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From XS to XL Urban Nature: Examining Access to Different Types of Green Space Using a 'Just Sustainabilities' Framework

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Abstract: Different types of urban green spaces provide diverse benefits for human health and environmental sustainability, but most studies on access to green space focus on neighborhood parks, with less work on smaller or larger green spaces. In this study, we examined sociodemographic differences in access to green spaces of different sizes for 14,385 census block groups in 12 U.S. cities using a 'just sustainabilities' framework. We classified green spaces into street-level greenery (XS), neighborhood parks (S–L; walking and cycling access), and large parks (XL; walking, cycling, and driving access). We ran spatial filtering models at the census block group level using different thresholds based on transportation modes. We uncovered a complex picture of inequality, with consistent injustices for XS green space, and fewer injustices for S–L and XL green space based on socioeconomic status and age, and some instances of just distributions for S–L and XL green space based on race/ethnicity. Our findings present a concerning picture for 'just sustainabilities': the green space type that is most often part of sustainability and climate adaptation strategies—street greenery—is unjustly distributed, likely as a result of structural racism in U.S. institutions. By examining multimodal access to green spaces of different sizes, this study helps urban greening professionals develop more just and sustainable strategies.

Keywords: green space; street greenery; green space size; environmental justice; just sustainabilities

1. Introduction

1.1. Access to Green Space

Urban green space is a central element of sustainable cities, providing multiple health, environmental, social and economic benefits [1,2]. A growing body of literature suggests that the type and magnitude of such benefits may vary by the size of green spaces. The smallest type of green spaces (XS), such as street-level greenery, improve thermal comfort and aesthetic value in daily living environments, increase abutting property values, and bolster ecological functions [3–6]. As local destinations, neighborhood parks and trails (S–L) function as community gathering places, increase neighborhood satisfaction, and have particularly significant economic impacts on nearby property values [1,7–11]. As regional or national travel destinations, large parks—including regional parks, state parks, and national forests and parks (XL)—have strong benefits for human health and sustainability, as they provide diverse recreational resources and increased ecological diversity [12–18]. Thus, green spaces of different sizes have unique benefits for environmental sustainability and human health, and they can serve complementary functions to improve urban residents' quality of life [19,20].

A large body of research shows that neighborhood parks (S–L nature) are unjustly distributed across the cities of the Global North and Global South, with low-income and racial/ethnic minority people having lower access to such parks than more privileged groups [2,21–23]. Although no systematic review has examined environmental justice issues in the access to green spaces of different sizes, our analysis of the literature to date shows that there might be injustices for street-level greenery (XS) and large parks (XL), in addition to neighborhood parks (S–L), for which reviews are available [21]. Regarding XS urban nature, several studies have found that trees (in private and public settings) are unjustly distributed across income and racial/ethnic groups [24–27], fewer have focused on publicly accessible street trees [28,29], and even fewer have examined street greenery [30], also finding evidence of injustice. Not many studies have examined access to XL green spaces (i.e., large parks), but those studies generally found that large parks are unjustly distributed [31–34].

1.2. Environmental Justice and Just Sustainabilities

Uneven distributions of green space have been deemed environmental injustices due to the numerous benefits that green spaces provide for human health and environmental sustainability [31,33]. Many scholars have defined environmental justice as a tripartite concept [35]: distributional justice, involving a just distribution of environmental hazards and amenities; procedural justice, describing the meaningful participation of low-income people of color to environmental decision-making; and recognition, involving the inclusion of the different cultures and needs of the demographic groups affected by environmental policies. Based on this definition, the unequal access to green space mentioned above is considered a distributional injustice [31,36]. In the U.S., studies have linked these injustices to the legacy of structural racism, as redlining, racially restrictive covenants, and real estate practices have led to the segregation of low-income people of color in disinvested, park-poor neighborhoods [31,33].

Like others [31,36–38], we argue that definitions of distributional justice should adopt an equity lens to consider the populations who need environmental amenities the most. In this sense, a just distribution of green space is one wherein marginalized groups (e.g., low-income and racial/ethnic minority people) have better access to green space than more privileged people (e.g., affluent and white people), and an unjust distribution is when the opposite occurs. A major needs-based consideration of our equity lens is that low-income people and people of color experience worse physical and mental health outcomes than more privileged groups around the world [39–42], and green space exposure helps improve health [43,44]. Another needs-based consideration for the definition of distributional justice is that public green spaces are freely accessible to anyone, including low-income people, whereas some private recreation and exercise opportunities might not be accessible to low-income people due to monetary constraints (e.g., sports clubs, gyms) [45,46]. On the flip side, affluent people might have the means to access private recreation settings [47].

Furthermore, race and ethnicity are central to the environmental justice movement, which around the world has sought to reverse the negative environmental impacts of structural racism [48–50]. In the U.S., the movement originated from Black people mobilizing to denounce their excessive exposure to environmental hazards such as landfills [49], whereas, in the Global South, indigenous people have protested the negative environmental and health impacts of colonialism [48,51]. Additionally, environmental injustice can occur at different scales, including between neighborhoods, cities, and even world regions [48,52]. Indeed, significant injustices exist between the Global North and Global South, which suffers disproportionately from harmful exposures and the effects of climate change [48,51].

Increasingly, green space planners and advocates recognize that sustainable initiatives such as new green spaces should also be just [53–55]. Julian Agyeman and colleagues conceptualized this integration of environmental justice values into sustainability initiatives and framework as "just sustainabilities," as a way to fill an "equity deficit" in sustainability efforts [35,53]. Specifically, Agyeman's definition of 'just sustainabilities' includes four conditions [35]: (1) improved well-being and quality of life; (2) ensuring that the needs of current and future generations are met, (3) environmental justice and

equity, including distributional justice, procedural justice and recognition; and (4) living within the limits of our planet's ecosystems. These conditions integrate key elements from the definitions of sustainability—including the environment, the economy, and equity (see [56])—and environmental justice (see [57]). Importantly, by mentioning an equity deficit, the definition of 'just sustainabilities' implicitly recognizes the usefulness of an equity lens to determine environmental justice outcomes [38], which aligns with the equity-based approach we use in this paper.

Similar to Agyeman, Boone and Fragkias argued that vulnerability science can help integrate sustainability and environmental justice by emphasizing reducing harm on people and the environment [58]. A vulnerability lens that seeks to limit both harms is particularly important because marginalized groups bear a disproportionate burden from the effects of climate change [59]. In the context of urban green spaces, the 'just sustainabilities' framework [35] can serve to highlight the need for green space to be justly distributed, and the need to improve the quality of life for all, now and in the future, with the understanding that more green space can help humans live within the limits of the earth's ecosystems.

1.3. Study Purpose

As noted earlier, although several environmental justice studies have focused on access to neighborhood parks (S to L urban nature), significantly fewer investigations have focused on street greenery and large parks (XS and XL urban nature, respectively). Furthermore, to our knowledge, no empirical study has comparatively examined access to urban green spaces of different sizes (from XS to XL) for the same sample of urbanized areas, and no systematic review has assessed this topic either.

Given these literature gaps, the purpose of this study is to analyze sociodemographic differences in access to green spaces of different sizes (from XS to XL) for a diverse sample of urbanized areas in the U.S. using the 'just sustainabilities' framework conceptualized by Agyeman [35]. This 'just sustainabilities' framework is useful to examine accessibility to urban green spaces for at least three reasons. First, green spaces of different sizes bring diverse benefits for environmental systems and quality of life, as they can support different types of activities [1,3,18]. Indeed, street greenery may serve as a city's 'everyday green', whereas large parks are more likely to be used for longer contacts with nature (e.g., hiking). Second, distinguishing which sociodemographic groups have higher access to different sizes of green spaces, including whether environmental injustices exist, can help green space planners, park advocates, and elected officials implement targeted policies and programs to achieve justice for green spaces of different sizes. Finally, different organizations plan and manage green spaces of various sizes—from community forestry nonprofits to parks and recreation departments to national park agencies [60,61]—to achieve various sustainability and livability goals and, therefore, the results of our study can inform the work of all such organizations.

