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Review

Urban Greening as a Response to Climate-Related Heat Risk: A Social–Geographical Review

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Abstract: With the increasing intensity, frequency and duration of heat waves, adaptation measures are becoming increasingly relevant and are moving up the agenda of decision-makers. In particular, urban areas require effective solutions due to the urban heat island effect and the increasing number of urban dwellers, including highly vulnerable social groups, such as people with low income or who lack access to public areas. However, despite there being strong agreement about the relevance of urban greening as an adaptation measure, there is still a limited understanding of where such measures should be implemented and for whom they are potentially accessible and beneficial. Through a systematic scoping review of the academic literature, this paper shows critical regional and methodological research gaps in mainstream adaptation research, including a bias towards Asian and European cities, and a lack of assessments of the socio-economic context and the accessibility of urban greening structures. Addressing the spatial issues of urban greening is of great importance for achieving the Sustainable Development Goals, given the ongoing urbanisation trends and projected increase in heat risk.

Keywords: urban heat island; heat stress; climate change; adaptation; thermal comfort; environmental justice

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1. Introduction

Observed and projected climate change is increasing the risk of heat stress across a wide range of regions worldwide [1]. In particular, cities, which are economic hubs with an increasing area and population, are expected to be confronted with increasing heat stress [2–4]. At present, global mean temperatures are approximately 1.09 °C above pre-industrial levels, and further warming is predicted [1]. More frequent and greater temperature extremes, such as hot days and nights and heat waves, have been observed in urban areas [5–7]. Compared with their rural surroundings, cities are generally characterised by higher surface and air temperatures, a climate condition referred to as the urban heat island (UHI). The UHI intensity depends on spatial modification, for example, the distance from the city centre, the density of the built-up area and the type of land use (e.g., buildings, lakes, open spaces, parks) [8]. Owing to the progress of urbanisation, it is estimated that UHIs will intensify significantly up to 2050, with the intensification depending on the climate zone and settlement size, with temperate and tropical zones, as well as medium-sized urban clusters, likely to be most affected [3].

Since even climate projections that include unprecedented efforts to mitigate greenhouse gas (GHG) emissions nonetheless predict further global warming and urban expansion, increased heat stress in human populations is likely [5,9,10]. The especially vulnerable social groups include children, elderly people, people living in poverty, pregnant people, those working outdoors, and people with underlying medical conditions [11–13]. Consequently, adaptation is necessary to offset the risk to human health and ensure liveable cities in the future [14,15].

Considering the future aggravation of heat stress, and the inequalities that exist between regions and within cities [16], the need for solutions and evidence of their efficiency in different contexts is apparent. Nature-based strategies such as urban greening, which is listed among several other feasible adaptation options in the IPCC special report on global warming of 1.5 °C [17], represent an ecosystem approach with mitigative as well as adaptive capacity [18–21]. Furthermore, such adaptation measures can also contribute to some of the Sustainable Development Goals (SDGs), such as no poverty (SDG1), good health and wellbeing (SDG3), sustainable cities and communities (SDG11) and climate action (SDG13) [22,23]. Therefore, urban greening can play an important role in climate-resilient development [24] and in achieving the climate goals set in the Paris Agreement and UN Agenda 2030. Urban greening describes a complex city planning approach that aims to tackle the urban challenges that are associated with climate change and urbanisation while meeting local needs. It is founded on the connection of bio-based urban features and constructed green infrastructure. Green infrastructure networks comprise various types of green assets, such as street trees, parks and green open spaces, original wetland, grassland and woodland, and engineered solutions, such as green roofs and facades [25].

Adopting the notion that urban greening can be regarded as one of the most suitable urban planning tools for climate change mitigation and adaptation, several reviews have explored associations between the UHI intensity and the degree of urban greening. Shishegar [26], Balany et al. [27] and Knight et al. [28] explicitly assess the effectiveness of urban greening areas in reducing heat stress in terms of temperature. Leal Filho et al. [29] compare a range of cities across different climate zones in which different types of urban greening measures have been implemented. However, despite the recognition of urban greening as an adaptation measure in the context of urban heat stress, particularly regarding increasing climate-related heat stress, nature-based solutions in cities are still "under-recognised and under-invested in urban planning" [20]. Moreover, there is insufficient evidence on where and for whom urban greening measures are implemented and their effect on reducing heat stress [30,31]. Place-specific instruments such as urban greening may not be implemented equitably across countries, regions or cities, and may not be equally effective or accessible for all social groups [32]. This gap in understanding has led to the call for addressing environmental justice considerations in research on urban greening [30,33–35].

Therefore, this literature-based study uses a social–geographical perspective, including dimensions of environmental justice, such as the regional and socio-economic contexts, and the accessibility of urban greening measures [36]. Specifically, we ask the following overarching research question: Where and how is urban greening as a response to climate-related heat risk documented? Further sub-questions are as follows: How is urban greening studied? Which regions are represented? In which social–geographical context are studies located?

