Green Energy and Fuel Research

Review

Integrating Environmental and Energy Justice into Climate-Adaptive Urban Planning: A Systematic Review

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Abstract: Rapid urbanization and climate change are intensifying extreme climate events such as heat waves and air pollution episodes, and energy stress in cities. These interconnected risks disproportionately affect residents, especially vulnerable groups, and have pushed environmental justice and energy justice to the forefront of climate-adaptive urban planning. Drawing on journal articles indexed in the Web of Science Core Collection from 1996 to 2025, this study systematically reviews the evolution of environmental and energy justice concepts in climate-adaptive urban planning. The review identifies persistent inequities in exposure to heat and air pollution, access to green and cooling services, and disparities in energy efficiency and resilience during and after climate events. In response, multi-scale strategies have emerged, including spatial planning, low-carbon infrastructure, cooling service and clean-energy deployment. Yet current research and practice still emphasize physical environmental modifications and engineering resilience, with limited attention to structural issues such as social vulnerability and unequal resource distribution. This study calls for a shift from single-factor optimization to equity-driven systemic governance and highlights environmental and energy justice as a critical pathway toward resilient and low-carbon urban development, offering actionable insights for researchers and policymakers alike.

Keywords: environmental justice; energy justice; climate-adaptive urban planning; vulnerability

1. Introduction

With the intensification of global climate change and rapid urbanization, cities have become epicenters of escalating environmental and socioeconomic risks, facing compound disaster threats such as extreme heat, flooding, deteriorating air quality and energy pressures. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report projects that continued global warming will further increase the frequency and intensity of extreme weather events. Meanwhile, uneven urban development has led to spatial isolation and social stratification, intertwined with escalating climate and energy risks [1]. This exacerbates the health and welfare burdens borne by residents, particularly vulnerable groups such as the elderly, low-income households and outdoor workers, thereby intensifying patterns of inequity within urban environments [2].

The concept of environmental justice, which originated from civil rights movements initiated by ethnic minorities in the United States during the 20th century in response to the placement of polluting facilities, has evolved into a comprehensive framework for analyzing the distributional, recognitional and procedural dimensions of environmental burdens and benefits [3–5]. In urban contexts, environmental justice research has broadened from its original focus on pollution exposure to include access to environmental infrastructures such as green space, cooling services and healthy living conditions [6–8], thereby providing a powerful lens for assessing how urban planning decisions shape both risks and benefits for different social groups.

While environmental justice has long focused on the uneven distribution of environmental burdens and benefits, energy justice provides a complementary perspective that centers on fairness within energy production, access and consumption [9–11]. Yet urban planning decisions on land use, building form and infrastructure deployment directly shape energy access, affordability and distribution [12,13]. As climate adaptation increasingly intersects with energy use, housing energy performance, and access to clean technologies, the complementarities between the two frameworks have become essential for achieving equitable urban resilience.

Integrating environmental and energy justice perspectives is particularly salient for climate-adaptive urban planning, where interventions in the built environment simultaneously affect exposure to climatic hazards and patterns of energy use [14,15]. Nevertheless, prevailing studies and practices remain predominantly focused on physical environmental modifications and engineering resilience, with insufficient attention to structural drivers of social vulnerability, unequal resource distribution and energy justice dimensions [4].

In view of these gaps, we conduct a structured review of studies indexed in the Web of Science (WOS) Core Collection. This paper categorizes and discusses relevant measures, integrating recent developments into a coherent conceptual framework, identifies emerging patterns of inequity in climate and energy adaptation, and discusses their implications for future urban planning and policy. The study provides researchers and practitioners with a comprehensive understanding of how justice-oriented perspectives can inform the design of equitable, resilient and low-carbon urban systems.