This study makes several contributions to both the growing literature on access to green space and sustainability practice. First, the main contribution is an examination of the accessibility of different scales of green spaces, which, as noted earlier, can both advance our understanding of environmental injustices and help green space organizations develop strategies to address them. Second, while studies examined the presence of vegetation and trees in both public and private settings [25], we analyze public green space. Focusing on street greenery as the XS green space measure allows us to describe small-scale green spaces that can be enjoyed by the public (as opposed, for example, to backyards). Third, by examining access to green spaces of different sizes in a relatively large sample of urbanized areas (*n* = 12), we shed light on whether the scale of green space matters in environmental justice outcomes. Finally, we recognize that travel to green spaces of different scales might occur through various travel modes, and include those travel modes in our analysis, whereas much previous literature focused on walking access to green spaces alone (e.g., [21,25]).

2. Materials and Methods

2.1. Study Areas

The study areas are 12 U.S. Census Urban Areas systematically selected to represent urban regions of various population sizes and diverse geographical contexts (see Table 1 and Figure 1). The U.S. Census Bureau identifies urban areas as "a densely settled core of census tracts and/or census blocks that meet minimum population density requirements (at least 1000 people per square mile)," which also commonly include abutting territory with lower population density [62]. This definition is useful because the areas of interest in this study are urban neighborhoods that, given limited public resources, de facto compete with each other for green spaces, unlike exurban areas that might be rich in natural environments.

Table 1. Regional context, population size, climate, sociodemographic, and green space information by urban area.

Urban Area [1]	US Region	Total Pop [2]	Avg. Temp (°F) [3]	Precip Per Year (in.) [3]	Reg Pop Den [2]	Reg Med HH Inc [2]	Reg Percent NH White [2]	XS Green Spaces (acre) (%) [4]	S–L Green Spaces (acre) (%)	XL Green Spaces (acre) (%)
Seattle, WA	West	3,399,109	54.7	35.8	3310	81,662	62%	203,286 (31%)	7704 (1.2%)	375,712 (57%)
Salt Lake City-West Valley City, UT	West	1,104,330	56.7	13.2	3971	70,836	71%	25,490 (14%)	1789 (1.0%)	286,477 (161%)
Fresno, CA	West	696,171	66.5	8.67	4,058	52,641	32%	12,602 (11%)	1172 (1.1%)	11,852 (11%)
Minneapolis-St. Paul, MN-WI	Mid west	2,819,056	46.5	33.6	2536	75,500	72%	187,795 (26%)	13,412 (1.9%)	131,291 (18%)
Kansas City, MO-KS	Mid west	1,590,067	54.7	40.8	2322	62,175	68%	96,923 (22%)	4208 (1.0%)	67,428 (15%)
Grand Rapids, MI	Mid west	607,374	49.7	44.5	2121	58,065	72%	32,048 (17%)	1038 (0.6%)	34,583 (19%)
Houston, TX	South	5,594,567	71.1	52.5	3306	64,307	32%	180,654 (17%)	4768 (0.4%)	93,620 (9%)
Raleigh, NC	South	1,019,591	61.5	60.3	1949	75,971	60%	47,566 (14%)	1991 (0.6%)	53,477 (16%)
Sarasota-Bradenton, FL	South	706,835	74.4	48.7	2082	55,439	78%	24,488 (11%)	1292 (0.6%)	91,459 (42%)
Boston, MA-NH-RI	North east	4,420,143	52.4	53.3	2278	84,738	69%	251,807 (20%)	18,501 (1.5%)	285,137 (23%)
Providence, RI-MA	North east	1,198,954	52.9	65.5	2111	61,709	73%	71,518 (20%)	4079 (1.1%)	181,883 (50%)
Buffalo, NY	North east	932,270	49.4	41.7	2443	53,484	75%	42,626 (17%)	1437 (0.6%)	15,689 (6%)

[1] The Urban Area names in the following sections will be denoted as the major city in each area; [2] the socio-demographic data are based on Census American Community Survey 2014–2018 5-year estimates; [3] the temperatures and precipitations represent the major city data in each urban area (source: National Oceanic and Atmospheric Administration, 2018); [4] the percentage of green space over the size of an urban area.

To select study areas, we first classified all of the U.S. Census Urban Areas into 12 categories defined by three different population sizes (more than 2 million, more than 1 million and less than 2 million, and more than 0.5 million and less than 1 million) and four U.S. regions (West, South, Midwest, and Northeast). As urban agglomerations with a continuously built-up area (also called metropolitan areas) commonly consist of at least a population of 0.5 million or higher [63], we used this number as the lowest threshold and created categories enabling a selection urban regions of various sizes. Then, we selected one urban area from each of the 12 categories to obtain a geographically dispersed sample across the country. The 12 urban areas included in the sample also represent various population sizes (from 5.6 million in Houston, TX, to 0.6 million in Grand Rapids, MI), average temperatures (from 7.5 °C in Minneapolis-St. Paul, MN, to 23.5 °C in Sarasota-Bradenton, FL), and annual precipitations (from 8.7 inches in Fresno, CA, to 65.5 inches in Providence, RI-MA). These diverse characteristics both enhance the generalizability of our findings and allow for comparisons within the sample.
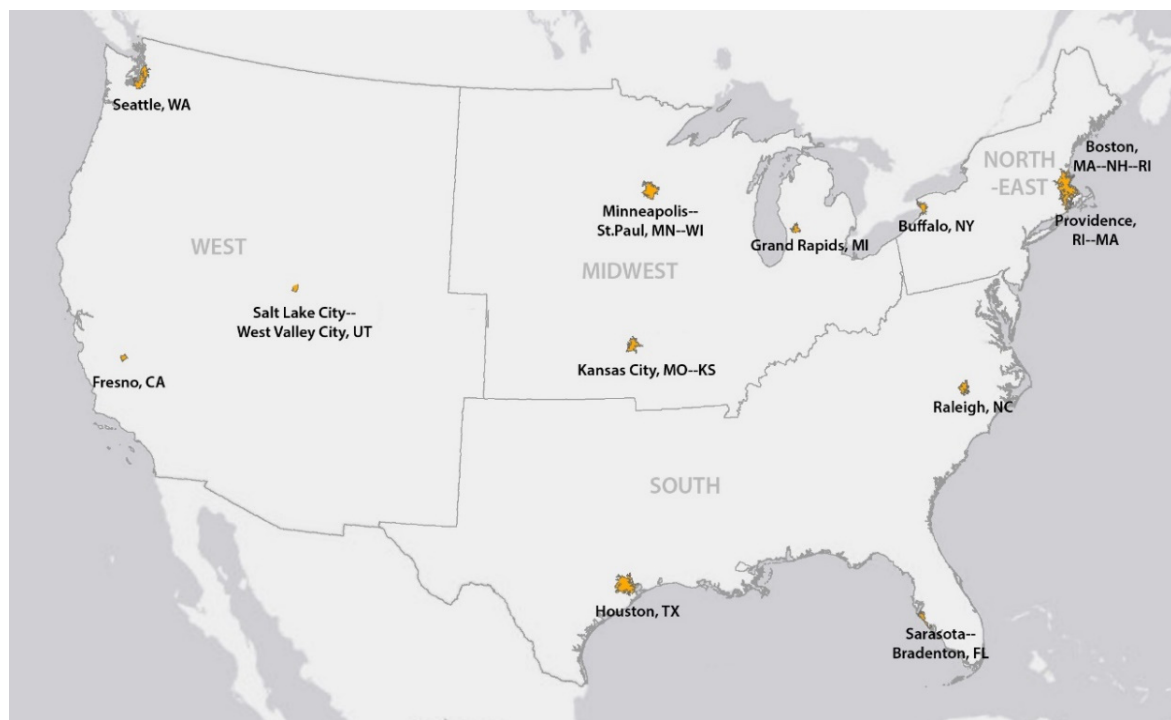
Figure 1. Study areas: 12 urban census areas that represent urban communities of various population sizes and diverse geographical contexts.