We conduct a scoping review of the literature that corresponds to the IPCC 6th Assessment Cycle through an explorative approach, rather than via a hypothesis-based analysis of various contextual factors, in order to provide directions for subsequent social–geographical research on urban greening in the context of climate change.

2. Materials and Methods

This scoping review builds on the systematic map methodology [37] to transparently and critically assess current research trends on the use of urban greening as a response to climate-related heat risk with a social–geographical perspective. Systematic maps, systematic reviews, or systematic scoping reviews are an increasingly applied method of evidence synthesis in the environmental sciences, and recently also in climate change adaptation research [38,39]. These methods have in common that they follow a transparent and reproducible review methodology that aims to comprehensively synthesise the available evidence regarding a specific research question. Therefore, they aim to reduce researcher bias, and highlight research clusters and gaps as a basis for further in-depth reviews and empirical studies [37]. For this scoping review, we followed the ROSES Reporting standards for systematic evidence syntheses [40] and operationalised the research question according to its key elements, adapting the PICo scheme [37]:

- Population: cities worldwide
- Intervention: urban greening as an adaptation measure
- Context: climate-related heat stress

The search string builds on these key elements and was used to search for English language peer-reviewed journal articles in the Web of Science Core Collection and PubMed databases by searching for "(TOPIC/title, keyword, abstract)", with synonyms that allowed us to find as much relevant research as possible (see Table 1). These two databases were used as they represent the mainstream academic literature on the topic, and the researchers had access to them through their institutions. The search string was developed by building on existing search terms and strings, as in the case of climate change and adaptation [41]. We followed a more inductive approach for search terms related to cities, urban greening and heat stress, iteratively testing various combinations of keywords according to the most comprehensive search results. Following the approach of several recent reviews on climate change adaptation [42–46], we included all the literature that falls within the latest assessment report of Working Group II of the IPCC (which has its cut-off date for included articles on 1 November 2020).

Table 1. Search strings for database search in Web of Science Core Collection and PubMed.

Key Element	Search String
Population: cities	(urban OR city OR cities OR town* OR metro* OR municipal*)
	AND
Intervention: adaptation	(adapt* OR resilien* OR (risk NEAR/3 manag*) OR (risk NEAR/3 reduc*))
	AND
Intervention: urban greening	(urban greening OR nature-based climate adaptation* OR green urban area* OR ecosystem-based adaptation* OR nature-based solutions* OR nature-based approaches* OR nature-based design OR nature-based responses* OR urban forestry* OR green space* OR green infrastructure* OR urban green space*)
	AND
Context: climate change	(climat* OR global warming)
	AND
Context: heat stress	(heat stress* OR heat risk* OR heat*)

The * is a truncation command for searching for the root of a word and then retrieve any alternate endings.

The screening of articles to be included in the synthesis followed a two-step approach, comprising a combined title and abstract screening, followed by full-text screening. Two independent researchers reviewed each article. The principal investigator resolved screening decisions that resulted in conflicts between the two screeners. The screening was performed with the online platform Sysrev [47]. The inclusion criteria for articles to be considered in the review were primary research studies that provided empirical evidence on observed urban greening measures in the context of climate change or heat stress in cities. Studies that built only on models, reviews, and meta-analyses were excluded during the screening stages. The full-text screening also filtered out studies with insufficient information to be included in the synthesis, for example, due to the insufficient focus of the study on the temperature reduction/increase in wellbeing through urban greening (as opposed to, for example, other adaptations, other urban elements, rural areas, other hazards), insufficient information/data about the urban greening measure itself, or insufficient transparency (e.g., unclear description of the method used to measure the temperature reduction). All articles that were excluded at the full-text screening stage were done so with a documented justification.

The included articles were systematically coded in Sysrev by two independent researchers in parallel, with conflicting codes resolved by the principal investigator. The codes included sets of codes on (a) metadata describing the publication; (b) the location of the study, allowing us to analyse regional patterns and potential bias; and (c) thematic codes describing the adaptation measure and its context. The thematic codes were developed deductively, adopting approaches from existing reviews and including indicators on socio-economic inequalities, access and geographical contexts [32,48,49], and urban greening types [28] (Table 2). Finally, the coded data were exported into an Excel spreadsheet for descriptive statistical analysis with SPSS [50].

Table 2. Overview of variables and labels used for coding.

