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Urban Sustainability Studies as an Integrated Academic Field: A Systematic Review

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Abstract

Although urban studies are vital for a sustainable society, comprehensive meta-level overviews are scarce. To map the field and identify emerging areas, we analyzed over 100,000 publications containing the terms "urban" and "sustainable" or "sustainability" using citation network analysis and natural language processing following the PRISMA protocol. Emerging areas encompassed the economic–environmental relationship, smart sensing and urban air mobility, green development at the metropolitan scale, soil heavy metal pollution, tourism and emissions, and heatwave exposure countermeasures. Future research priorities included developing an integrated theoretical framework to evaluate locality in terms of the interaction between urbanization, economic growth, and environmental quality, organizing health-related data, researching underlying technologies, and determining the generalizability or contextual adaptability of policy applications. Comparing the newest sub-clusters with sub-clusters including the term "design" indicates the necessity and opportunity to integrate environmental, economic, and social dimensions into a bottom-up multiscale theoretical framework by connecting terminology and concepts that vary according to scale and synthesizing emergent issues into the conventional urban planning realm. These findings will inform decisions regarding funding and investment in scientific research by governments, companies and research institutions.

Keywords: sustainable; urban; bibliometrics; network analysis; natural language processing

1. Introduction

Scientific achievements in various fields, particularly urban studies, are vital for realizing a sustainable society. As the global urban population is expected to grow throughout the 21st century, urbanization is recognized as an accelerator of SDGs [1]. The IPCC's Special Report on Climate Change and Cities [2], expected to be published in the near future, will underscore the significant role and responsibility of cities in achieving a sustainable society. Simultaneously, cities must address interrelated "wicked problems" [3], including climate change. This requires a comprehensive understanding of urban studies that span diverse fields within the natural and social sciences. Urban planning, by its very nature, aims for integration. Urban planning is identified as a pioneer of integration in policy integration research [4].

Urban sustainability, which has gained prominence in urban planning and decision-making [5–7], was introduced in the 1992 Rio Declaration on Environment and Development [8]. The core concept of urban sustainability rests on three pillars: environment

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(bio-physical), economy, and society. Subsequently, urban sustainability has gained increasing importance in political agendas and scientific research in the past few decades. Urban sustainability has been defined in various ways, but the primary focus is on improving long-term human well-being by optimizing resource consumption, minimizing environmental damage, and ensuring equity and justice [9]. Another study points out that urban sustainability is often defined in terms of intergenerational equity, intragenerational equity, natural resource conservation, economic sustainability and diversity, social resilience, social welfare, and the fulfillment of basic needs [10]. Most definitions of urban sustainability are derived from the definition of sustainability itself, focusing on enhancing long-term human well-being by balancing the three dimensions of sustainability. These studies have contributed to the materialization of the three pillars of urban sustainability. Based on the above, this study defines urban sustainability as having three aspects: environment (bio-physical), economy, and society. In order to approach urban sustainability research as an integrated disciplinary field, this study adopted a more general and abstract definition.

In the field of urban studies focusing on climate change, there are review studies related to sustainability issues. However, these studies are limited to reviews of specific concepts and do not provide an overview of the broader field of urban sustainability studies as a whole. For instance, some studies have reviewed concepts such as urban resilience [11], climate change adaptation and mitigation [12], and climate change and urbanism [13]. While these studies clarified important concepts within urban sustainability studies, they may only cover a small fraction of the broader research landscape and address only one facet of complex issues.

On the other hand, the bibliometric approach is well-suited for surveying a vast number of research papers because it analyzes large volumes of bibliographic information. Studies [14–16] provided comprehensive maps of sustainability research by analyzing large amounts of bibliographic information. Asatani et al. (2020) [17] analyzed the largest dataset, examining 312,584 papers published in Scopus with the highest number of connected components in its citation network. Such studies are useful for clarifying how the subject matter has diversified and for identifying the most recent topics. However, given the rapid growth of sustainability research in recent years, these results are now outdated. Furthermore, such studies are too broad to offer specific insights into urban research and practice. In particular, it lacks a perspective that presents insights on how to integrate these elements, offering practical implications for urban planning and development. Therefore, there remains room for a bibliometric approach from the perspective of urban planning as an integrative discipline.

Thus, the purpose of this study is to create a comprehensive map of urban sustainability studies and to understand the scientific trends within this realm as an integrated academic field. First, we collected papers related to urban sustainability studies from Scopus using the "sustainab*" query proposed by Kajikawa [14], and "urban" query. Next, we classified 105,733 urban sustainability papers using citation network clustering [18]. By analyzing the clusters' information and representative words, we identified the current landscape of urban sustainability studies. Furthermore, we decomposed these clusters into sub-clusters to examine the research topics that urban sustainability studies have focused on in recent years. We also examined sub-clusters that encompassed the term "design" in frequent keywords as a concept integrating various elements through space. By comparing these results, we can gain an overview of new trends in urban sustainability studies and an integrated perspective across them.

This study created a research map of urban sustainability studies by using net-work-based classification and text analysis to examine over 100,000 publications containing the terms "urban" and "sustainable" or "sustainability." This process visualized the cross-

cluster structure and identified emerging fields. Furthermore, it presented research agendas from three perspectives—theoretical, technological, and policy-related—for future topics. These agendas include developing an integrated framework to assess the interactions between urbanization, economic growth and environmental impacts, preparing health-related data and examining the generalizability and contextual adaptability of policies. Comparing it with the analysis of sub-clusters that encompass the term "design" in frequent keywords, the study indicated the necessity and opportunity to integrate environmental, economic, and social dimensions into a bottom-up multiscale theoretical framework.

2. Materials and Methods

2.1. Data

A widely accepted consensus on the definition of urban sustainability studies does not yet exist. Considering the potential practicality and scientific knowledge interrelatedness of research aimed at realizing a sustainable society, many studies are related to urban sustainability. As a result, we opted to review studies that specifically included the words "urban" and "sustainability" or "sustainable." Essentially, we explored whether scientific attention was directed towards urban and sustainable elements. On 6 September 2025, a total of 105,733 papers were retrieved from the Scopus database. Figure 1 shows a dramatic annual increase in the number of papers. We analyzed 69,113 papers included in the largest connected component of the citation network, excluding irrelevant papers that merely used the terms "sustainab*" and "urban."