2.2. Green Space Data

Nature in urban environments exists in various forms and sizes. On the smallest scale, residents might be exposed to street greenery during their daily outdoor activities and on travel routes. On the other side of the size continuum, larger-scale green spaces include large parks, which people visit to enjoy a variety of wildlife and recreational programs, often traveling farther from home to reach these destinations. As green spaces of different sizes support different types of activities [1], we define urban green spaces in three different categories based on their size: extra-small (XS), small to large (S–L), and extra-large (XL) green spaces.

2.2.1. XS Green Spaces

We define XS green spaces as street greenery, which includes vegetation accessed or viewed on the street, including street trees, park strips, front yards, and median strips [3,30,64]. Street greenery does not have a consolidated planning and management system, as some elements are managed by private individuals or companies (e.g., front yards), whereas others are controlled by public agencies (e.g., median strips). Regardless, XS nature can help improve physical health outcomes by promoting physical activity, and mental health outcomes by helping relieve stress [65,66].

We collected data to operationalize XS nature from aerial images generated by the U.S. National Agriculture Imagery Program (NAIP) in 2014–2016. NAIP aerial images are remotely-sensed during the agricultural growing seasons, and are available in one-meter resolution or finer; thus, such 'leaf-on' images can efficiently represent vegetation in urban neighborhood streets. NAIP images include four color bands (red, green, blue, and near infrared), which were used to calculate the Normalized Difference Vegetation Index (NDVI). NDVI is a popular indicator to operationalize vegetation [67].

Following the NDVI standards used in earlier studies [68,69], we used an NDVI value of 0.12 or higher to identify any vegetated pixels from the aerial images. After creating vegetation raster images, we removed vegetation that cannot be accessed or viewed on public streets by using buffers around street centerlines to measure street-level greenery (see Figure 2). For the road buffers, we utilized the

2019 Census TIGER (Topologically Integrated Geographic Encoding and Referencing) Road shapefiles, and created a buffer from street centerlines of 100 feet (30.48 m) for main arterials, and a buffer of 50 feet (15.24 m) for local neighborhood roads [70]. The two different buffers take into account the width of the main arteries and neighborhood roads. Based on guidelines from the American Association of State Highway and Transportation Officials [71], we estimated the total width of arterial streets—including more than two travel lanes, shoulders, sidewalks and front yards in each direction—as 200 feet (60.96 m). Applying similar logic, we estimated the width of local neighborhood streets with two travel lanes and other street elements as 100 ft.
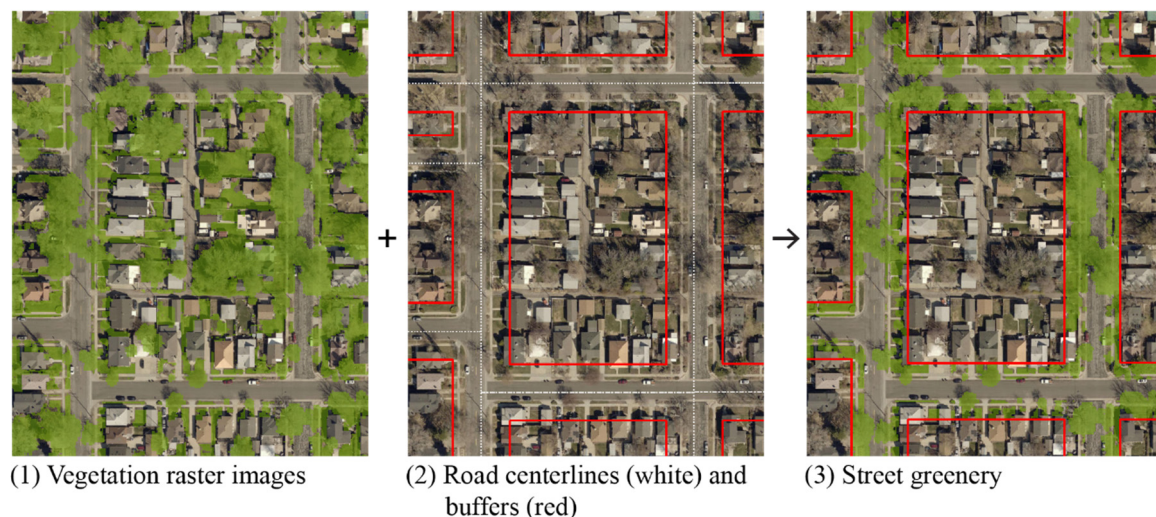

| (1) Vegetation raster images | (2) Road centerlines (white) and buffers (red) | (3) Street greenery |

Figure 2. Street greenery extraction using vegetation raster images and road buffers.

2.2.2. S–L and XL Green Spaces

In U.S. cities and other Global North contexts, the most typical type of urban green space larger than street greenery (XS) is the urban park (S-XL) [21]. Different organizations and scholars have classified urban parks by their size and function. Table 2 shows examples of park classifications in different countries, highlighting the variations in terminology and size criteria. Such variations are inevitable, because park classifications are often the basis of park and open space planning (e.g., a standard for per capita park acreage), and each community has different recourses and demands [72]. Although parks of various sizes individually play an important role in serving different social needs, large parks have received special attention, given their complexity in programs, ecology, and relation to abutting urban environments [73]. While smaller parks might be designed with a focus on the facilities and amenities needed in the local communities, large parks containing a variety of natural habitats and vegetation provide a unique natural experience [15] and improved social, health, and environmental benefits [14,16,17]. Thus, in this study, we separately examine access to neighborhood parks (S–L) and large nature (XL).

A typical size threshold separating large parks from smaller, neighborhood-level parks ranges between 10 to 50 acres (4 to 20 hectares). Following the example of a U.S. national investigation of neighborhood park use [74], we used an upper-bound size limit of 20 acres (8.1 hectares) to define neighborhood parks, and thus operationalized large parks as those with an area equal to or bigger than 20 acres. We collected park data from the ParkServe® dataset, which the Trust For Public Land [75] compiled by surveying thousands of municipalities, counties, and states in the U.S. This database includes a variety of green spaces, ranging from local parks to national parks. We first selected publicly-accessible green spaces from the database. Subsequently, we classified S–L green spaces as those that are less than 20 acres in size, and classified XL green spaces as those with an area of 20 acres or more.

Table 2. Classification of urban green space in different countries.

Country	Source	Type	Size Criteria
United States	National Recreation and Park Association (Mertes and Hall, 1995)	Mini park	0.4–2 ha (1–5 acres)
		Neighborhood park	2–4 ha (5–10 acres)
		Community park	8–20 ha (20–50 acres)
		National resource area, etc.	variable
United Kingdom	Greater London Authority (2016)	Pocket parks	under 0.4 ha (1 acre)
		Small open spaces	under 2 ha (1–5 acres)
		Local parks and open spaces	2 ha (5 acres)
		District parks	20 ha (50 acres)
		Metropolitan Parks	60 ha (150 acres)
		Regional parks	400 ha (1000 acres)
Canada	City of Toronto (2013)	Parkettes	under 0.5 ha (1.2 acres)
		Neighbourhood Parks	over 0.5 ha (1.2 acres)
		Community parks	over 3 ha (7.4 acres)
		District parks	over 5 ha (12.4 acres)
		City parks	over 15 ha (37.1 acres)

2.3. Dependent Variables: Accessibility to Green Spaces

The transportation modes that people use to access XS, S–L, and XL urban nature are likely to vary. Street greenery (XS nature) is a nearby green space that does not necessarily represent a destination in the same way as larger types of green space, and thus most studies have measured the total area or density of street-level vegetation in a neighborhood or other bounded geographies, likely accessed by walking [25,76]. To access neighborhood parks (S–L nature), urban residents most likely either walk or use a personal vehicle [45,47,77–79]. For example, Derose et al. [77] found that, in Los Angeles, 42% of survey respondents usually walked to get to a neighborhood park, while 54% came in a car and 4% biked. The access mode choice varies depending on race/ethnicity and socioeconomic status, such as car ownership. Derose et al. [77] showed that Latinos/as were more likely to walk to parks than other racial/ethnic groups (51% vs. 38%). Similarly, Loukaitou-Sideris and Stieglitz [45] found that more children living in marginalized inner-city areas walked, biked, or used skateboards to access parks, whereas those in more affluent suburban communities tended to drive a car to reach parks. In the case of large parks (XL nature), private vehicles and public transit are more common access modes [47,80,81]. Such a discrepancy in access modes to urban green space reveals the limitation of conventional park accessibility studies which exclusively focus on walking, and requires a multimodal approach to measure access to green space.