Category/Variable Name	Input Format or Label
(a) Metadata	
Year of publication	numeric
Type of publication (single answer)	• journal article • book chapter • conference paper
Journal discipline	according to Clarivate ESI journal list or SJR journal rankings, as applicable
(b) Location of study	
Continent	• Africa • Asia • Australia and Pacific • Europe • North America • South America
Country	open
City	open
Coordinates	• latitude • longitude
Climatic Zone	after Köppen–Geiger
Number of Inhabitants (city)	Numeric
Country category	after the World Bank income groups
(c) Thematic	
Type of urban greening (multiple answers possible)	• park • vegetated building • green wall • roadside trees • forest • shrubs • grass • generic/green space
Accessibility	• private • public • unclear
Scale	• single element/structure (e.g., roof) • expanded area or ensemble of elements (e.g., park) • multiple structures and areas across a city or neighbourhood (e.g., green areas in general)

Table 2. *Cont.*

Category/Variable Name	Input Format or Label
Land uses	• residential • commercial • industrial • mixed • unclear
Socio-economic context of the neighbourhood (if there was a lack of information in the article, secondary data was used to answer this field)	• high income • low income • mixed • unclear
Climate impact/hazard (multiple answers possible)	• heat islands • heat stress • climate warming • other
Temperature measured?	• yes • no
Is a temperature reduction measurable?	• yes • no
Where was the temperature reduction measurable (if applicable)? (multiple answers possible)	• on-site • surrounding areas • city-wide • other
Thermal comfort increase reported or subjective temperature reduction perceived?	• yes • no
Type of study/method (multiple answers possible)	• remote sensing • in situ observation • survey • interview • experiment • other

3. Results

After completing the database search and full-text screening, 40 articles were included in the narrative synthesis (see Figure 1). The Supplementary Material provides the complete set of results as an evidence database.

3.1. Study Background

The 40 journal articles on urban greening in response to heat risk included in this review were published in 28 different journals. Half of the articles were published in journals with an environmental or ecology focus, followed by geosciences (n = 8) and engineering (6). Only three articles were published in journals focusing on social sciences, and one was published in an explicitly multidisciplinary journal (Figure 2). Most studies (22) used remote sensing as a method to analyse urban greening, followed by in situ observations (16) and experiments (9). Only a few studies (5) also included interviews with local populations.

3.2. Geography

The geographical overview of publications shows a clear regional bias towards cities in Europe and parts of Southeast Asia. Although every inhabited continent is represented in this review, there is only one article each for North America, South America and Africa

(Figure 3). The largest city included in the review is Beijing (around 22 million inhabitants), the smallest one is Rosignano Solvay (Italy, approximately 20,000 inhabitants), and the average population of cities is about 4 million inhabitants. Most studies were conducted in high-income (25) and lower-middle-income (14) countries. The country featured in the most articles is China (11), followed by Australia and Spain (3 each), with several other countries featured in one or two articles. From a climatological perspective, most articles analyse urban greening measures in temperate/mesothermal climates (27), followed by continental/microthermal (7), tropical/mega-thermal (5) and dry (desert and semi-arid) (2) climates. None of the included articles featured studies in polar climates.