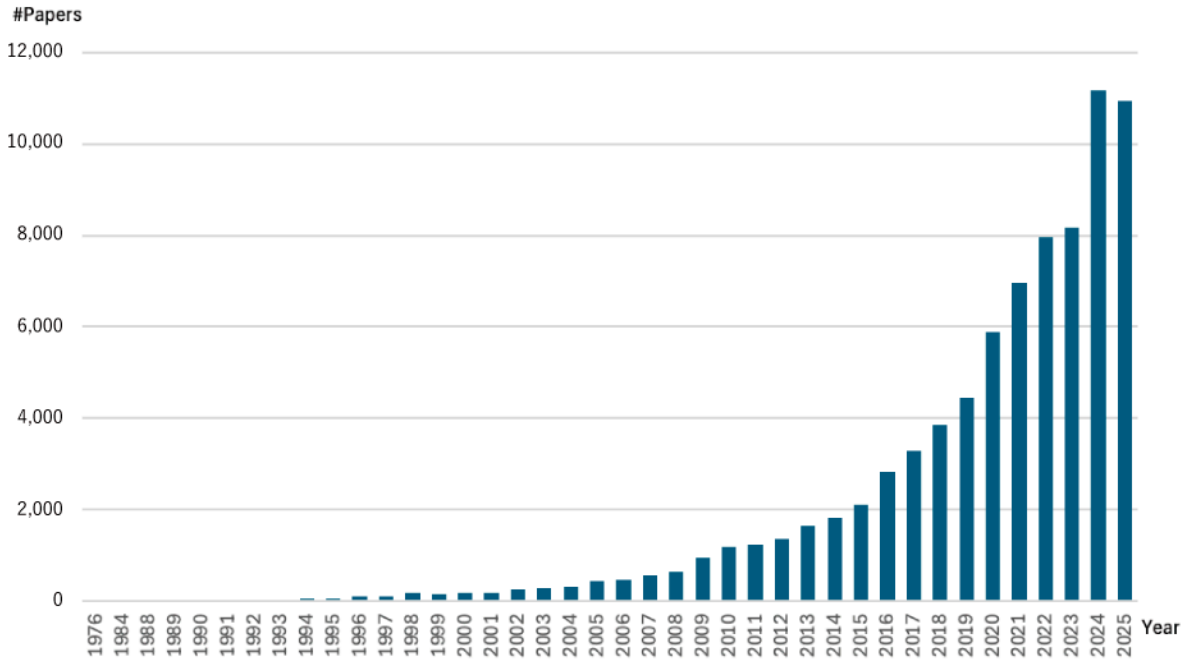


Figure 1. Number of papers including the terms "urban" and "sustainable" or "sustainability" in each year in the titles, keywords or abstracts. (Not all papers published in 2025 have been included in Scopus yet). The vertical axis represents the number of papers.

2.2. Methods

The procedure for shaping the landscape of academic publications involves two main steps: first, conducting clustering of the citation network, and second, identifying key terms and essential data (such as keywords and the average year of publication) from each cluster. This study used a systematic literature review guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [19] paradigm to

ensure rigor, transparency, and replicability in article identification, screening, and inclusion (Supplementary Materials).

The network's nodes were organized into clusters using the Leiden clustering technique [18]. This approach aims to find the optimal set of clusters by maximizing the modularity Q value [20]. The modularity Q indicates the ratio of the density of edges between the same cluster nodes to that when considering a random node assignment while maintaining the sizes of the clusters. We used Python 3.13's default random number generator for clustering. The Leiden method provides the necessary clustering accuracy and processing speed in real-time compared with the Louvain method [21], which is widely used in network analyses. The Leiden method is typically faster than the Louvain method and returns partitions of a higher-quality cluster. The Leiden method also performs well on small, medium, and large-scale networks [22]. Our chosen implementation of the Leiden method maintains modularity optimization, making it vulnerable to the resolution limit. Upon calculating the clusters of urban and sustainable papers, we found that some clusters comprised a significant number of papers. To conduct a thorough analysis, we employed recursive calculations to pinpoint the sub-clusters within each cluster that had more than 50 papers. Through this process, as mentioned above, 69,113 academic papers were extracted from 105,733 papers as the largest connected component based on the results of the citation network analysis. The other papers were excluded because they were not directly related to urban sustainability studies (see Figure 2).

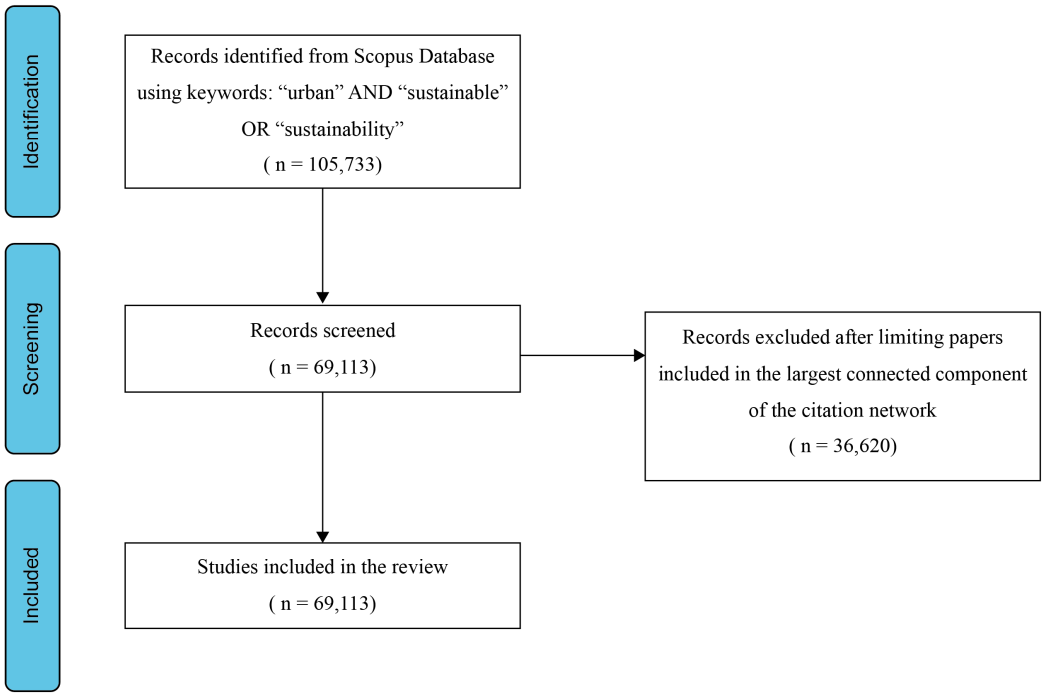


Figure 2. Prisma flow map. Source: Authors' elaboration based on Scopus data (2025), 6 September 2025.

The second-largest connected component included only 11 papers. Almost all other connected components included one paper. Therefore, the extracted 69,113 academic papers can be regarded as covering the whole discussion among the papers including the terms "urban" and "sustainable" or "sustainability" without overlooking other aggregation of academic discussion. Additionally, the number of the papers including the term "urban" was 1,657,316, while the number of the papers including the term "sustainable" or "sustainability" was 1,126,725. These papers may be related to urban sustainability studies, even if they do not include both terms "urban" and "sustainable" or "sustainability." For example, emerging urban technologies that will contribute to enhancing urban sustainability in the

future may be ignored. This is a methodological limitation of the present study. However, as this study focused on urban sustainability as an integrated academic field, we reviewed papers that explicitly included the keywords.

We employed natural language processing to identify key terms for each cluster. N-gram terms, which are sequences of n words that may include non-term sequences like "is a," can be extracted, and words such as "algorithm" and "algorithms" might be treated as distinct. To address this, we used the NLTK WordNet Lemmatizer [23] and extracted the terms that met the part-of-speech pattern [24] (<JJ>* <NN.*> + <IN>)? <JJ>* <NN.*> +. This allowed us to extract terms like "high accuracy algorithm" while excluding terms like "is different." Subsequently, we singularized the extracted terms using the Python inflection library.

Following this, we calculated the representative terms for each cluster. Initially, we combined the titles and abstracts of all papers within the clusters to form the "document" for each cluster. We then assessed how representative each word was for each cluster document using TF–IDF [25], which is the product of the term frequency (TF) and the inverse document frequency (IDF). This straightforward term-scoring method is empirically effective across various datasets and has been shown to represent "the amount of information of a term weighted by its occurrence probability" [26]. The equation for TF–IDF is provided below.

$$tfidf(t,d) = tf(t,d) \cdot idf(t) \quad (1)$$

$$tf(t,d) = \log(1 + f_{t,d}) \quad (2)$$

$$idf(t) = \log \frac{N}{df_t} \quad (3)$$

Here, t and d denote the term and the document, respectively; $tf(t, d)$ refers to the logarithmic value of the term frequency, and $idf(t)$ represents the inverse proportion of documents containing the term $t(df_t)$. We examined the cluster contents by exploring the terms with high TF–IDF values within each cluster.

Additionally, we extracted the average published year and the 20 most-cited papers for each cluster. Examining the average published year of each cluster allows us to understand the temporal trends in research topics. This process was performed for both the parent clusters and sub-clusters. We selected the top 20 papers because this number provided a sufficient number of papers with characteristic TF-IDF values that differentiated each cluster from the others.