2. Materials and Methods

This study adopts a structured review methodology to synthesize the evolution of environmental and energy justice research in the context of climate-adaptive urban planning. The WOS Core Collection was selected as the sole database, given its comprehensive coverage of internationally recognized journals across environmental studies, urban planning, energy systems and the social sciences. The literature search was conducted in the Web of Science Core Collection database, covering the period from 1996 to 2025. We explicitly applied Boolean keyword combinations consisting of three conceptual groups: (1) environmental and energy justice terms ("environmental justice", "climate justice", equity, justice, vulnerability); (2) adaptation-related terms ("climate adaptation", "adaptation", "climate resilience"); and (3) urban spatial planning terms ("urban planning", "urban development", "urban built environment"). These terms were combined using AND/OR operators to ensure that selected studies simultaneously addressed justice perspectives, climate adaptation, and urban planning contexts. Only peer-reviewed journal articles written in English were retained. Reference lists of highly relevant papers were also examined to supplement the database results. After duplicate removal and screening, 154 journal articles were ultimately retained for analysis.

After collecting the full set of eligible studies, we reviewed each article in detail to identify its primary focus and analytical orientation. This step involved examining how each study approached issues of climate risk, exposure, adaptation and recovery, as well as whether its emphasis lay in environmental conditions, social vulnerability, energy access or built environment performance. We grouped the literature according to the dominant processes through which inequities become visible, including differential exposure to climate hazards, uneven access to adaptive resources and disparities in recovery capacity. These recurring patterns formed the basis of the conceptual structure presented in Section 3, which synthesizes how environmental and energy justice concerns intersect across the stages of climate adaptation.

The evolution shown in Figure 1 and Table 1 reflects a gradual but significant broadening of the field. Early emphasis was centered primarily on environmental burdens and exposure, with equity discussions appearing only intermittently. Over time, the rise of climate adaptation and vulnerability-related terms indicates a shift toward understanding climate impacts as socially differentiated processes rather than solely physical phenomena. The more recent emergence of energy justice signals further conceptual expansion, showing how energy access, affordability and infrastructural reliability have become integrated into debates on climate resilience. Together, these shifts suggest that justice concerns in urban planning have moved from isolated themes toward a more interconnected framework that links environmental conditions, social vulnerability and energy systems.

Table 1. List of relevant keyword.

Theme Categories	Keyword	Frequency	Earliest Publication Date (Year)
Environment-related	Environmental Justice	48	2012
	Climate Change	32	2011
Adaptive-related	Adaptation	38	2013
Equity-related	Equity	70	1996
	Justice	78	2005
Vulnerability-related	Vulnerability	39	2014