Thus, in this study, we employed six accessibility measured defined by green spaces of various sizes and different travel modes (Table 3). We used a variation of the container approach, which measures how much green spaces is within reach, and is widely employed across the literature [21,82]. Accordingly, we measured the XS green space accessibility as the density of street greenery in a block group—the area of green pixels within 100 feet (30.48 m) for arterials and 50 feet (15.24 m) for local roads divided by the block group area. We measured S–L green space accessibility using walking and bicycling as base travel modes, with an assumption that neighborhood parks primarily serve nearby communities. S–L nature accessible by walking describes the total park acreage in a 10 min walking distance (0.5 miles), and the one accessible by bicycling shows the total park acreage in a 10 min bicycling distance (2 miles). Ten minutes are commonly considered as a desirable travel time threshold for neighborhood parks, as also shown by a park advocacy initiative in the U.S. named the '10 Minute Walk' campaign (https://10minutewalk.org/). Lastly, we computed three accessibility measures to XL green spaces

based on walking, bicycling, and driving. XL nature accessed by walking and bicycling was estimated using the same logic and thresholds used for accessibility measures for S–L green spaces—the total park acreage in 0.5 miles for walking and 2 miles for bicycling, respectively. Similarly, we measured the XL park acreage accessed by driving using a 20-min driving distance (20 miles with 60 mph speed). The 20-min threshold was chosen because, according to the 2017 National Household Travel Survey, the average car travel time for recreational activities was 23 min. All of the travel distances were calculated using the network analyst tool in ArcGIS Pro. The boxplots in Appendix A show regional variances in green space accessibility.

Table 3. Variables included in the statistical model.

Type	Construct	Name	Definition	Level
Dependent variables	Accessibility to XS green spaces by walking	XS	Density of publicly accessible street greenery in a neighborhood	Block Group
	Accessibility to S–L green spaces by walking	S–L_walk	Acreage of S–L parks (<20 acres) within 0.5 mile network distance	Block Group
	Accessibility to S–L green spaces by biking	S–L_bike	Acreage of S–L parks (<20 acres) within 2 mile network distance	Block Group
	Accessibility to XL green spaces by walking	XL_walk	Acreage of XL parks (≥20 acres) within 0.5 mile network distance	Block Group
	Accessibility to XL green spaces by biking	XL_bike	Acreage of XL parks (≥20 acres) within 2 mile network distance	Block Group
	Accessibility to XL green spaces by driving	XL_drive	Acreage of XL parks (≥20 acres) within 20 mile network distance	Block Group
Independent variables	Race and ethnicity	Percent NH Black	Percentage of non-Hispanic Black population	Block Group
		Percent NH Asian	Percentage of non-Hispanic Asian population	Block Group
		Percent Latino/a	Percentage of Latino/a population	Block Group
	Socioeconomic status (SES)	Med HH Inc	Median household income	Block Group
		Percent College	Percentage of people with a bachelor's degree or higher	Block Group
	Age	Percent Child	Percentage of children (<18 years)	Block Group
		Percent Older	Percentage of older adults (≥65 years)	Block Group
Control variables		Pop Den	Population per square mile	Block Group
		Reg Pop Den	Population per square mile in a region	Urban Area
		Reg Med HH Inc	Median household income in a region	Urban Area
		Reg Percent NH White	Percentage of non-Hispanic White population in a region	Urban Area

2.4. Independent Variables: Sociodemographic Characteristics

We focus on three constructs that define marginalized groups that might be affected by environmental injustices: race and ethnicity, socioeconomic status (SES), and age (Table 3). Recent definitions of environmental justice require a more comprehensive fair treatment of all people

regardless of race, color, national origin, income, and educational attainment [83–85]. Further, the environmental justice literature has increasingly incorporated age as a variable of interest, arguing that children and older adults need particularly easy access to environmental amenities [25,86]. As noted in the introduction, we considered distributions of green space as just if a marginalized group (e.g., low-SES or racial/ethnic minority people) had better access to green space than the corresponding privileged group (e.g., high-SES or non-Hispanic white people), and as unjust if the opposite happened. Instances wherein no difference existed between marginalized and privileged group were considered as equal distribution, which, in the context of marginalized groups' high need for public green space [37,55], does not constitute a just outcome.

To measure race and ethnicity, SES, and age, we used the 2018 American Community Survey (5-year estimates) as a sociodemographic data source for the 12 urban areas. First, we calculated three variables for race/ethnicity, representing minority populations: the percentage of the Non-Hispanic Black population, the percentage of the Non-Hispanic Asian population, and the percentage of the Latino/a population. Black communities have a history of racial discrimination, with evidence showing environmental injustices such as greater exposure to environmental hazards (flooding: [87]) and poorer access to urban amenities (parks: [31]; trees and shrubs: [24]). The recent instances of police brutality against Black people in the U.S., such as the killing of George Floyd, show evidence that structural racism is still prevalent in the country (see [50,88]). Also, although Asian people are a fast-growing minority group in the U.S., only a few studies have incorporated them into the environmental justice framework and revealed greater health risks than non-Hispanic white people [89–91]. Latino/a residents, representing one-sixth of the U.S. population, are also more likely than non-Hispanic white people to live areas with higher exposure to pollutants [92], higher crime rates [93] and smaller parks [52,93]. We did not include other racial and ethnicity groups (e.g., American Indian and Alaska Native, Native Hawaiian and Pacific Islander) in this study because their share of the total population is relatively small in the sampled urban areas.

Second, we considered two SES factors: income and educational attainment. We chose the median household income as it efficiently represents the typical level of the economic status of households in a neighborhood, not being affected by the extreme ends of the distribution. For educational attainment, we computed the percentage of people older than 25 years of age with a bachelor's degree or higher.

Lastly, we included two age-related variables: the percentage of people under 18 years of age (children and teenagers) and the percentage of people older than 65 years (older adults). These two age groups have limited mobility and fewer transportation choices than young adults and, thus, might require enhanced accessibility to recreation opportunities and other key destinations. Particularly, seniors and children living in marginalized neighborhoods are likely to have a higher level of obesity [94,95]. Nevertheless, many environmental justice studies focus on adults [96], and some seniors and children experience a lack of access to opportunities (seniors and healthy food: [97]; children and parks: [98]).

In addition to the seven sociodemographic variables of interest, we included several block group- and region-level control variables in our models (Table 3). As our study sample includes urban areas of various sizes and characteristics, it is essential to control for built environment characteristics (region and block group levels) and SES at the regional level. Studies revealed poorer walking access to neighborhood parks in areas with a lower population density [31,32,52]. Furthermore, park acreage is lower in cities with lower SES, and the quality of urban park systems is lower in cities with higher percentages of minority residents [52,99]. Thus, at the regional level, we included population density, median household income, and the percentage of non-Hispanic white people as control variables. Additionally, we incorporated a block-level population density variable to account for within-region variance in density. Table 1 (urban area level) and Table 4 (block group-level) show the averages of variables included in this study.

Table 4. Block-group-level averages of sociodemographic variables by urban area.