Regarding parent clusters, analyzing the breakdown of journal classifications for the top 20 most-cited papers deepens our understanding of the academic field of urban sustainability and its interdisciplinary nature. The analysis process involved extracting the journal in which each paper was published and its corresponding Scopus ASJC (All Science Journal Classifications) code. We then counted the frequency of these codes. Counts were compiled for both the first two digits (major category) and all four digits (detailed category). Journals may have multiple codes, all of which were counted without specific weighting. The literature group includes books. As books do not have assigned codes, they were excluded from the count.

Regarding sub-clusters, we conducted a detailed analysis of the newest 15 sub-clusters by average published year because they indicate emerging research trends. Specifically, we reviewed the limitations of the research and directions for future research stated in the conclusions of the extracted literature to derive suggestions for concrete future research topics. When deriving TF-IDF of sub-clusters, IDF was calculated based on the parent cluster's papers rather than the entire paper collection, ensuring that the TF-IDF exhibited greater variation. This process clarified the differences between the sub-clusters.

Furthermore, publication year does not necessarily indicate greater significance. From the perspective of urban sustainability research as an integrative discipline, we analyzed sub-clusters containing the word "design" based on the TF-IDF observed across multiple parent clusters. Because design incorporates various elements across space, it is a fitting keyword for exploration in an integrative discipline [27]. Additionally, comparing the analysis results of these sub-clusters with those of the subcluster with the newest average publication year allows us to position recent research interests from a perspective that transcends both time and topic.

3. Results and Discussion

3.1. Research Clusters of the Urban Sustainability Studies

The 69,113 academic papers were sorted into 22 distinct clusters, with an analysis conducted on 19 clusters, each containing over 500 papers. The details of all clusters including more than 500 papers are provided in the Supplementary Materials (Table S1). Figure 3 illustrates these clusters, with each color representing a different cluster. The authors assigned heuristic labels to each cluster after the fact, using TF-IDF and the top 20 most cited papers as a basis (Table 1 provides detailed information for each cluster). The clusters are numbered according to the number of papers they contain. The layout of each paper was derived from text embeddings using OpenAI TextEmbedding3-Small, with the dimensions reduced to two via UMAP. In short, the nodes (papers) are arranged so that neighboring nodes are close together. Therefore, the distance between nodes on the map indicates the closeness of the relationship, but the position itself and the axes have no intrinsic meaning.

Table 1. Details of retrieved academic clusters. The row of "#" represents the number of clusters.

#	Name	#Papers	Year	TFIDF
1	Urbanization	8211	2020.80	land, ecological, development, urban, spatial, china, urbanization, use, rural, ecosystem
2	Mobility	7282	2019.49	transport, mobility, transportation, urban, public, travel, traffic, cities, sustainable, transit
3	Water	6351	2018.13	water, urban, management, groundwater, wastewater, stormwater, flood, systems, drainage, treatment
4	Smart City	6061	2019.19	smart, cities, city, urban, development, sustainability, sustainable, energy, planning, data
5	Land Cover	5379	2019.78	land, urban, lst, study, use, cover, area, heat, lulc, areas
6	Landscape	5223	2019.30	urban, green, spaces, cities, planning, ecosystem, landscape, ecological, space, areas
7	Social	5144	2018.15	urban, heritage, social, development, cultural, regeneration, sustainability, city, sustainable, planning
8	Resilience	4502	2017.71	urban, resilience, sustainability, development, cities, sustainable, indicators, city, environmental, social
9	Agriculture and Food	3579	2018.86	food, agriculture, urban, production, farming, agricultural, systems, rural, sustainability, sustainable
10	Metabolism	2960	2017.96	urban, energy, water, cities, metabolism, consumption, development, city, ecological, environmental
11	Waste	2407	2020.09	waste, solid, management, msw, energy, recycling, environmental, municipal, generation, urban

Table 1. *Cont.*

#	Name	#Papers	Year	TFIDF
12	Economic	1876	2021.41	energy, emissions, environmental, urbanization, economic, carbon, consumption, growth, renewable, development
13	Building Energy	1773	2019.75	energy, building, urban, solar, buildings, design, consumption, renewable, cities, systems
14	Forest	1638	2015.48	forest, species, disturbance, forests, management, soil, tree, ecosystem, disturbances, logging
15	Governance	1573	2018.57	urban, sustainability, governance, cities, transitions, research, development, energy, transition, city
16	Soil	1320	2017.92	soil, land, urban, soils, tillage, crop, ca, use, agricultural, water
17	Logistics	1306	2020.03	logistics, freight, transport, delivery, urban, vehicles, city, mile, traffic, transportation
18	Greening	1020	2019.97	green, roofs, roof, energy, urban, building, buildings, thermal, water, environmental
19	Tourism	739	2018.64	tourism, urban, tourist, development, mangrove, tourists, rural, destinations, destination, sustainable

Urban sustainability studies comprised diverse research clusters. Urbanization (1) encompassed research on urbanization and associated environmental changes, including land use, biogeochemical cycles, climate (e.g., urban heat islands), hydrological systems and biodiversity. (e.g., Grimm et al., 2008) [28]. As seen in the TF-IDF analysis including China, research targeting China, where urbanization is prevalent, was among the top 20 most-cited papers (e.g., Guan et al., 2018) [29]. Mobility (2) was a research domain that covers various transportation modes, accessibility [30], walkability [31], and health issues related to air pollution linked to transportation [32]. Water (3) encompassed research on water management, including flood [33], water quality [34], and wastewater management [35]. Smart City (4) comprised studies that debate whether smart cities, which apply big data, ICT, and IoT to urban environments, contribute to sustainability [36–38]. Land Cover (5) comprised studies on land use and land cover (LULC) related to the urban heat island (UHI) effect. Some study explored the relationship between land use and land cover change and land surface temperature using remote sensing [39].

Landscape (6) was a series of studies on urban green spaces [40], green infrastructure [41] and nature-based solutions [42]. This cluster discussed the positive and negative aspects of urban nature, such as its benefits and disparities [43]. Social (7) was a group of studies on social sustainability. Regarding social sustainability, for example, Dempsey et al. [44] defines it as two main dimensions of "social equity" and "community sustainability," while Vallance et al. [45] defines it as "development sustainability" addressing basic needs, the creation of social capital, justice and so on, 'bridge sustainability' concerning changes in behavior so as to achieve bio-physical environmental goals and 'maintenance sustainability' referring to the preservation—or what can be sustained—of sociocultural characteristics in the face of change, and the ways in which people actively embrace or resist those changes. This cluster also included research on the adaptive reuse of cultural heritage [46]. Resilience (8) was a group of studies on resilience. It included papers on conceptualizing resilience [47] and evaluation indicators [48]. Agriculture and Food (9) was a group of studies on agriculture and food topics. This cluster's papers examined the environmental sustainability and health impacts of dietary changes accompanying

urbanization and rising incomes [49], the factors driving these changes [50], food safety within increasingly complex supply chains [51], and the potential threats of pesticide use in urban areas [52]. Metabolism (10) was a group of studies that quantify the overall flow of energy, water, materials, waste, and nutrients into and out of an urban region [53].