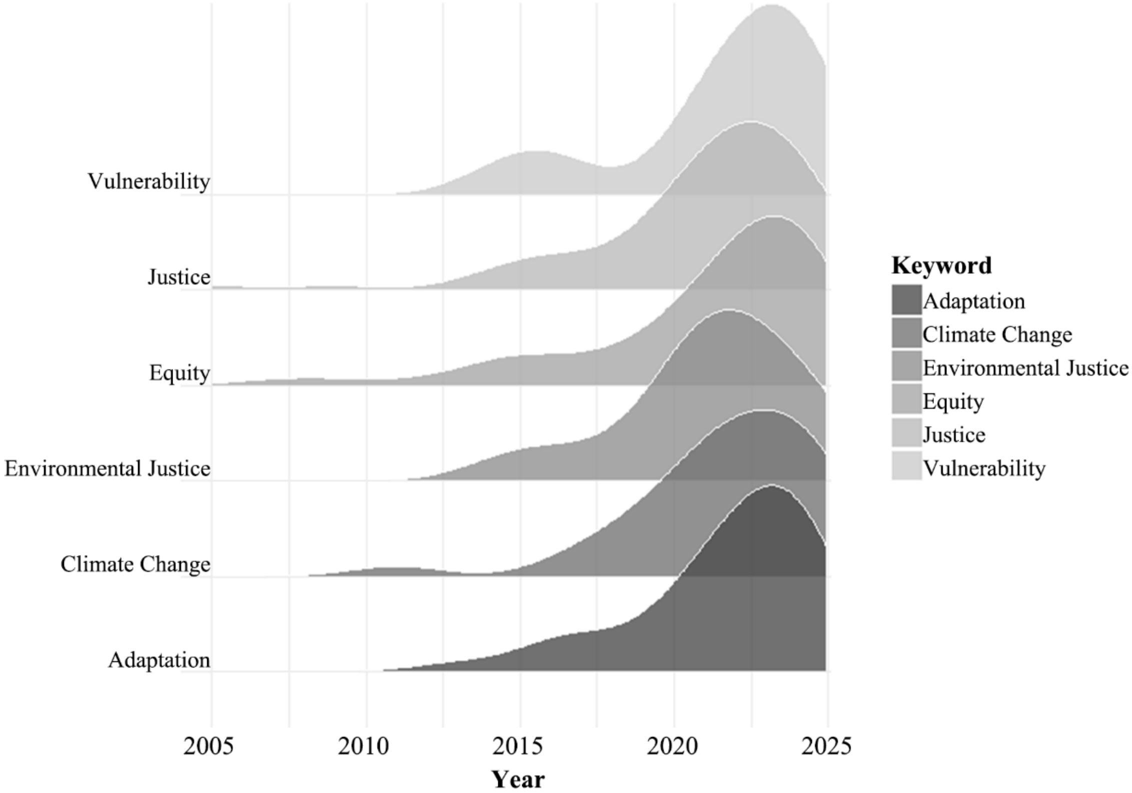

Figure 1. Temporal evolution density map of relevant keywords (2005–2025).

3. Inequity in Climate Adaptation and Energy Systems

Inequities in climate adaptation and energy systems unfold across the interconnected stages of exposure, adaptation and recovery. These stages are shaped not only by the physical distribution of climatic hazards but also by structural disparities in social vulnerability, energy access and institutional capacity. A justice-oriented analysis requires tracing how disadvantages accumulate and intersect across these phases, creating layered vulnerabilities within urban systems. To conceptualize how these multidimensional injustices interact and how planning can respond, Figure 2 presents an integrated framework linking environmental and energy justice within climate-adaptive urban planning.

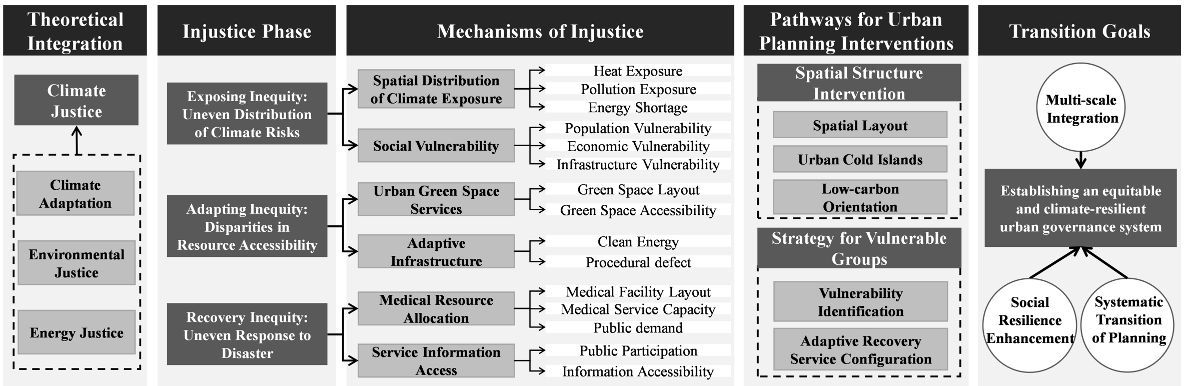

Figure 2. Conceptual Framework of environmental and energy justice in climate-adaptive urban planning.

3.1. Exposure Inequities: Climate and Energy Risks

Urban residents are differentially exposed to climate-related environmental hazards, particularly extreme heat and deteriorating air quality. Researches in various cities including China and the United States demonstrate clear spatial gradients: central districts, industrial zones and dense residential areas record systematically higher land surface temperatures and pollutant concentrations than suburban counterparts [8,16–18]. For instance, heatwave episodes have been shown to intensify ozone concentrations and exacerbate particulate matter exposure, forming compound high-risk zones [19]. These areas often coincide with dense low-income neighborhoods and aging housing stock, magnifying the health burden on already vulnerable residents [20,21].

Exposure disparities cannot be understood through physical indicators alone. Age, income, occupation and housing conditions critically shape the degree of hazard exposure [22]. The elderly, children and outdoor workers are disproportionately affected due to reduced mobility, pre-existing health conditions and limited access to protective infrastructure [23–26]. Spatial analyses have revealed that districts with higher proportions of elderly or low-income populations consistently align with zones of heightened climatic exposure, illustrating how environmental and social vulnerabilities overlap [18,27–29].