Urban Area	# Block Groups	Percent NH Black (%)	Percent NH Asian (%)	Percent Latino/a (%)	Med HH Inc	Percent Bachelor (%)	Percent Child (%)	Percent Older (%)	Pop Den
Seattle	2153	6%	13%	10%	91,312	43%	21%	14%	6852
Salt Lake City	600	2%	4%	18%	75,413	35%	25%	12%	6022
Fresno	390	6%	11%	47%	54,749	21%	27%	13%	6373
Minneapolis	1907	10%	7%	7%	80,476	44%	22%	14%	5352
Kansas City	1130	18%	3%	12%	65,886	35%	23%	14%	3679
Grand Rapids	356	11%	3%	12%	61,271	34%	24%	13%	4338
Houston	2352	18%	7%	41%	70,550	30%	25%	11%	6392
Raleigh	407	19%	6%	9%	82,361	52%	22%	13%	3063
Sarasota	431	6%	2%	12%	58,256	31%	14%	36%	3120
Boston	3008	8%	8%	12%	95,001	48%	20%	15%	10,956
Providence	864	6%	3%	14%	66,719	31%	20%	17%	6578
Buffalo	787	17%	3%	6%	54,645	30%	20%	17%	6129

2.5. Data Analysis: Spatial Filtering Regression Models

We modeled each green space accessibility measure as a function of sociodemographic variables of interest and other control variables (Table 3). Our study sample consists of neighborhoods from 12 regions, and the neighborhoods in a region share similar regional characteristics (e.g., compactness, climate, transportation network). Thus, to represent the nested structure of the sample, we employed multi-level models, with block groups at Level 1 and the urban area at Level 2. For example, a modeling equation for the XS variable is as follows:

$$XS_{ij} = \beta_{0j} + \beta_{1j}Race_{ij} + \beta_{2j}Socioeconomic_{ij} + \beta_{3j}Age_{ij} + \beta_{4j}Control_{ij} + \varepsilon_{ij}$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01}Control_j + u_{0j};$$

$$\beta_{1j} = \gamma_{10} + u_{1j}; \ \beta_{2j} = \gamma_{20} + u_{2j}; \ \beta_{3j} = \gamma_{30} + u_{3j}; \ \beta_{4j} = \gamma_{40} + u_{4j}$$

where XS_{ij} refers to the accessibility to XS green space for block group i in region j, and β_{0j} is the intercept of the dependent variable in region j. β_{1j} and $Race_{ij}$ represent a set of race/ethnicity-related coefficients and variables, respectively, for block group i in region j. Similarly, β_{2j} and $Socioeconomic_{ij}$ indicate coefficients and variables of income and educational attainment, β_{3j} and Age_{ij} are components of children and senior population, and β_{4j} and $Control_{ij}$ are for a block-group-level control variable we included. ε_{ij} is the block group level residual. The intercept in the Level 1 equation (β_{0j}) consists of the level 2 intercept for each covariate (γ_{00}), the level 2 coefficient (γ_{01}) and control variables such as population density and median household income ($Control_j$), and the level 2 residual (u_j).

We examined the presence of spatial autocorrelation in our data through preliminary non-spatial multi-level regression models. When a dataset displays spatial autocorrelation—the tendency where areas close to each other have similar residual values—it violates the assumption of the independence of residuals in regression models and leads to inflated effect sizes. Our preliminary analysis showed spatial autocorrelation; thus, we used spatial filtering approaches that separate the redundant effects of a variable caused by spatial dependency [100]. Spatial filtering finds latent spatial patterns in the independent variables and creates eigenvectors that show the level of spatial autocorrelation [101]. Through this method, we extracted eigenvectors that reduce spatial autocorrelation in the residuals and used them as additional control variables in the regression models [102]. Although there are other modeling approaches capable of addressing spatial autocorrelation—such as spatial lag, spatial error, and geographically weighted regression models—the spatial filtering technique has three advantages: (1) it can be applied to a generalized linear model specification (e.g., nominal or skewed variables), and is thus more flexible; (2) it has no multicollinearity issues; and (3), most relevant to this study, it allows for multilevel modeling [100,103].

We ran two sets of models: the main models for the entire sample and individual models for each urban area (also referred to as 'regional models'). We ran all of the models in R 4.0.0. For the main model, we used the *meigen* and *resf* functions in the *spmoran* package to extract Moran's eigenvectors and run spatial regression models with random effect eigenvectors, respectively. For the regional models, we employed the *meigen* and *esf* functions in the same package to find eigenvectors and run a linear eigenvector spatial filtering model. Through the spatial filtering approach, we successfully removed the effect of spatial autocorrelation for all of the main and region-wide models. Following Griffith's [100] thresholds for autocorrelation levels, the scaled Moran's I values for the residuals of all of the models only showed slight-to-weak autocorrelation, ranging between 0.01 and 0.29.

3. Results

3.1. Main Models for the 12 Urban Areas

Table 5 summarizes the multi-level spatial filtering model results for the 12 urban areas, with shaded cells showing statistically significant results for environmental injustice (orange) and justice (green). The results for access to XS green space show environmental injustices based on race/ethnicity and income. Specifically, wealthier neighborhoods have access to more XS green space, whereas areas with larger percentages of racial/ethnic minority residents (i.e., Hispanic, non-Hispanic Black, and non-Hispanic Asian) have less XS green space. Neighborhoods with a higher share of older adults or children have more street greenery, showing just outcomes for the two examined age subgroups.

Table 5. Multi-level spatial filtering model results for 12 urban areas (dependent variables: green space accessibility).

Variables	XS	S–L_Walk [1]	S–L_Bike [1]	XL_Walk [1]	XL_Bike [1]	XL_Drive [1]
Intercept	−1.00 ***	−8.63	−14.46 *	0.78	−9.98	−10.23 ***
Percent NH Black	−0.05 ***	0.98 ***	0.56 ***	0.79 ***	1.45 ***	0.02
Percent NH Asian	−0.12 ***	−0.91 **	−0.11	0.10	0.83 ***	0.15 ***
Percent Latino/a	−0.07 ***	0.99 ***	0.63 ***	0.41 *	0.27 *	−0.02
Med HH Inc [1]	0.05 ***	−0.59 ***	−0.42 ***	−0.08	0.03	0.00
Percent College	0.00	1.74 ***	0.98 ***	1.14 ***	0.69 ***	0.07 *
Percent Child	0.13 ***	−0.96 *	−0.80 ***	−0.10	−0.59 **	−0.14 **
Percent Older	0.15 ***	−0.78 *	0.31	0.07	0.02	0.01
Pop Den [1]	0.06 ***	0.93 ***	0.52 ***	−0.14 ***	0.09 ***	0.04 ***
Reg Pop Den	0.04	0.04	1.38	−0.01	1.02	2.11 **
Reg Percent NH White	0.10	2.35	−0.58	1.42	0.16	2.45
Reg Med HH Inc	0.00	0.06 *	0.20 ***	0.02	0.15 ***	0.19 ***
Adjusted R²	0.62	0.29	0.45	0.09	0.28	0.90

[1] Log-transformed variable; * $p \le 0.05$; ** $p \le 0.01$; *** $p \le 0.001$; shaded cells show statistically significant results for environmental injustice (orange) and justice (green) ($p \le 0.05$).

Walking access to S–L parks also shows both environmental justice and injustice outcomes among different sociodemographic variables. Walking access to S–L green space is higher in areas with lower incomes and a larger share of non-Hispanic Black residents or Latino/a residents, showing environmentally just outcomes. However, walking accessibility to S–L green spaces is lower in neighborhoods with larger percentages of non-Hispanic Asians, older adults, or children, showing environmental injustice for those groups. Biking access to S–L green space shows environmentally just outcomes for the percentage of non-Hispanic Black people, the percentage of Latino/a people, and household income, but it also highlights injustice regarding educational attainment and the percentage of children. Indeed, areas with larger shares of college-educated residents and smaller percentages of children have higher bicycling access to S–L green space.

Walking access to XL parks increases with the percentage of people holding a bachelor's degree or higher, representing injustice related to educational attainment, but also shows an increase with the percentage of non-Hispanic Black and Latino/a people, showing just access to XL green space for these minority groups. Bicycling access to XL green spaces increases with larger shares of college-educated people and smaller shares of children, but larger shares of Black or Asian residents are associated with higher cycling access to XL parks. Driving access to XL green space shows similar patterns; no injustice was found regarding race/ethnicity (larger shares of Asian residents mean higher access), but a larger percentage of college-educated residents and a lower percentage of children are associated with higher driving access to XL green space.