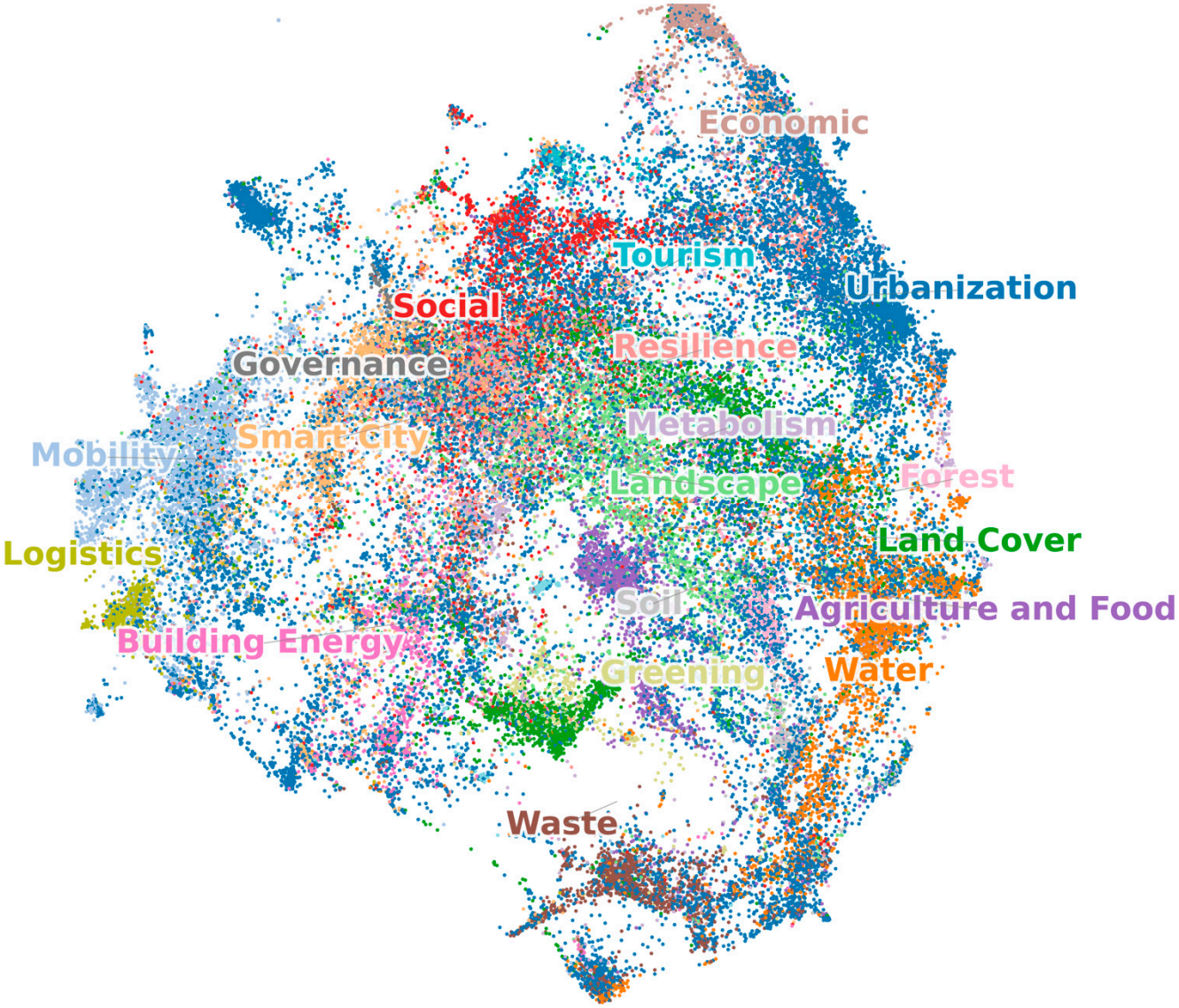


Figure 3. Map of urban sustainability studies. Nodes correspond to papers. Colors indicate clustering results based on citation network.

Waste (11) focused on the management of various types of waste, including solid waste [54] and food waste [55], and their processing and reuse. The cluster also included the topics of bioenergy and biomaterials, which regard negative-valued waste as potential renewable feedstocks [56]. "Economic" (12) was the only cluster in the TF—analysis that included the term "economic," representing research that discussed the relationship between economic growth and environmental quality. The cluster primarily focused on exploring the interactions between energy consumption, carbon emissions, and the adoption of renewable energy in urban areas based on frameworks such as the Environmental Kuznets Curve (EKC) [57,58]. Building Energy (13) was a group of studies on energy consumption in urban buildings. This cluster's papers included development of urban building energy models (UBEM) to support urban energy planning and building renovation decisions [59,60] and solar power generation potential considering urban form dependen-

cies [61]. Forest (14) encompassed research on the impacts of deforestation associated with urbanization [62]. Governance (15) covered research on sustainability transitions [63]. This cluster also examined living labs as experimental governance spaces for advancing transitions on the ground [64,65].

Soil (16) was a group of studies concerning soil quality, including biodiversity and contamination [66–68]. Logistics (17) encompassed studies on urban logistics, which are essential to the urban economy but also cause negative impacts, such as congestion, emissions, and space consumption [69,70]. Greening (18) was a research cluster focusing on wall and roof greening and cool roofs that use high-reflectivity coatings [71,72]. Some studies examined cooling, carbon sequestration, and air pollution mitigation [73]. Tourism (19) was a research cluster on sustainable tourism, including stress relief for urban residents [74] and the need for participatory and collaborative policy approaches [75].

The largest cluster was Urbanization (1). The related areas located near it in Figure 3 are all other clusters, while Social (7), Resilience (8), Metabolism (10), Economic (12), and Tourism (19) are very close to Urbanization (1). This suggests that urbanization is the main focus of urban sustainability studies. The second-largest cluster was Mobility (2). The related areas are Smart City (4) and Logistics (17). These clusters focused on technology, especially in the transportation field. The third-largest cluster was Water (3). The related areas are Land Cover (5), Landscape (6) and Forest (14). All these clusters' research were mainly based on system thinking. Building Energy (13) is close to Greening (18). These clusters focused on the building scale.

The average published years of papers in the clusters were between 2015 and 2021. The recency of the average published year indicates the level of recent scientific attention. The Economic (12), Urbanization (1), Waste (11), Logistics (17), and Greening (18) clusters contained relatively recent publications. The next newest groups were Land Cover (5), Building (13), Mobility (2), Landscape (6), and Smart City (4). The Agriculture and Food (9), Tourism (19), Governance (15), and Social (7) clusters had intermediate or slightly older average published years. The Forest (14) cluster had an average published year of 2015, meaning that relatively few papers have been published recently. The details of all clusters including more than 500 papers are provided in the Supplementary Materials (Table S1).

However, it is not fair to conclude that topics in relatively older clusters do not attract recent scientific attention. Two reasons for the freshness of clusters are considered: research areas either emerged recently or researchers working in these areas recently associated their work with urban sustainability. Furthermore, a cluster's "freshness" is influenced by the publication speed within that field. Publication speed is generally faster in natural sciences than in humanities and social sciences. Therefore, the fact that clusters such as Governance (15) and Social (7) are relatively older does not mean that they are less important.

The breakdown of the journal names of the top 20 most-cited papers in each cluster revealed that urban sustainability studies encompass various research areas. First, the top 20 most-cited papers comprised 215 journals. Among them, the most frequently cited journals were Landscape and Urban Planning, Renewable and Sustainable Energy Reviews, Journal of Cleaner Production, Sustainable Cities and Society, Proceedings of the National Academy of Sciences of the United States of America, Science, and Science of the Total Environment. According to these results, urban sustainability may be considered a popular topic, even in the general science category. Table 2 lists journals with a frequency of five or higher. The details of all the journals are provided in the Supplementary Materials (Table S2).

The ASJC major categories comprised 22 fields (Table 3), although the entire number of papers in the clusters may be higher. Environmental Science, Social Sciences, Engineering, Energy, and Agricultural and Biological Sciences each accounted for 5% or more. Further-

more, the ASJC detailed categories comprised 121 fields. The top frequencies were held by 3305 Geography, Planning, and Development; 2105 Renewable Energy, Sustainability, and the Environment; 2303 Ecology; 2309 Nature and Landscape Conservation; and 2308 Management, Monitoring, Policy, and Law (Table 4). These results reaffirm that urban planning is an interdisciplinary field integrating 2300 Environmental Science, 3300 Social Sciences related to socio-economic and political aspects, and 2200 Engineering related to technology. The complete results of Table 4 are documented in the Supplementary Materials (Table S3).