Energy-related exposure refers to unequal conditions that shape residents' ability to maintain safe indoor environments. These conditions include whether energy services are affordable for households, whether building insulation and ventilation can effectively protect residents from heat and pollution, and whether clean and reliable energy is accessible during periods of extreme climate stress. When one or more of these conditions are lacking, indoor thermal discomfort and household air pollution can accumulate, especially among elderly individuals, low-income families and those living in poor-quality housing [30–32]. Therefore, energy poverty is not only an economic issue but also a critical determinant of climate exposure, as it shapes residents' ability to maintain safe indoor environments during extreme heat and pollution events.

These findings demonstrate a consistent pattern: spatially concentrated climatic hazards tend to overlap with socially vulnerable neighborhoods, forming "dual exposure" zones where environmental risks and socioeconomic disadvantages reinforce each other. Such coupled inequities highlight the need to consider environmental hazards and demographic sensitivity jointly, rather than as isolated phenomena.

3.2. Adaptation Inequities: Unequal Access to Resources and Services

Urban adaptation resources such as parks and blue–green infrastructure, are unevenly distributed across the urban landscape. Researches confirm that the quality and distribution of green spaces and open areas are significantly correlated with areas' economic levels [33–35]. Empirical studies have demonstrated that even when green spaces are geographically proximate, disparities in their quality, accessibility and microclimatic performance often result in unequal benefits for different population groups [36–39]. Consequently, adaptation resources that should enhance resilience may reinforce existing patterns of spatial and social inequity.

Parallel injustices are evident in the energy domain [40]. Projects promoting renewable energy deployment, energy-efficient building retrofits and electrified transportation often benefit high-income households with greater economic capacity, while vulnerable groups remain reliant on outdated appliances and fuel methods, facing higher energy costs and pollution risks [41]. Such inequities are further intensified by the uneven distribution of clean-energy infrastructure, such as solar installations, which is more prevalent in economically advantaged areas [42,43].

Adaptation inequities also stem from procedural shortcomings. Marginalized communities are often excluded from decision-making processes, resulting in policies that fail to reflect their needs and priorities [17,44]. In urban planning, achieving equitable formulation and implementation of environmental policies requires strengthening broad participation from citizens and community organizations. Cities should establish shelter infrastructure accessible to all residents, meeting their diverse needs that are both social and climate-resilient.

In summary, the unequal distribution of adaptation resources and decision-making power means that the very measures designed to enhance resilience can inadvertently deepen social and spatial disparities, especially for those who are already most vulnerable.

3.3. Recovery Inequities: Disparities in Post-Disaster Capacities

The recovery phase following extreme climate events exposes pronounced inequities in the capacity of urban populations to cope with, respond to and recover from environmental and energy disruptions. While adaptation measures aim to reduce vulnerability before disasters occur, the effectiveness of recovery mechanisms largely determines the long-term resilience and social equity of urban systems.

A major dimension of recovery inequity lies in the uneven spatial distribution of healthcare and social support services. Empirical research in large cities demonstrates persistent mismatches between areas of high climatic exposure and the availability of health-care infrastructure [8,45]. Core urban districts typically possess a dense concentration of hospitals and emergency services, whereas peripheral neighborhoods and low-income communities often experience chronic shortages despite facing higher exposure to heat waves, floods or air-pollution episodes [16]. Vulnerable groups such as the elderly and those with chronic illnesses are particularly disadvantaged, constrained by mobility limitations, poor housing conditions and inadequate medical support [46–48]. These spatial and demographic disparities undermine timely medical responses and exacerbate health risks alongside social inequities.

A further source of disparity arises from unequal energy resilience. Energy systems play a crucial role in post-disaster recovery, yet access to reliable and affordable energy remains highly uneven. Low-income families are least able to afford alternative energy sources, making them particularly vulnerable facing climate challenges [46]. In contrast, affluent districts with advanced energy infrastructure can maintain essential services and recover more rapidly, accentuating the gap in resilience.

Ultimately, recovery capacity is strongly conditioned by existing social and infrastructural disadvantages, so climate shocks do not create new inequities but rather expose and magnify those that have long been embedded within the urban system.