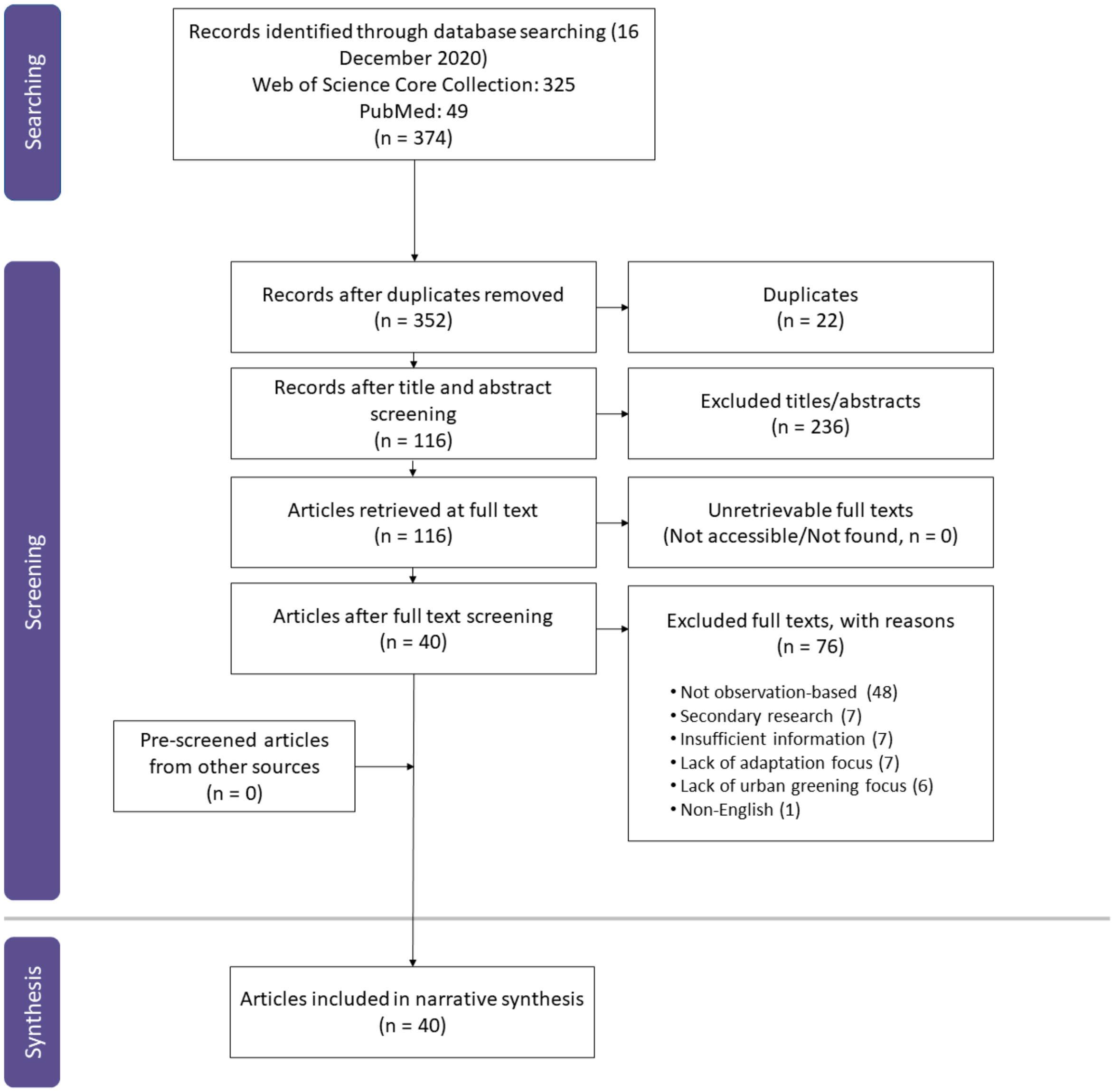

Figure 1. ROSES (RepOrting standards for Systematic Evidence Syntheses) flow diagram after [40].

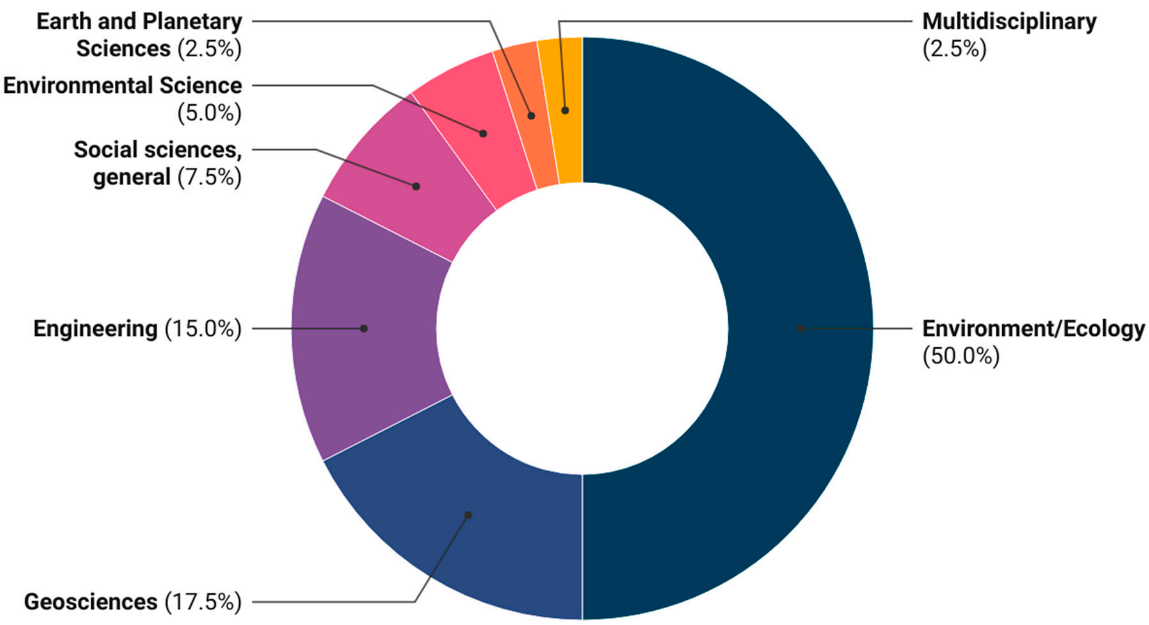

Figure 2. Percentage of publications for each journal discipline.