Table 2. Frequency percentage based on journal name.

Journal Name	Frequency Percentage (n)
Landscape and Urban Planning	4.5% (17)
Renewable and Sustainable Energy Reviews	3.9% (15)
Journal of Cleaner Production	3.2% (12)
Sustainable Cities and Society	2.6% (10)
Proceedings of the National Academy of Sciences of the United States of America	2.4% (9)
Science	1.6% (6)
Science of the Total Environment	1.6% (6)
Applied Energy	1.3% (5)
Building and Environment	1.3% (5)
Cities	1.3% (5)
Habitat International	1.3% (5)
Land Use Policy	1.3% (5)
Philosophical Transactions of the Royal Society B: Biological Sciences	1.3% (5)
Sustainability	1.3% (5)
The Lancet	1.3% (5)

Table 3. Frequency percentage based on ASJC major category.

ASJC Major Category	Frequency Percentage (n)
2300 Environmental Science	30.4% (301)
3300 Social Sciences	21.1% (209)
2200 Engineering	10.2% (101)
2100 Energy	8.5% (84)
1100 Agricultural and Biological Sciences	7.9% (78)
1400 Business, Management and Accounting	3.6% (36)
2700 Medicine	3.2% (32)
1000 General	2.0% (20)
1700 Computer Science	1.9% (19)
1300 Biochemistry, Genetics and Molecular Biology	1.9% (19)
2000 Economics, Econometrics and Finance	1.6% (16)
1900 Earth and Planetary Sciences	1.3% (13)
1800 Decision Sciences	1.2% (12)

Table 3. *Cont.*

ASJC Major Category	Frequency Percentage (n)
2600 Mathematics	1.0% (10)
1600 Chemistry	0.8% (8)
1500 Chemical Engineering	0.7% (7)
1200 Arts and Humanities	0.7% (7)
3100 Physics and Astronomy	0.5% (5)
3200 Psychology	0.5% (5)
2500 Materials Science	0.4% (4)
3000 Pharmacology, Toxicology and Pharmaceutics	0.4% (4)
2900 Nursing	0.1% (1)

Table 4. Frequency percentage based on ASJC detailed category.

ASJC Detailed Category	Frequency Percentage (n)
3305 Geography, Planning and Development	7.3% (72)
2105 Renewable Energy, Sustainability and the Environment	6.0% (59)
2303 Ecology	5.0% (50)
2309 Nature and Landscape Conservation	4.6% (46)
2308 Management, Monitoring, Policy and Law	4.3% (43)
2205 Civil and Structural Engineering	3.8% (38)
2300 Environmental Science(all)	3.6% (36)
3322 Urban Studies	3.2% (32)
3313 Transportation	2.9% (29)
2305 Environmental Engineering	2.7% (27)
3312 Sociology and Political Science	2.3% (23)
3303 Development	2.1% (21)
2310 Pollution	2.0% (20)
1000 General	2.0% (20)
2700 Medicine(all)	1.9% (19)
2304 Environmental Chemistry	1.8% (18)
1408 Strategy and Management	1.7% (17)
2215 Building and Construction	1.7% (17)
2311 Waste Management and Disposal	1.6% (16)
2002 Economics and Econometrics	1.4% (14)
1107 Forestry	1.4% (14)
1409 Tourism, Leisure and Hospitality Management	1.4% (14)
2209 Industrial and Manufacturing Engineering	1.4% (14)
1102 Agronomy and Crop Science	1.3% (13)
2210 Mechanical Engineering	1.3% (13)

Table 4. *Cont.*

ASJC Detailed Category	Frequency Percentage (n)
2301 Environmental Science (miscellaneous)	1.2% (12)
1105 Ecology, Evolution, Behavior and Systematics	1.2% (12)
2312 Water Science and Technology	1.1% (11)

3.2. Emerging Areas of Urban Sustainability Studies

To retrieve the trend within each cluster, we investigated the sub-clusters of each cluster. Figure 4 shows the average publication years of the sub-clusters. In this figure, the subcluster data are aligned vertically with their corresponding parent clusters. The results in the figure indicate that relatively older/newer sub-clusters exist within each cluster. Concretely, some sub-clusters within Economic (12) represent the newest topics among all sub-clusters. Others, such as Urbanization (1), Mobility (2), Smart City (4), Soil (16), and Land Cover (5), contain the next newest sub-clusters. The details of each sub-cluster are provided in the Supplementary Materials (Table S4).

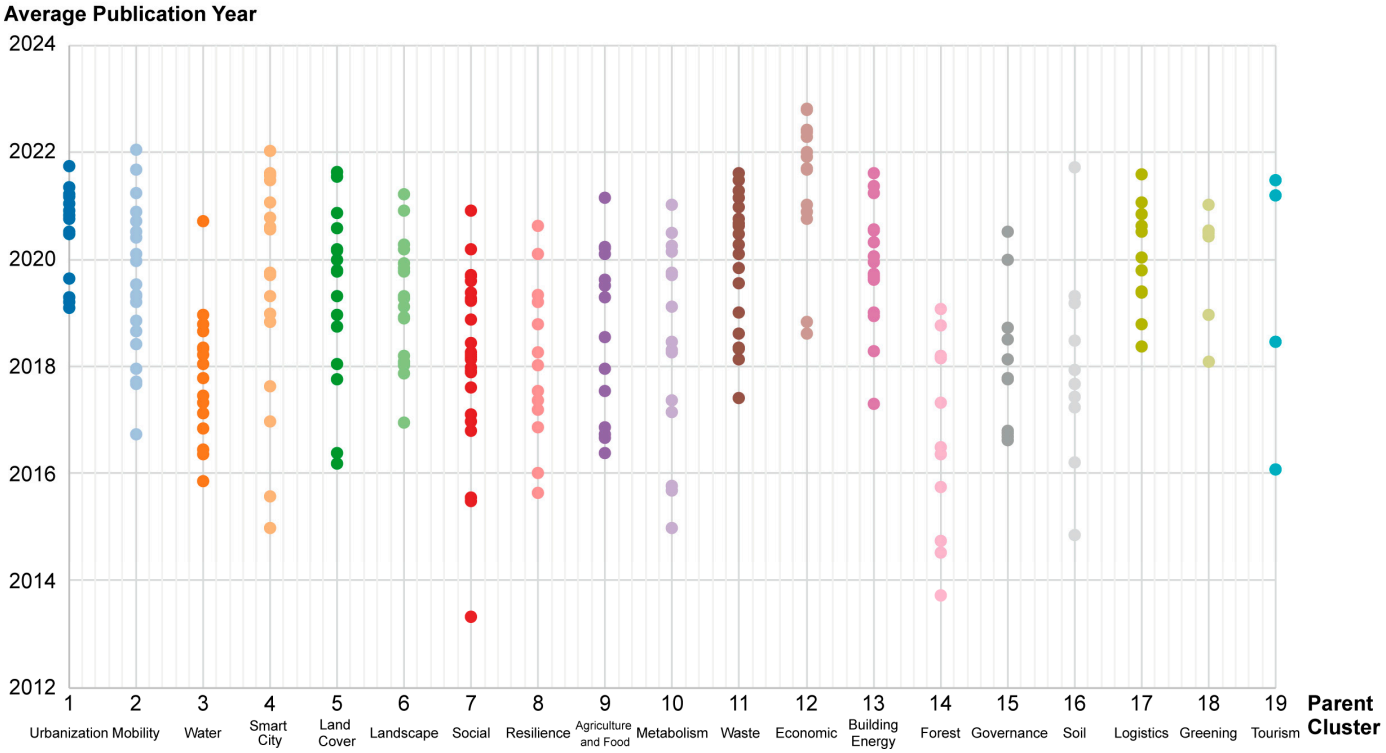


Figure 4. Sub-clusters of each cluster of urban sustainability studies. Nodes denote sub-clusters. The vertical axis represents the average published year of papers belonging to each subcluster. The horizontal axis represents the numbers of parent clusters.