4. Responsive Strategies and Planning Pathways

Addressing inequities in climate and energy adaptation requires urban planning to adopt justice-oriented, multi-scale and participatory approaches. Integrating environmental and energy justice principles into planning practice calls for strategies that simultaneously enhance spatial resilience, reduce social vulnerability and ensure equitable access to adaptive resources. Existing studies reveal three interrelated pathways through which urban planning can respond to unequal exposure, adaptation and recovery.

First, spatial planning and design strategies serve as a fundamental mechanism for redistributing environmental and climatic benefits. At the city scale, the spatial configuration of green–blue infrastructure, ventilation corridors and water systems can be optimized to alleviate urban heat islands and air pollution while enhancing ecological connectivity [35,49,50]. Strategically locating urban parks, green roofs and ventilation corridors in high-risk and resource-deprived communities can provide both environmental and social benefits [33,51–53]. Studies in Belfast, Changzhou, Wuhan and Seoul demonstrate that prioritizing adaptive infrastructure in vulnerable districts improves both climatic resilience and spatial justice [49,54–56]. In the energy domain, integrating renewable energy installations within land-use and building design plans can provide energy resilience, reduce emissions and lower long-term costs for disadvantaged communities [57].

Second, community-scale and socially inclusive adaptation emphasizes localized interventions and participatory governance. Neighborhood-level urban renewal projects, such as pocket parks, shaded walkways and vertical greening, not only enhance thermal comfort but also promote environmental justice when integrated with social vulnerability mapping [58–62]. Participatory planning tools, including community surveys, resident perception assessments and public hearings, have proven effective in strengthening procedural justice by incorporating marginalized voices into adaptive design [63,64]. In parallel, targeting energy-efficiency retrofits for low-income housing and deploying community solar can directly address energy poverty, providing affordable and reliable access to clean energy [65]. These strategies bridge environmental and energy justice by linking spatial inclusion with energy accessibility and autonomy.

Third, governance and methodological innovation underpin the long-term integration of justice in adaptation planning. Quantitative equity assessment frameworks, such as exposure-vulnerability-adaptation models and distributed risk maps, can enhance the ability to identify spatial mismatches between climate risks and adaptive resources [56,66–68]. Advances in geospatial technologies, remote sensing and big-data analytics (including social media and mobile signaling data) enable planners to monitor dynamic changes in heat exposure, pollution and energy demand in real time [37,69,70]. Embedding such data-driven equity assessment into planning decisions can guide resource allocation toward the most vulnerable populations.

In sum, responsive planning for climate and energy justice entails a paradigm shift from technical adaptation toward systemic, justice-driven governance. By linking spatial, social and energy dimensions, urban planning can move from mitigating environmental risks to restructuring the distribution of adaptive capacity itself, thereby fostering cities that are not only resilient and low-carbon but also inclusive and just.

5. Research Trends and Future Directions

The integration of environmental and energy justice into climate-adaptive urban planning marks a paradigmatic shift in sustainable urban development. Over the past three decades, scholarship has evolved from diagnosing single-dimensional environmental inequities to advancing governance frameworks that operationalize justice in spatial and energy transitions. This review identifies the key trajectories that characterize this evolution and provide guidance for future research (Figure 3).

Early research on climate adaptation primarily addressed physical environmental inequities, such as unequal exposure to urban heat, air pollution and flooding. Since the early 2010s, there has been a marked conceptual expansion from environmental justice toward integrated frameworks that combine environmental and energy justice. This transition reflects growing recognition that vulnerability is shaped not only by spatial exposure but also by differential access to adaptive resources, infrastructure and energy services. As cities pursue low-carbon and climate-resilient development, understanding how environmental and energy systems jointly influence social vulnerability has become a central challenge. Future scholarship should therefore advance integrated framework that bridge urban planning, energy transition and social welfare, framing justice as both a normative goal and an operational principle in climate governance.