Population density is statistically significant in all of the main models (see Table 5). All of the XS and S–L accessibility measures were greater in denser neighborhoods, possibly due to more investments in green spaces in areas with more people. On the contrary, walking access to XL green spaces decreases with population density, which is attributable to large parks commonly existing at the fringe of cities, where density is low. Nevertheless, when faster travel modes (bicycling or driving) are available and reachable distances increase, access to XL nature again increases with population density, implying that denser neighborhoods might be located near XL nature.

Regional population density and the percentage of non-Hispanic white people were not significant in any model, except for the positive relationship between regional population density and driving access to XL nature. This shows that neighborhood-level differences in population density and race/ethnicity matter more for green space accessibility than city-level differences. On the contrary, regional income levels present a positive association with most accessibility measures, except for bicycling access to XL green spaces, meaning that cities with wealthier residents tend to provide residents with better access to green spaces of various sizes.

3.2. Regional Models

Table 6 presents the results of spatial filtering regression models for each urban area. All the examined regions show clearer patterns of environmental justice and injustice in XS greenery accessibility compared to larger-scale accessibility measures. In particular, we found injustices related to race/ethnicity and SES for access to XS nature across almost all regions (see Appendix B for regional model results). Additionally, neighborhoods with larger shares of seniors and children enjoyed better XS greenery access in most regions, indicating just outcomes for these age groups.

In terms of S–L and XL accessibility, environmental (in)justice patterns are less clear. This might be attributable to more systematic provisions of green spaces intended to serve neighborhoods (S–L) and the region (XL) within an urban area, compared to street-level greenery. Nevertheless, bigger cities (e.g., Houston, Minneapolis, Boston) experience injustices associated with race/ethnicity and socioeconomic status. For example, in Minneapolis, all racial/ethnic minority groups have poorer bicycling access to S–L nature. In Boston, areas with larger shares of Asian or Latino/a residents have lower walking access to S–L green space, and areas with larger percentages of Black people have access to less XL green space within driving distance.

Table 6. Environmental justice and injustice types [1] in regional models of green space accessibility [2].

Urban Area	XS			S–L_Walk			S–L_Bike		
	Race [3]	SES [4]	Age [5]	Race	SES	Age	Race	SES	Age
Seattle	InJ(3)	InJ(1)	J(1)		J(1)				
Salt Lake City	InJ(3)	InJ(1)	J(2)						
Fresno	InJ(2)	InJ(2)	J(1)						
Minneapolis	InJ(3)	Mix(1/1)	J(1)	InJ(3)	J(1)				
Kansas City	InJ(3)	Mix(1/1)	J(2)			InJ(1)		J(1)	
Grand Rapids	InJ(1)	InJ(1)	J(1)						
Houston	InJ(3)	Mix(1/1)	J(2)		InJ(1)		InJ(2)		
Raleigh	InJ(1)	InJ(1)	J(1)						
Sarasota	InJ(2)	InJ(1)	InJ(1)						
Boston	InJ(3)	InJ(2)	J(2)	InJ(2)	J(1)				J(1)
Providence	InJ(3)	InJ(2)	J(1)		J(1)				
Buffalo	InJ(2)	InJ(2)	J(1)						
Total InJ types by EJ construct	29	16	1	5	1	1	2	0	0

Urban Area	XL_walk			XL_drive			Total InJ types by city		
	Race	SES	Age	Race	SES	Age	Race	SES	Age
Seattle							3	1	0
Salt Lake City							3	1	0
Fresno							2	2	0
Minneapolis		InJ(1)					6	2	0
Kansas City							3	1	1
Grand Rapids							1	1	0
Houston	J(1)			InJ(1)			6	2	0
Raleigh	J(1)	InJ(1)				J(1)	1	2	0
Sarasota							2	1	1
Boston		J(1)		InJ(1)	J(1)	Mix(1/1)	6	2	1
Providence							3	2	0
Buffalo			J(1)				2	2	0
Total InJ types by EJ construct	0	2	0	2	0	1	38	19	3

[1] J(#) refers to the presence and number of a just relationship(s), InJ(#) means the presence and number of an unjust relationship(s), and Mix(J#/InJ#) is a combination of J and InJ relationship(s). [2] Results from XL_bike models are not shown because they rarely have statistically significant coefficients across 12 models. [3] Race/ethnicity variables: % of non-Hispanic Black population, % of non-Hispanic Asian population, and % of Latino/a population. [4] Socioeconomic status variables: Median household income, % of people with a bachelor's degree or higher. [5] age-group variables: % of child population (<18 years), % of older adult population (≥65 years). Shaded cells show statistically significant results for environmental injustice (orange) and justice (green) ($p \leq 0.05$).

4. Discussion and Conclusions

4.1. Summary of Findings

In this study, we evaluated green space accessibility in 12 urban areas in the U.S. based on the 'just sustainabilities' framework. Access to green spaces promotes urban residents' quality of life and contributes to the creation of just and sustainable cities [53–55]. However, green spaces of different sizes might have diverse environmental and health benefits [1,3,18]. Thus, we distinguished three types of urban nature (XS, street greenery; S–L, neighborhood parks; and XL, large parks), measured six different green space accessibility variables defined by three travel modes (walking, bicycling and driving), and examined whether access to those green spaces is environmentally just, using neighborhoods' racial/ethnic, socioeconomic, and age characteristics as indicators for potential just or unjust access.

Our results from spatial filtering models across the 12 urban areas show that significantly less street greenery (XS) is available to racial/ethnic minority groups (e.g., Black, Asian, and Latino/a) and low-income residents, as is consistent with earlier studies [24,25,27]. This pattern of injustice is also found in most regional models, representing prevalent race/ethnicity-based and income-based injustice in 'everyday green' across the country. Research has shown that volunteer groups and nonprofit organizations might contribute to injustices in tree canopy cover, as those groups tend to be more active in affluent non-Hispanic white neighborhoods than in low-income minority communities [61,104]. Further, our results on XS nature can be tied to the ongoing legacy of structural racism in the U.S. A recent study shows that neighborhoods that were 'redlined' (i.e., targeted for disinvestment by banks) starting in the 1930s have 21% less tree canopy cover than neighborhoods that banks deemed desirable, on average [50]. Redlined neighborhoods were, and still are, mostly inhabited by low-income people of color [33,50,105]. Due in part to their lower tree canopy cover, redlined areas tend to be hotter and more vulnerable to extreme heat events than other neighborhoods [105].

Unlike access to street greenery, results about access to neighborhood parks (S–L) display more just patterns across the examined regions in terms of race/ethnicity (except for the percentage of Asians) and income level. Nevertheless, regional models highlight that some bigger regions (e.g., Minneapolis, Houston and Boston) experience racial/ethnic or income injustices in access to neighborhood parks. Furthermore, the main models with the 12 cities show that neighborhoods with larger shares of educated people, smaller shares of children, or smaller shares of seniors tend to have better access to neighborhood parks, regardless of travel mode. Overall, our results for neighborhood parks do not reflect those of two recent literature reviews focusing on such parks in the Global North and Global South, which show consistent injustices in park acreage based on race/ethnicity and socioeconomic status [21,22]. Our results are more aligned with those of a recent empirical study focusing on 10 U.S. cities, finding mixed results for socioeconomic status and race/ethnicity [25]. These discrepancies might be because, like Nesbitt et al. [25], we control for several possible confounders (e.g., population density), whereas many studies included in the two aforementioned reviews did not account for such confounders (see [21,22]).