To identify the current attractive scientific research fields, we listed 15 of the newest sub-clusters in Table 5. The numbers in the first column indicate the parent cluster and subcluster numbers. The sub-clusters are listed in order of their average published years. The sub-clusters were numbered sequentially based on the number of papers in each cluster. The sub-clusters provide an overview of recent trends in scientific attention to urban sustainability studies. Since the parent cluster, Economic (12), had the most recent average publication year among the parent clusters, its sub-clusters occupied the top five positions in terms of freshness. Subcluster 12-5 contained many studies that analyzed hypotheses concerning the relationship between economic growth and environmental quality. These

hypotheses included the Environmental Kuznets Curve hypothesis based on long-term panel data [76,77]. Subcluster 12-13 comprised studies on multi-objective optimization during the transition from fossil fuels to renewable energy, electrification, and efficiency improvements [78]. This subcluster also included research on digitalization [79,80]. Subcluster 12-2 consisted of research examining the drivers of CO_2 emissions and effective policy levers for reduction across various countries according to industrialization [81,82]. This subcluster included a paper comparing the structure of association between aging populations and CO_2 emissions internationally [83]. Subcluster 12-1 consisted of studies that primarily analyzed the relationship between ecological footprints and natural resources, renewable energy, and human capital [58,84]. Subcluster 12-10 analyzed the excessive development of natural resources and pollution [85].

Table 5. Top 15 newest subclusters. The row of "#" represents the number of subclusters.

#	Parent_cluster	#Papers	Year	TFIDF
12-5	Economic	132	2022.82	emissions energy ekc renewable brics lcf fdi environmental tourism load
12-13	Economic	68	2022.81	civilized bioenergy digital energy green renewable china rural emissions digitalization
12-2	Economic	195	2022.42	emissions carbon energy run renewable causality urbanization consumption growth industrialization
12-1	Economic	263	2022.39	footprint ecological ef energy environmental run renewable natural countries globalization
12-10	Economic	85	2022.29	cement energy natural emissions environmental resources biofuel pollution renewable carbon
2-18	Mobility	124	2022.06	uam aircraft evtol air aam maas evtols mobility flight flying
4-10	Smart City	174	2022.03	traffic smart air energy iot learning ml machine transportation data
12-7	Economic	99	2022.01	energy electricity access electrification e7 renewable ssa countries emissions consumption
12-6	Economic	107	2021.92	energy emissions transport logistics transportation consumption co2 environmental carbon sector
1-10	Urbanization	334	2021.74	ewp efficiency agglomerations green agglomeration eco tourism innovation welfare cities
16-6	Soil	61	2021.72	pb pollution zn cu metals cr cd heavy hms metal
12-14	Economic	58	2021.71	fintech energy renewable internet consumption nrp emissions africa poverty debt
2-3	Mobility	660	2021.69	covid pandemic minute 19 health 15 cities mobility transport travel
12-9	Economic	88	2021.68	tourism carbon energy ict emissions pakistan economic commerce emission renewable
5-17	Land Cover	53	2021.64	rpsc manila solar pavement energy uhi temperature asphalt tcc exposure

Subcluster 2-18 focused on urban air mobility (UAM) as a form of green transportation [86]. Subcluster 4-10 consisted of studies that monitored traffic, air quality, and energy consumption, using high-resolution sensing and citizen participation [87,88]. Subcluster 12-7 consisted of studies that primarily focused on access to clean energy sources and renewable energy consumption. A certain number of these studies targeted Africa, as the TD-IDF

in this subcluster included sub-Saharan Africa (SSA) [89,90]. Subcluster 12-6 consisted of studies that analyzed the relationship between logistics performance and environmental degradation [91,92]. Subcluster 1-10 examined green development on an urban scale and includes research on the impact of procurement on non-urban areas and improvements in development efficiency associated with the realization of wooden cities [93]. Subcluster 16-6 was a group of studies analyzing and evaluating soil contamination by various heavy metals [94,95]. Subcluster 12-14 focused on financial technology [96]. Subcluster 2-3 was a body of research on the X-minute cities, especially the 15 min city concept proposed by Carlos Moreno in 2016 [97], which gained significant policy attention during the COVID-19 pandemic [98,99]. Subcluster 12-9 focused on economic growth, energy consumption and CO_2 emissions, incorporating tourism [100]. Subcluster 5-17 focused on countermeasures against heatwave exposure [101].

We reviewed the 20 most highly cited papers in each of the top 15 newest sub-clusters based on the average published year to identify future research topics. We broadly categorized these topics into three areas: theory, technology, and policy. In the theoretical realm, we identified the need for research on frameworks that integrate interactions between urbanization, economic growth, and environmental quality, and enable the assessment of their local characteristics. Specifically, research is progressing beyond linear models toward nonlinear hypothesis-based frameworks, such as the EKC [77] and the load capacity curve (LCC) [102]. In this context, certain factors, such as globalization, natural resources, and finance, have positive or negative impacts on the load capacity factor (LCF), which indicates environmental quality. The impacts can vary by country [102]. Thus, further research is needed to construct an integrated framework that can detect and transform negative factors into positive ones. It is also crucial to expand theoretical frameworks that incorporate socioeconomic and political aspects, such as aging levels, human capital, education and governance factors [100], including government stability, corruption, the rule of law, and technological progress [82,103,104].

Furthermore, the need for research on urban spatial concepts has become apparent. X-minute cities have gained attention since the onset of the COVID-19 pandemic. It is necessary to verify the concept from an equity perspective by measuring disparities in responses based on race, gender, and socioeconomic status and assessing the negative impacts on individual and social freedoms, given their potential adverse effects [98]. Additionally, more research is needed on metropolitan regions or city-regions to mitigate CO_2 emissions associated with urbanization, such as transformation into timber cities [93]. Metropolitan areas are considered key drivers of global economic development [105] and important spatial units in the context of sustainable societies.

Technically, data preparation was a future topic. Specifically, it includes data on renewable energy consumption, tourism, and forest area [106] and a broader range of environmental pollution indicators beyond CO_2 emissions, including water pollution, air pollution, and land contamination [81]. This data preparation is expected to improve econometric approaches and enable more accurate predictions, such as those related to air quality [88]. However, privacy is a barrier to data preparation, and there is a need to expand the scope of non-intrusive load monitoring (NILM) technology [107]. Additionally, detailed physical activity data, including walking, cycling, sports, physical education, and unstructured activities during leisure time, are needed [108]. These data are associated with scientific interest in health.

Additionally, topics related to the development of materials and systems as underlying technologies were also presented. For instance, the necessity of researching the long-term durability of cool roof measurements has been emphasized [109]. The necessity of optimizing systems and examining the economic viability of enhancing energy collection

from road pavement solar collectors (RPSC) and reduce UHI surface temperatures has also been highlighted [110]. Furthermore, given the anticipated extensive use of composites in future vehicles, such as EVs and UAMs, not only for lightweight structural components but also for battery housing systems and efficient energy storage, the need for composite technology development was emphasized [111]. It was also noted that analyzing the social and economic impacts of UAM on local communities and addressing concerns about inequality, such as income disparities, is necessary [86].