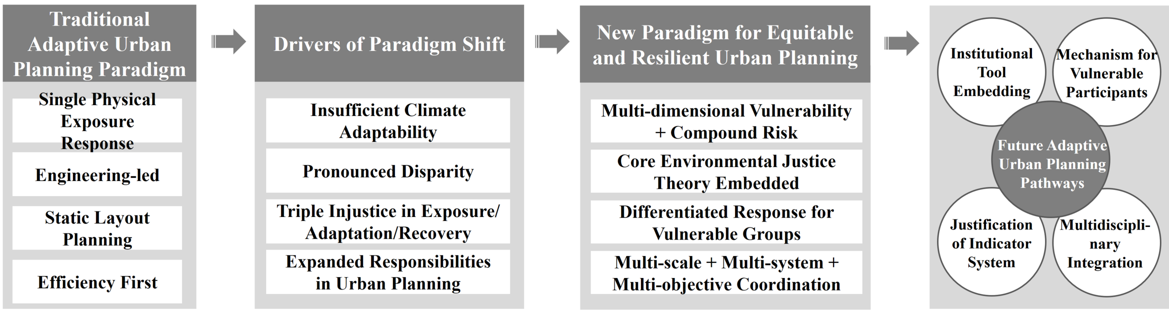

Figure 3. Paradigm transformation pathways in climate-adaptive urban planning.

Methodological innovation has also transformed the analytical landscape of justice-oriented urban studies. Traditional research relied on static and aggregated indicators, offering limited insight into intra-urban heterogeneity or temporal dynamics. In contrast, recent advances in geospatial modeling, remote sensing and machine learning enable high-resolution and multi-scalar analysis of exposure, vulnerability and adaptation. These techniques facilitate dynamic monitoring of heat, pollution and energy use, revealing evolving spatial disparities across neighborhoods and social groups. The integration of social, climate and energy datasets with data-driven methodologies can assist in evaluating how adaptation and mitigation policies redistribute benefits and burdens over time.

Beyond methodological refinement, the justice-oriented turn in climate adaptation underscores the need for institutional transformation. Emerging studies have begun to introduce practical instruments such as vulnerability-based zoning, environmental justice audits and participatory budgeting. However, empirical evaluation of these mechanisms remains limited, particularly regarding their effectiveness in reducing long-term vulnerability or promoting equitable energy access. Future research should explore how justice principles can be systematically embedded into planning regulations and evaluation frameworks. Comparative and longitudinal studies across different socio-political contexts are also needed to clarify how institutional settings mediate the operationalization of environmental and energy justice in urban planning.

Future developments concerning environmental and energy justice will still require advancement in three areas: theory, methodology and institutional frameworks. Theoretically, there is a need to integrate environmental and energy justice into a cohesive framework that connects equity with resilience and sustainability transitions. Methodologically, there remains a need for multi-source, high-resolution datasets to reveal the dynamic interactions between climate disasters, urban morphology and social vulnerability. Practically, closer collaboration between scholars, policymakers, and communities is essential to translate justice-oriented principles into actionable planning tools. By pursuing these directions, future research can support cities in moving toward genuinely equitable, low-carbon and climate-adaptive urban futures.

6. Conclusions

This review has systematically examined the integration of environmental and energy justice into climate-adaptive urban planning, highlighting the inequities in exposure, adaptation and recovery that exist within urban spatial structures and systems. By synthesizing nearly three decades of research, the study reveals that justice-oriented perspectives have gradually evolved from diagnosing environmental inequities to proposing multi-dimensional governance frameworks that embed justice within climate and energy transitions. The findings demonstrate that urban adaptation remains deeply uneven, as high-quality environmental and energy resources are severely inequitably distributed, while marginalized communities continue to experience deficits in access, functionality and participation. Although spatial planning, community-scale interventions and governance innovations have increasingly addressed these disparities, most adaptation practices still emphasize physical and technical resilience rather than distributive and procedural justice. Bridging this gap requires embedding justice principles at every stage of urban planning, so that adaptive capacity can be redistributed across social groups. The review also underscores the interdependence of environmental and energy systems in shaping urban resilience, indicating that ensuring equitable access to clean, affordable and reliable energy is essential for both climate mitigation and adaptation. Future research should focus on integrating justice, resilience and sustainability into a unified theoretical framework, advancing multi-source and longitudinal methods to track dynamic inequities, and evaluating the outcomes of justice-based planning interventions. Ultimately, achieving climate-adaptive urban resilience is not only a technical challenge but also requires placing environmental and energy justice at the core of sustainable and inclusive urban transformation.

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