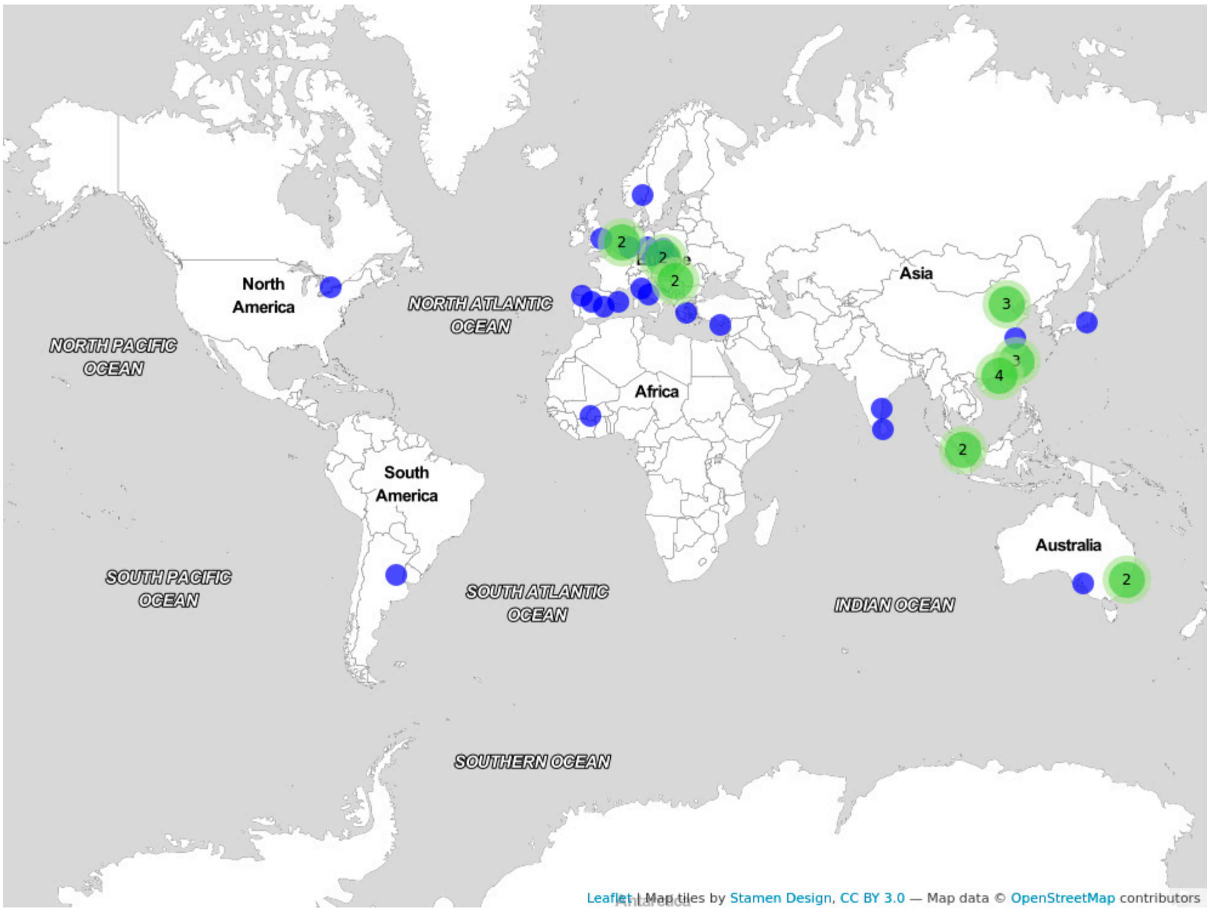

Figure 3. Locations in urban greening articles included in this review (created with EviAtlas [51]).

Regarding the city context of the various studies, most articles cover mixed urban areas (22), followed by 10 articles focussing on residential areas, 3 on commercial areas and only 1 on an industrial area (Figure 4a). A deep understanding of the socio-economic neighbourhood of the studies was generally not possible because such information was lacking in almost all the studies. By drawing on secondary data about the income levels of the neighbourhoods studied relative to the city average, we identified 5 studies set in mixed neighbourhoods, followed by 3 and 2 studies set in high- and low-income neighbourhoods, respectively. However, for most articles, it was impossible to identify the neighbourhoods' relative income levels within the scope of this review project (Figure 4d).