Our main models on access to large parks (XL) show similar patterns of environmental (in)justice: more instances of just access in terms of race/ethnicity, but also injustices associated with educational attainment and the share of children. Regional models present more nuanced findings, illustrating access to large parks and related environmental justice issues greatly depend on which region people live in. For example, in Houston and Boston, neighborhoods with larger shares of Black people have poorer driving access to large parks. Our findings somewhat conflict with the few available studies on access to large parks, which have shown some injustices based on race/ethnicity and socioeconomic status (e.g., [31,32,34]). As for the divergent findings for S–L nature, in the current study, we control for possible confounders (e.g., population density), whereas many previous studies on XL nature did not. Thus, previous studies might have found injustices in access to large parks because higher shares of affluent and non-Hispanic white people live in areas with low population density (often at the edges of urban areas), where many large parks are located.

4.2. Access to Green Space and 'Just Sustainabilities'

Taken together, the findings of the present study advance our understanding of just sustainabilities in relation to urban green space. Here, we focus on how our findings on environmental (in)justice intersect with the 'just sustainabilities' conditions [35] that more closely relate to the concept of sustainability: ensuring that the needs of current and future generations are met, and living within the limits of our planet's ecosystems. Specifically, green spaces of different sizes and types can provide diverse ecosystem services and other environmental benefits [106–108]. Thus, the findings of this study shed light on which demographic groups gain more environmental benefits from green spaces of different sizes, linking an analysis of environmental justice to environmental sustainability.

First, trees are considered to be a planning tool to slow down climate change and mitigate its negative impacts [109,110], and the consistent injustices we found for XS green space (representing street greenery including trees) are concerning in that regard. Indeed, the injustices of street greenery we identified in our study, combined with other environmental and economic injustices, might help explain that people of color and low-income people experience disproportionate impacts from climate change [59]. For example, marginalized groups tend to be more exposed to extreme heat and air pollutants than privileged groups, and trees can help mitigate the harmful impacts by lowering the local temperature and improving air quality [9,59,105].

Second, the mixed findings for S–L and XL nature—i.e., justice for some racial/ethnic minority groups and injustice based on educational attainment and age—are more reassuring for 'just sustainabilities' than the results for XS nature. Specifically, park size is associated with lower temperatures in surrounding areas [107,111,112] and increased ecological diversity [13,15]; thus, large parks (XL nature) bring more environmental benefits to nearby areas than neighborhood parks (S–L nature). Based on our results on walking access to large parks, non-Hispanic Black and Asian people might gain disproportionately large shares of these environmental benefits and related health benefits (just outcomes), which might contribute to addressing the health inequities borne by Black people in the U.S. (see [40]). However, people without a college degree and people under 18 years of age might have disproportionately low shares of the environmental and health benefits of S–L and XL nature (unjust outcomes).

Overall, the notable environmental injustices in the access to XS nature are the most problematic for 'just sustainabilities.' Indeed, street greenery represents nearby nature that should be the easiest to implement—i.e., all neighborhoods have streets where trees can be planted—whereas parks (and large parks specifically) are much more complicated to build in mature neighborhoods. Additionally, street greenery represents the 'everyday green' that people can experience without the need to travel to a destination (e.g., a neighborhood park), and thus XS nature can impact the quality of life significantly [20,113]. Furthermore, the acceleration of climate change makes street trees and greenery in marginalized neighborhoods fundamental tools for climate justice [114].

4.3. Strengths, Limitations, and Future Research

A primary strength of this study lies in its comprehensive analysis of access to green space through the 'just sustainabilities' framework, thus considering the intersections of justice and environmental sustainability. This study adds to the park accessibility literature by analyzing multiple scales of green spaces—from XS (street greenery) to XL (large parks)—in several urban areas across the U.S. Beyond studying walking access to neighborhood parks (e.g., a 10-min walk; https://10minutewalk.org/), our analyses also cover bicycling and driving access to larger parks, as well as a daily dose of urban nature at the street level. The latter (XS nature) may be enjoyed sensibly (mostly visually) through any mode of transportation when someone travels around their neighborhood. Examining the accessibility to different scales of green spaces via different travel modes can both advance our understanding of distributional (in)justice outcomes and help green space organizations to develop strategies to address injustices.

The use of multi-level spatial filtering models is another strength of our analyses. Previous studies about inequity in access to parks mostly relied on exploratory spatial analyses [24,31–34] or spatial regression models with a spatial lag or error term [25,26,28,30]. The multi-level spatial regression models we use can address the spatial clustering effect of green space access within a region while separating between-region variations from within-region variations. Spatial filtering is particularly useful when the dependent variable, a measure of green space accessibility, is not normally distributed (e.g., positively skewed, a large number of zero values), as it was the case in our data [100].

Our study entails several limitations that can be addressed in future research. First, we did not consider green space quality, including the presence of amenities and tree canopy in parks, and quality has increasingly been studied as a key aspect of environmental justice (e.g., [32,115]).

Second, different demographic groups tend to have various levels of mobility, mode choice, and safety barriers for some transportation modes. In particular, 'transportation disadvantaged' individuals (e.g., people with disabilities, low-income people, seniors, children) may lack access to personal automobiles and rely more on other transportation modes, such as public transit or paratransit to get to urban nature [116]. Further, Black and Latino/a people in the U.S. are significantly more likely to be killed in cycling crashes than non-Hispanic white people [117]. Thus, universally-accessible road environments, varying travel thresholds, road safety, and public transit accessibility may be additional considerations in future research about green space access. Third, we did not control for zoning or land use due to differences in land use classifications among the 12 urban areas, and block groups with industrial land uses might have fewer parks [118]. Lastly, in addition to park supply, park demand (i.e., the surface of parks divided by the potential number of park users) might also be an important measure to evaluate environmental justice in green space access. Residents in different neighborhoods might compete for the same green space, especially regional parks (i.e., XL nature). High levels of crowding in a green space may be particularly harmful when people try to maintain social distancing in public space during a pandemic (e.g., COVID-19: [119]). Thus, beyond our 'absolute accessibility' measures, future work could also focus on 'relative accessibility' to green space, which is measured by standardizing green space quantity by population size [120,121].

4.4. Implications

This study has a series of implications for urban planners, policymakers, and green space advocates. First, our results show that environmental justice outcomes vary by green space size. In other words, green space size matters for justice outcomes, and planning efforts to address injustices need to consider each city's existing access to XS, S–L, and XL green spaces. For example, we found that Minneapolis experiences racial/ethnic-based injustices for XS and S–L green space, but not for XL green space. Justice-oriented efforts to improve access to green space in racial/ethnic minority neighborhoods in that city should focus on street greenery (XS) and neighborhood parks (S–L). Thus, the results of our study suggest that the first important step to reverse environmental injustices for green spaces is analyzing for which types of green space injustices exist.

Second, we found that environmental injustices in street greenery (XS green space) are the most consistent across the 12 cities we studied. Cities around the world have recently implemented tree planting initiatives, motivated in part by climate change mitigation goals [122,123]. Specifically, programs in New York (MillionTreesNYC) and Los Angeles (MillionTreesLA) aimed to plant one million trees in areas with low levels of tree canopy [122,123]. However, only Los Angeles' program moved the needle toward environmental justice, as more trees were planted in racial/ethnic minority neighborhoods than in non-Hispanic white neighborhoods [122]. This shows that these programs need to have clear criteria about socioeconomic status, race/ethnicity, and even age to ensure that the existing injustices are addressed [122]. Furthermore, although research has shown that nonprofit organizations have contributed to increased injustices in tree canopy cover in some cities [61,104], some nonprofits in Los Angeles are doing just the opposite, by planting trees in marginalized communities [124]. Thus, public agencies that distribute grants to urban forestry nonprofits (see [125]) should prioritize nonprofits working in low-income communities of color to help reverse the legacies of structural racism regarding tree canopy cover.

Third, we also found some injustices for neighborhood parks (S–L) and large parks (XL), although they are less frequent than for street greenery (XS) across our sample of 12 cities. Effective work to address injustices in access to neighborhood parks has included public agencies prioritizing funding in low-income, park-poor communities [37] and nonprofits using sophisticated strategies to build new parks in such communities [55]. Furthermore, because building large parks is much harder than neighborhood parks due to the difficulty of securing large plots of land in mature neighborhoods, possible solutions include tailored transportation services, such as transit-to-parks programs (see [126]).