Regarding policy aspects, topics related to the generalizability and contextual applicability of policy implementation were identified. These included the effectiveness of public investment in renewable energy research and development in countries with low levels of renewable energy investment [112], the carbon reduction effects of green technologies and renewable energy based on income levels and other socioeconomic factors [113], the applicability of digital policies that promote growth and sustainability [79,80], and the impact of environmental taxes on regional characteristics [85]. In relation to this, the importance of integrated policy evaluation was also stressed, such as the multifaceted evaluation of energy, emissions, air pollution, and health associated with heating fuel conversion [114], and the cost–benefit of renewable energy policies and energy efficiency policies [115]. Although the scale of analysis was mostly national, it was suggested that analyses should also be conducted at the regional level to implement region-specific policies [104,116].

Furthermore, multiple subcluster papers emphasized the need to expand investment in education because improving human capital significantly reduced dependence on fossil fuels [117,118]. Additionally, the need for long-term, environmentally oriented urban planning programs was noted based on the impacts of urbanization [102]. Furthermore, some studies referred to the guidelines for developing and disseminating new technology. For example, regarding the introduction of cool materials, the need for comprehensive guidelines outlining the minimum regulatory requirements for the solar reflectance index (SRI) was argued [109].

Based on the above, we identified future research topics related to theory, technology, and policy. First, although various nonlinear models concerning economic growth and environmental quality are being studied, policy design should differ depending on whether economic growth is accompanied by environmental deterioration or improvement. Additionally, nonlinear model variables are still being explored, necessitating technological development to prepare data that enable privacy protection and interoperability. Incorporating socioeconomic and governance aspects as variables is necessary for the generalizability of policies. Since theory, technology, and policy are mutually related, research integrating them to achieve their co-evolution is necessary for urban sustainability studies.

3.3. Design in Urban Sustainability Studies as an Integrated Academic Field

The issues contained within the latest sub-clusters are not necessarily themes of medium-to long-term importance. Therefore, to identify more cross-cutting and significant issues, we analyzed sub-clusters containing the word "design," a concept that is spatially integrated with TF-IDF. Fifteen such clusters were identified. This term appeared most frequently in the TF-IDF, except for terms related to individual parent clusters. The average publication year for these sub-clusters ranged from 2013 to 2020. This suggests that these papers represent a relatively mature field. By comparing the analysis of sub-clusters containing "design" with the analysis of new sub-clusters based on publication years from the previous section, we identified cross-cutting themes that are important over the medium to long term. The importance of the research topic in this study reflects whether it has been debated for a long time yet remains unresolved to this day from the perspective of an integrated academic field (Table 6).

Table 6. Sub-clusters including the term "design" in TF-IDF. The row of "#" represents the number of subclusters.

#	Parent_cluster	#Papers	Year	TFIDF
4-4	Smart City	620	2014.99	planning sustainability policy urbanism local development design housing land new
6-4	Landscape	448	2017.88	ecology landscape ecological biodiversity urban species design ecosystem landscapes cities
6-15	Landscape	127	2019.31	biophilic design nature coastal geoai ocean biophilia urbanism rup urban
7-4	Social	363	2013.33	planning regeneration policy design housing urban book renaissance city residential
7-9	Social	160	2018.45	vernacular traditional architecture satisfaction architectural thermal heritage bioclimatic villages design
7-11	Social	159	2018.18	crime housing fear hanoi prevention cpted design security vietnam street
7-15	Social	119	2019.71	streetscape street furniture visual streets design space syntax tall legibility
7-16	Social	115	2019.60	spaces public placemaking design streets space cohousing parks checklist place
7-20	Social	87	2015.54	uk futures birmingham design eastside future process sustainability engineering geomedia
9-15	Agriculture and Food	72	2016.86	lisbon food design streets planning rocinha street eating aviv tel
10-15	Metabolism	55	2020.25	biomimicry biomimetic regenerative biomimetics design dentists dental architecture built building
13-2	Building Energy	153	2019.72	solar energy building form block design morphology blocks buildings outdoor
13-8	Building Energy	77	2017.30	energy building buildings design lidar consumption umis competitions modelling parametric
13-9	Building Energy	76	2020.32	design performance generative optimisation tall muzo building buildings energy ikn
16-5	Soil	66	2016.20	landscape landscapes cultural linpan carpathian design rural historical heritage ecoregion

Subcluster 4-4 comprised studies that primarily focused on the trade-offs between economic growth, environmental conservation, and social justice at the urban scale [119,120]. This subcluster included research that argued for the necessity of a national-scale housing and welfare framework from the perspective of a just city [121]. Subcluster 6-4 comprised studies that discussed urban planning from an ecological perspective, focusing on concepts such as "safe to fail," ecosystem services [122] and landscape stewardship [123]. This subcluster included papers on social-ecological-technical systems (SETS) theory for understanding the complex nature of urban systems [124]. Subcluster 6-15 comprised studies on designs utilizing nature, such as biophilic design [125,126] and nature-based solutions [127]. This subcluster included a review article on research estimating greenery levels from street views [128] and a review article on GeoAI research [129]. Subcluster 7-4 comprised studies exploring both positive and negative aspects of proximity, such as diversity [130], social mixing [131], studentification [132], and compact cities [133]. Subcluster 7-9 comprised studies evaluating vernacular traditional architecture from a sustainability perspective [134–136]. Subcluster 7-11 focused on crime prevention. Some

studies have argued that the theory of crime prevention through environmental design (CPTED) is a useful tool for enhancing urban sustainability [137]. Subcluster 7-15 was a group of studies on street space design and sustainability that conceptualized sustainable streets [138]. Furthermore, one study argued that visual diversity contributes to sustainable and comfortable spatial design in urban streets [139]. Subcluster 7-16 included studies that evaluated public spaces from the perspective of urban sustainability and explored design methodologies [140,141]. This subcluster included research on urban commons. One study emphasized the importance of designing place-based rights [142]. Subcluster 7-20 was a group of studies on urban design processes, including scenario evaluation and education [143,144]. This subcluster included numerous studies targeting British cities, such as the VivaCity2020 project [144]. Subcluster 9-15 comprised a group of studies on the connection between urban agriculture and social cohesion [145]. This subcluster included research [146] presenting frameworks for how urban agriculture contributes to participatory city building and research [147] aiming to bridge food policy and urban planning. Subcluster 10-15 comprised research groups focusing on biomimicry [148] and regenerative design [149]. Subcluster 13-2 was a group of studies analyzing the impact and trade-offs of building density, form, and layout on solar energy utilization and the suppression of excessive heat gain [150,151]. Subcluster 13-8 comprised a group of studies on standard parameterization systems for urban 3D morphology using LiDAR/photogrammetry and Digital Surface Models (DSM) [152,153]. Subcluster 13-9 comprised research groups focusing on high-rise building design [154], such as multi-zone optimization (MUZO) to support decision-making for an entire high-rise building considering multiple floor levels and performance aspects, and generative urban design (GUD) leveraging artificial intelligence (AI) and computational capacity [155]. Subcluster 16-5 was a group of studies focusing on the cultural landscape of rural areas [156,157].

We organized future research topics from the papers in these sub-clusters containing the term "design," considering theoretical, technical, and policy aspects. We compared the results of this analysis with those of a new subcluster based on the average publication year. In the theoretical realm, it has been repeatedly suggested that a research framework is needed to expand the value conflicts between environment, growth, and fairness, as well as culture, safety, and health, across time, space, and the multi-layered structure of institutions, and to evaluate them holistically using composite indicators. For example, it was highlighted to integrate cities as SETS and develop comparative research and urban evolution that explores common principles through a systems-oriented and transdisciplinary approach [158,159]. Furthermore, the necessity of sequencing theory, which emphasizes the importance of prioritizing actions and decisions while acknowledging trade-offs, was also highlighted [160]. Additionally, the need to integrate insights from environmental criminology, heritage and landscape studies, food systems, and biomimicry within the context of urban sustainability studies has become apparent. These theories can form a theoretical foundation that contributes to arranging and overcoming value conflicts. For example, some studies claimed that a multi-criteria and multidisciplinary approach should be followed in close cooperation with stakeholders, owners, and users to achieve a sustainable balance between the preservation of authenticity and the environmental retrofitting of heritage buildings [161]. Thus, the perspective of comprehensively considering the environment, economy, and society while weighing trade-offs and synergies was consistent across both the research groups analyzed in the subcluster containing the term 'design' and the new subcluster based on publication year. Although the definition of urban sustainability includes societal aspects, developing theoretical frameworks that incorporate socioeconomic and political dimensions remains a challenge.