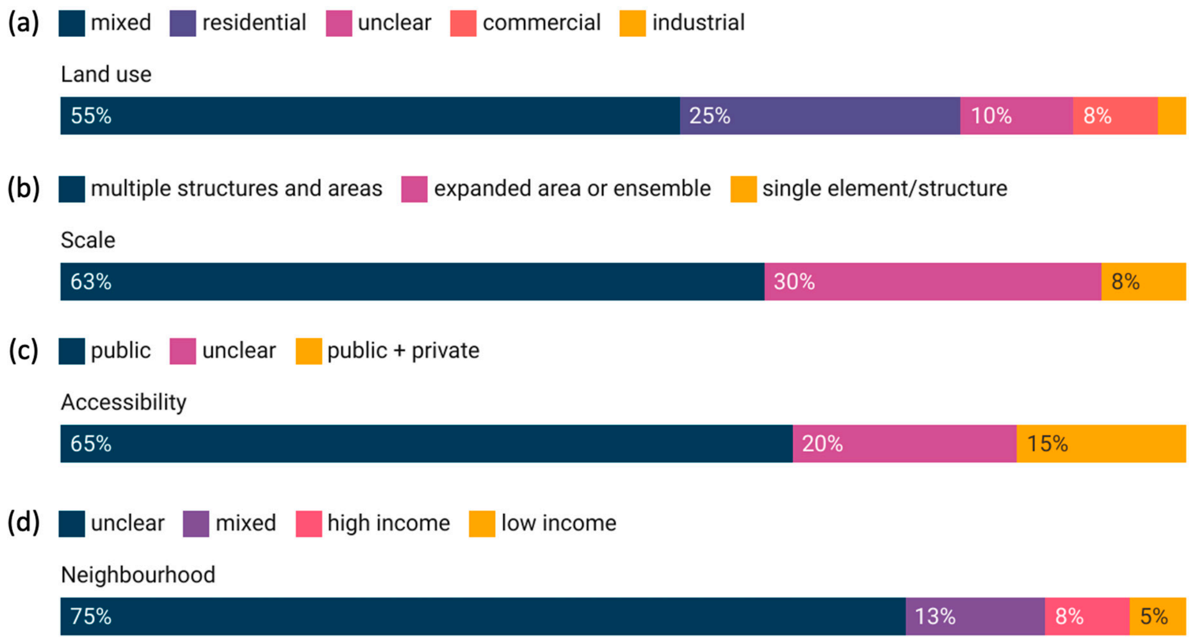

Figure 4. Percentage of publications for each social–geographical context of urban greening structures: (**a**) land use, (**b**) scale, (**c**) accessibility, (**d**) neighbourhood.

Only a vague pattern can be seen in the types of urban greening across different city areas. For example, parks and vegetated buildings are documented relatively often in residential areas, whereas roadside trees often feature in commercial areas. In most articles, however, the various types of urban greening were not clearly identifiable for specific city areas because the articles dealt with multiple or mixed areas (Figure 5).

	residential	commercial	industrial	mixed	unclear
grass	2	1	0	9	1
shrubs	0	0	0	5	1
roadside trees	2	3	0	10	2
park	5	1	0	9	0
vegetated building	4	0	0	3	2
forest	1	1	0	3	0
generic green space	0	1	1	8	0

Figure 5. Number of publications for each city area and type of urban greening.

The distribution of the types of urban greening across different climate zones shows few geographical trends. We found that grass areas and parks are the measures most often studied in oceanic climates (Cfb) and in some temperate and continental climate zones.

Vegetated buildings appeared relatively often in case studies in oceanic and dry-winter humid subtropical climates. Roadside trees were found across all generic climate zones (except polar climates, i.e., (A–D) (Figure 6).

	Af	Aw	BSh	Bsk	Cfa	Cfb	Cfc	Csa	Csb	Cwa	Dfb	Dpa	Dwa
grass	0	0	0	0	1	6	0	0	2	0	1	1	2
shrub	0	0	0	0	0	2	0	0	0	0	1	1	2
roadside trees	2	0	0	1	2	3	0	3	2	1	2	1	1
park	0	0	0	0	2	5	0	3	0	0	2	0	3
vegetated building	1	1	0	0	0	2	1	0	0	3	0	1	0
forest	1	0	0	0	1	1	0	1	0	1	1	0	0
generic green space	1	2	0	0	2	2	0	1	0	1	0	0	2

Figure 6. Number of publications for each climate zone and type of urban greening.

3.3. Urban Greening Interventions

Although all studies included in this review examine urban greening in the context of climate change, only 13 describe it primarily as a response to climate-related warming. Most articles analyse urban greening primarily regarding its effect on reducing the UHI intensity (30) or heat stress (20) in general.

The most common urban greening element studied is roadside trees (17 articles), followed by parks, general grass areas or unspecified green spaces. Moreover, shrubs (6) and forests (5) are common elements in several studies. Among the green structures, 10 articles focus on vegetated buildings and 2 focus on green walls (see Figure 7).

