combination of biosolar roofs, permeable surfaces, and urban shading can be included as a coherent "family of interventions" in urban development programs. Finally, financial and institutional coordination is also essential. The results of integrated indicators should be directly connected to urban green bonds, energy performance contracts, and microgrid incentive tariffs. Revising building codes to emphasize microgrid readiness, standardizing biosolar roofs, and promoting low-carbon public procurement can provide institutional support for this transition. Establishing a permanent "Resilience–Energy–Climate Working Group" with the authority to integrate budgets and projects will help align infrastructure, energy, and environmental justice policies.

In summary, the present study provided a systematic depiction of the scientific evolution of this field. It demonstrated that future research and policy directions must move toward the multi-scalar integration of nature-based solutions (NBS) with clean energy systems, the development of integrated Resilience–Energy–Ecosystem indicators, and the institutionalization of justice in the energy transition process. Achieving resilient and low-carbon cities is possible only when urban planning, data, and investment are organized based on measurable, multi-scalar, and justice-oriented indicators. The study offered a systematic portrayal of the twenty-five-year transformation of global literature connecting the triad of urban resilience, renewable energy, and climate change. Scientometric analysis showed that this field has evolved from a theoretical and fragmented discourse in the 2000s into a data-driven and interdisciplinary network in the 2020s — a transformation shaped by the combined pressures of international climate policies, clean energy technology development, and increasing climate risks at the urban scale. Despite the remarkable growth of scientific production, the knowledge structure remains discontinuous in terms of conceptual and scalar integration. Dominant approaches still tend to focus either on the technological aspects of energy or on social and infrastructural resilience. At the same time, few studies have successfully integrated these two dimensions into urban decision-making frameworks. Therefore, future research should focus on developing multi-level and multidimensional models that can quantitatively represent the linkages among infrastructure, ecosystems, and spatial justice.

To strengthen the analytical depth of this field, it is recommended that future studies:

- Go beyond bibliometric analysis and integrate scientometric methods with textual content and semantic network analyses to identify more profound conceptual transformations;
- Test and calibrate integrated Resilience–Energy–Ecosystem indicators using empirical city data;
- Conduct comparative interregional studies between Global North and Global South cities to analyze differences in energy justice and resilience capacities;
- Undertake scenario-based and spatiotemporal modeling to simulate the future impacts of energy on urban climate risks; and
- Finally, design knowledge translation frameworks between the scientific community and urban policymakers to convert scientometric results into usable policy actions.

In general, the future pathway of this field depends on a shift from descriptive analyses toward integrated, data-driven, and justice-oriented approaches. Only through the multi-scalar integration of renewable energy systems, green infrastructure, and social policies can a genuine model of resilient, low-carbon, and equitable cities in the face of climate change be realized.

Authors' Contributions

First Author: 35% – Second Author: 35% – Third Author: 30%.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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