Furthermore, some terminologies and concepts differed when the scales were changed, whereas others remained the same despite the scale change. For the former, for example, regarding reducing car use, district-scale studies emphasized improving walkability, whereas city-scale studies emphasize improving air pollution. The convergence of these differing terminologies and concepts onto the same policy measures suggests the scope for exploring insights into which terminologies or narratives influence the feasibility of urban policies from the perspective of comprehensive sustainability sequencing and local political and social path-dependency. The latter included themes such as food, which are not central to conventional urban planning topics.

Technically, the preparation of regional data was identified as a future topic. In the research on multi-objective optimization, it has been suggested that new approaches, such as machine learning predictive algorithms, should be explored to address the increase in computation time associated with larger scales and more variables [150]. Conversely, the sub-cluster with newer publication years emphasized the need for data preparation concerning broad environmental pollution indicators, indicating that data preparation at large scales remains a consistent challenge. Furthermore, the newer sub-clusters indicated that privacy protection is a barrier to data preparation. The sub-clusters containing the term "design" highlighted the need for technological development of low-cost, open citizen-participatory measurement tools, such as smartphone sensors [162], suggesting greater potential for development in citizen science approaches. Citizen science approaches have focused on specific domains such as landscapes. Therefore, exploring the scalability of these approaches could overcome privacy protection challenges by enabling citizens to disclose information.

From the policy perspective, institutionalization and verification of policies as design under multi-level governance that transcends individual cities are required. Within this framework, it is increasingly important for the research community to develop and provide methodologies and tools that enhance decision-making and governance through both top-down (administrative planning, state intervention, and think tank concepts) and bottom-up approaches (grassroots activities, civil society, and community action groups). Methodological approaches provided by landscape ecological sciences, such as various indicator sets, multi-criteria analysis, spatial modeling, landscape mapping, and multiple forms of social assessment, were argued to be applicable to policy design [158]. Meanwhile, the newer sub-clusters of publications highlighted the importance of research at the regional level. The regional level is perceived as a scale that should be addressed more in the future in both research and policy. A new conceptual framework for metropolitan food systems [147] that integrates the institutional environment of planning and urban design is being explored, suggesting that regional-level research based on trans-scale topics is becoming more important.

These discussions create challenges and opportunities for transforming complexity approaches into bottom-up approaches from the perspective of integrating multiple issues. Among the papers analyzed in this study, empirical bottom-up approaches are limited. This is interpreted as contributing to the lack of social aspects as a future challenge. In environmental studies, adaptive governance [163] represents an approach that seeks to solve environmental problems while incorporating local social issues. This resonates with passive design and biophilic principles. A holistic passive design emphasizes bottom-up, locally led frameworks that will help empower stakeholders who understand the local climate and cultural context. Leadership in Energy and Environmental Design (LEED), developed in the United States, has become a global certification system for cities and buildings, with some adaptations for local customization. For example, LEED Canada replaced U.S.-centric credit requirements with Canadian equivalents that reflect the country's unique climate, regula-

tory standards, and construction practices [164]. By incorporating these location-specific conditions, it serves as a national-level example of bottom-up localization that effectively enhances urban sustainability. Additionally, under the biophilia hypothesis [165], biophilic design presents causal pathways showing that urban nature leads to resilient city outcomes, such as reduced vulnerability, by promoting positive health outcomes (e.g., mental health) and resilient behavior by fostering walking and physical activity, socialization, social capital, friendship, and stress reduction [166]. Bottom-up approaches that start at the individual level are also being explored in this regard. Such approaches should be more actively introduced into the field of urban planning, where bottom-up approaches have long been discussed as seen in the work of Jacobs [167] and Alexander [168].

4. Conclusions

This study used network-based classification and text analysis to examine the scope and extent of scientific interest in urban sustainability as an integrated academic field. By surveying the landscape of urban sustainability studies, this paper identified emerging fields and future research topics. Specifically, it found that clusters of urban sustainability studies comprised at least 22 diverse research fields. This deepens our understanding of the trend toward urban studies as an integrated discipline. Additionally, it identified emerging areas such as the economic–environmental relationship, smart sensing and UAM, green development at the metropolitan scale, soil heavy metal pollution, tourism and emissions, and heatwave exposure countermeasures. Furthermore, we identified future research topics from the perspectives of theory, technology and policy. These topics included an integrated theoretical framework that enables the evaluation of locality regarding the interaction between urbanization, economic growth, and environmental quality, the organization of health-related data, underlying technologies and the generalizability or contextual adaptability of policy applications. To contextualize future research topics in these new areas and gain an integrated perspective that cuts across individual sub-cluster analyses, we compared them with future research topics in sub-clusters containing the term "design" that appeared in multiple parent clusters. The results indicate the necessity and opportunity to integrate environmental, economic, and social dimensions into a bottom-up multiscale theoretical framework by connecting terminology and concepts that vary according to scale and synthesizing emergent issues into the conventional urban planning realm.

These findings will inform decisions regarding funding and investment in scientific research by governments, companies and research institutions. Regarding practical implications, urban planners should engage in planning that crosses scales, focusing on the same themes—even if they are topics traditionally outside planning, such as food—while maintaining consistent terminology and concepts regardless of scale changes. Policymakers should undertake sequencing that improves environmental aspects while incorporating socioeconomic and political dimensions. Funding institutions should invest in technological development that promotes citizen science approaches to address privacy concerns.

This study excludes academic papers that do not contain the terms "sustainability," "sustainable," or "urban." This method carries the risk of excluding papers addressing relevant themes. Furthermore, while analyzing papers published up to the analysis start date of 6 September 2025 should reflect the latest trends, the analysis focuses on the top 20 most cited papers within each parent cluster and subcluster. Consequently, it may not capture the latest micro-level innovations in the field.

More comparative research is needed in all aspects of theory, technology, and policy. While not all sub-clusters and searched terms are discussed here, further details are included in the Supplementary Materials and may influence the interpretation of the findings reported in this study. Comparative urban studies are particularly important for

co-learning, especially given the argument that cities play a larger role in climate change than nations [169]. Attempts are emerging to experimentally compare developed and developing countries in different contexts [170], which could contribute to insights that are generalizable beyond the developed-developing dichotomy. Finally, it is important to note that the findings of this study may become outdated within a few years.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su18010201/s1. Table S1: Detail of all clusters including more than 500 papers. Table S2: Details of all the journals in the top 20 most cited papers in each cluster. Table S3: Details of frequency percentage based on ASJC detailed category in the top 20 most cited papers in each cluster. Table S4: Detail of all subclusters; PRISMA_2020_checklist.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	artificial intelligence
ASJC	All Science Journal Classifications
CPTED	Crime prevention through environmental design
DSM	Digital surface models
EKC	Environmental Kuznets Curve
GUD	Generative urban design
IDF	Inverse document frequency
LCC	Load capacity curve
LCF	Load capacity factor
LEED	Leadership in Energy and Environmental Design
LULC	Land use and land cover
MUZO	Multi-zone optimization
SETS	Social-ecological-technical systems
SRI	Solar reflectance index
TF	Term frequency
UAM	Urban air mobility
UHI	Urban heat island

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