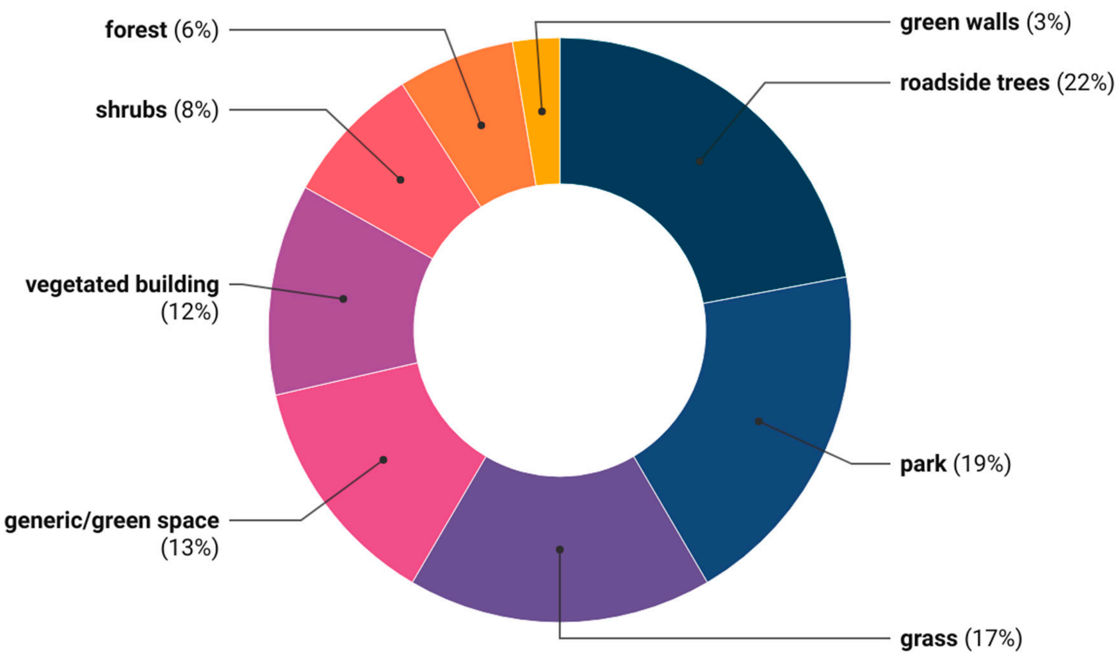

Figure 7. Percentage of publications for each type of urban greening.

The reviewed literature mainly covers multiple structures and areas (25) and ensembles (12), as opposed to single elements or structures (3) (Figure 4b). Moreover, these elements and areas are mostly located on public land (32) and, in a few cases (6), on private properties (Figure 4c).

In 39 articles, a measurable temperature reduction in or surrounding the site of the urban greening element is reported. Furthermore, 15 articles report a calculated or perceived increase in thermal comfort in locations with urban greening.

4. Discussion

How is urban greening studied?

Our review showed a bias towards natural science studies on urban greening. These studies mostly use remote sensing or experimental methods, amongst others, and are the methods most commonly used in the context of research on the UHI [27]. Despite the rapidly increasing quantity of evidence proving the effects of urban greening on reducing heat stress and other stresses, as well as other positive effects through such methods, significant knowledge gaps remain. Our findings reveal a lack of participatory methods, for example, those involving local stakeholder perceptions. Moreover, as Knight et al. [28] identified in their review, there are limitations to the applied study designs, particularly a lack of uniformity, standardisation and reproducibility. This fact reduces confidence in the existing evidence and its generalisability and applicability to prospective policies and measures.

On the one hand, a more standardised study design and an increased potential for generalisation are desirable, especially regarding the studies that aim to quantify the effects of specific urban greening measures in a defined area or on a defined population. Furthermore, studies drawing on natural science approaches can and need to consider also the increasing stress that climate change is placing on urban green areas [52]. On the other hand, we call for more social science research that considers environmental justice, diverse local contexts and diversity within a social context. However, such approaches are often of a qualitative nature and are developed in a grounded theory manner that makes generalisation across different sites difficult by definition. Therefore, further research on both sides of the spectrum and mixed methods studies are needed to fill knowledge gaps in the social–geographical context.

Which regions are represented?

We found that study sites in high-income and lower-middle-income countries are most often reported upon in the academic literature, with a strong bias towards Europe and Asia. Due to the spatial variation in the estimated warming, cities in temperate and cold zones are expected to experience the greatest rise in heat risk. These cities often feature a high GDP and therefore have high adaptation potential, whereas urban areas in temperate and tropical zones of the Global South are prone to future heat risk because of substantial prospective warming and fewer resources available for adaptation [3].

Our findings confirm the findings of Knight et al. [28], which highlight the limited geographical coverage of studies in Africa and South America, both tropical and arid zones. These spatial limitations are mostly in line with Vincent and Cundill's [53] findings; they perceived an increasing number of publications on empirical adaptation research in the Global South that remain focused on specific areas and topics, neglecting sub-Saharan Africa and the Middle East/North Africa (MENA), as well as cities in general. A recent study by Zittis et al. [54] considers this gap. It identifies the possibility of unprecedented heat waves and consequent heat stress, especially in urban MENA areas, by 2060 under a business-as-usual pathway. They call for prioritising and intensifying mitigation and adaptation efforts in the region, and highlight the necessity for further research [54]. Furthermore, the study by Dipeolu et al. [55] provides an example of evidence of the multiple health benefits of urban greening in Lagos, Nigeria. Research on how urban greening is implemented in cities of the global south is also needed, due to the increasing trends in urbanisation and the growing number of informal settlements with a highly vulnerable population; this is alongside necessary research on challenges that exist in formalised urban planning [20].

Our review also shows a gap in evidence in North America, similar to Balany et al. [27], but different from Knight et al. [28], who use a broader framing and also include literature on ozone concentrations, amongst others. Indeed, North American cities also experience heat stress and social–geographic inequalities concerning access to urban green space [31]. Hence, follow-up social–geographical research on adaptation to heat stress through urban greening should target this underrepresented region more explicitly.

In which social–geographical context are studies located?

The results of our review show that the majority of studies are about urban greening in public spaces and mixed and residential neighbourhoods. The documented benefits of urban greening in public areas are highly relevant, as they include factors of appearance, accessibility and safety in the green area [56–59]. Furthermore, public green urban areas represent loci of interaction between urban dwellers in spaces for recreational and social activities, which contribute to human physical and mental well-being [60]. In addition to their cooling effects, public parks can, therefore, also provide diverse health benefits for different social groups and reduce inequalities.

From an economic perspective, urban greening projects, such as parks, can revitalise neighbourhoods by attracting visitors and consumers, consequently stimulating economic activity and investments. Despite these positive effects, urban green spaces can also lead to increased rents and property prices, contributing to green gentrification and the consequent displacement of the original residents [61,62]. The possible contribution of urban green areas towards the displacement and isolation of socio-economically vulnerable groups highlights an aspect of inequality and thus the necessity of policies that foster equity in terms of access to public green urban areas [63,64]. Findings from Wüstemann et al. [32] indicate that thorough analysis before their implementation might be necessary to ensure the equal provision of urban green spaces.

Our review reveals a lack of consideration of the socio-economic background of urban greening case studies. From a social-geographical perspective, this context is highly relevant, given potential inequalities in the provision of green spaces within cities depending on income, ethnicity, education, age and household composition [32,65]. Differences in levels of vulnerability towards heat stress exist likewise on a smaller scale within a city's population, with children, elderly people, people with ill health and lower-income groups being at greater risk [14,66,67].

Our findings show a strong focus on city areas with mixed uses and residential areas. While these areas are certainly hotspots of heat stress, other areas should not be neglected and deserve more attention in the research on urban greening. For example, green areas in industrial areas have been proven to have an impact on particulate matter and air temperature, with a positive effect also on neighbouring residential areas [68]. Furthermore, commercial areas are not only areas with a high density of people, especially during the day time, but also offer a specific potential for more extensive urban greening measures, such as the greening of malls and parking lots [69]. Spatial aspects are important regarding the large-scale effectiveness of urban greening measures, since expanded and interconnected areas of green space have a greater cooling effect than single elements or islets [70]. Therefore, these areas are also of greater benefit to urban populations as a whole, rather than just to specific sites or people. However, increasing urbanisation trends when turning urban green areas into new residential zones threaten the equitable provision of urban greening benefits to urban communities [34].

Limitations

Our review focuses on the mainstream literature that feeds into assessments such as the IPCC's. For higher comparability with such assessments, we limit the time span of the review to the assessment period and focus on two core databases (Web of Science Core Collection and PubMed), which may exclude evidence from other publication sources not included in these databases. We also acknowledge the regional bias of our results due to only including English-language articles.

As a global scoping review that includes a highly heterogenous evidence base, we frame the review in a descriptive manner with limited depth. Hence, specific considerations of urban inequality, such as inequalities in resources, individual access and capabilities, or structural inequalities in terms of gender, race and ethnicity, and income and wealth [49], may not all be covered in the same way among the reviewed literature. Nonetheless, our method builds on proxy indicators that provide insights into aspects of access and inequality. In addition, the review revealed that the limited social sciences data in articles hinder the identification and discussion of social vulnerabilities in urban greening studies (e.g., income levels).

5. Conclusions

Our study complements reviews on the effect of urban greening on temperature reduction, for example, in the context of the UHI. It addresses the call for urban greening, specifically as a response to global warming and how environmental justice considerations in urban greening implementation are represented in the mainstream literature on urban greening as a climate change adaptation measure in the past IPCC assessment period.

Our research shows an urgent need to include social–geographical considerations in studies and evaluations of urban greening, in order to stress its impact on climate change, and to fill regional knowledge gaps to ensure that studies are relevant to not only specific hotspots, but also to vulnerable cities with differing capacities to implement urban greening measures for their populations. Similarly, there is insufficient evidence beyond individual studies on the general effectiveness of different urban greening structures when used as climate change adaptation measures for different social groups. Future in-depth research on urban greening should consider questions about accessibility for specific vulnerable social groups and urban areas of the global south. Specific questions to be addressed by urban greening research could be around which types of urban greening provide the most benefits to specific social groups, how equitable access to public urban areas can be guaranteed, and how preferences and the effectiveness of urban greening areas differ across regional and social contexts.

This review provides insights that can support policy-makers and urban planners to avoid maladaptation and consider social aspects in the implementation of urban greening measures, relating to questions regarding who benefits from planned adaptation measures in dynamic and diverse urban contexts. Given the increasing trends in urbanisation and urban transformation, and considering the UN Agenda 2030 slogan 'leave no one behind', environmental justice concerns, regarding the planning and implementation of climate change adaptation measures, such as green infrastructure, are of the utmost importance. In addition, urban greening is a matter of not only climate change adaptation, but also its mitigation, and therefore is an important factor in achieving the Paris temperature targets.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15064996/s1, Evidence Database.

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