Yet we urge policymakers, planners, and advocates, to prioritize efforts to increase walking access to green spaces, as most of their environmental benefits are detected in their proximity (see [127]).

Finally, green space programs motivated by environmental sustainability alone, without concerns about 'just sustainabilities,' are likely to result in unjust outcomes for marginalized people, as shown by research on the 'sustainability fix' (see [128]). Specifically, 'sustainability fix' initiatives tend to prioritize the values of elected officials, business groups, and lobby groups over those of marginalized communities, such as low-income people and people of color [128]. As a result, urban greening initiatives, such as the construction of new parks and tree plantings in low-income and racial/ethnic minority neighborhoods, have resulted in green gentrification, which describes the influx of new wealthier residents and the increase in housing prices after greening has been implemented [129–131]. The boomerang of green gentrification shows the importance of using a 'just sustainabilities' approach to urban greening initiatives in marginalized neighborhoods, including coupling greening with initiatives to protect and produce affordable housing for longtime, low-income residents [35].

Appendix A. Green Space Accessibility by Urban Area

The observed green space accessibility measures vary by urban area. With regard to walking and biking access, larger urban areas tend to have a better green space accessibility, on average, but also show greater within-region variation. In addition, driving access to XL green space is noticeably higher in Salt Lake City and Grand Rapids, compared with the other ten regions.
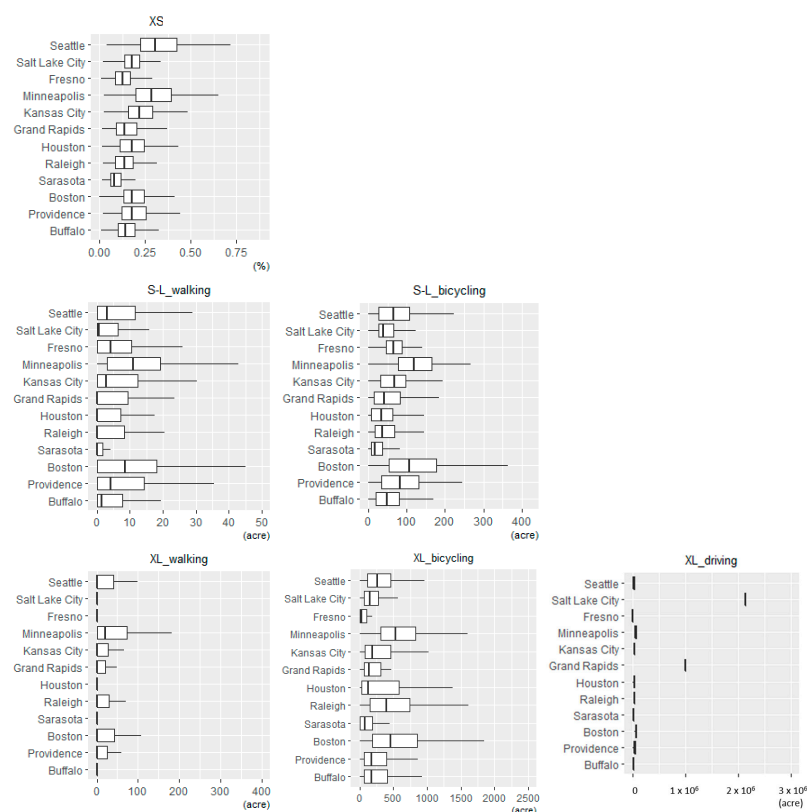

Figure A1. Box plots of XS, S–L, and XL green space accessibility by urban area (some outliers are not present in the graphs because we adjusted the *x*-axis dimensions to highlight regional variables)

Appendix B. Regional Models

Table A1. Spatial filtering model results by urban area (cities in West and Midwest regions).

Urban Area	Seattle						Minneapolis					
Variables	XS	S–L_walk	S–L_bike	XL_walk	XL_bike	XL_drive	XS	S–L_walk	S–L_bike	XL_walk	XL_bike	XL_drive
Intercept	−1.11 ***	−11.30 ***	2.61 **	7.52 ***	5.88 ***	10.23 ***	−1.30 ***	−10.13 **	4.45 ***	−1.62	6.62 ***	11.07 ***
Percent NH Black	−0.08 **	−1.53	−0.37	−0.64	−0.64	−0.17	−0.20 ***	−1.84 *	−0.22	−0.13	−0.20	−0.03
Percent NH Asian	−0.14 ***	0.59	0.25	−0.08	−0.08	0.16	−0.18 ***	−2.37 *	−0.10	−0.26	0.12	−0.02
Percent Latino/a	−0.10 ***	−1.14	−0.20	0.17	0.17	−0.04	−0.12 ***	−2.45 *	−0.01	0.31	0.17	0.10
Med HH Inc	0.07 ***	0.47	−0.03	−0.12	−0.12	0.01	0.08 ***	0.51	−0.07	0.29	−0.12	−0.02
Percent College	0.03	−1.72 *	−0.46	−0.18	−0.18	−0.02	−0.10 ***	−1.46 *	−0.14	1.91 ***	−0.35	0.08
Percent Child	0.05	−0.39	0.09	−0.22	−0.22	−0.23	0.09 **	1.86	−0.26	−1.56	−0.72	0.01
Percent Older	0.15 ***	0.82	0.47	0.25	0.25	−0.29	0.03	1.46	−0.43	0.51	−0.40	−0.06
Pop Den	0.08 ***	0.68 ***	0.17 ***	0.10 *	0.10 *	0.04 *	0.10 ***	0.73 ***	0.14 ***	0.04	0.16 ***	0.00
Adjusted R^2	0.75	0.43	0.80	0.28	0.64	0.95	0.70	0.22	0.42	0.27	0.52	0.52

Urban Area	Salt Lake City						Kansas City					
Variables	XS	S–L_walk	S–L_bike	XL_walk	XL_bike	XL_drive	XS	S–L_walk	S–L_bike	XL_walk	XL_bike	XL_drive
Intercept	−0.86 ***	−5.05	1.08	1.07	0.55	14.57 ***	−0.59 ***	−3.68	2.04	−2.11	4.43 **	10.35 ***
Percent NH Black	−0.13 *	−0.50	0.07	−2.57	1.30	0.00	−0.13 ***	0.35	0.27	0.97	0.22	−0.01
Percent NH Asian	−0.10 **	−0.41	−0.52	0.52	−1.73	0.00	−0.24 ***	−2.35	0.11	0.23	−0.88	0.02
Percent Latino/a	−0.06 **	−1.17	−0.04	−0.65	−0.48	0.00	−0.07 **	0.59	0.10	0.32	−0.16	−0.02
Med HH Inc	0.04 ***	0.32	0.16	0.30	0.52	0.00	0.03 ***	−0.13	−0.08	0.26	0.05	0.00
Percent College	−0.01	−1.23	−0.68	−0.02	−1.54	0.00	−0.05 *	−0.65	−0.73 *	0.47	−0.22	−0.01
Percent Child	0.07 *	1.14	0.01	−0.19	0.24	0.00	0.10 ***	−3.45 *	−0.76	0.11	−0.07	−0.04
Percent Older	0.13 ***	−0.23	−0.11	0.07	2.28	0.00	0.10 ***	−1.36	0.81	0.88	0.10	0.02
Pop Den	0.06 ***	0.01	0.11 *	−0.35 *	−0.04	0.00 **	0.06 ***	0.63 ***	0.36 ***	0.02	0.03	0.01 **
Adjusted R^2	0.97	0.31	0.70	0.31	0.71	0.97	0.72	0.27	0.64	0.21	0.63	0.97

Urban Area	Fresno						Grand Rapids					
Variables	XS	S–L_walk	S–L_bike	XL_walk	XL_bike	XL_drive	XS	S–L_walk	S–L_bike	XL_walk	XL_bike	XL_drive
Intercept	−0.66 ***	−13.93	1.45	−1.93	4.65	8.29 ***	−0.64 ***	−4.02	5.31	−0.49	3.58	13.81 ***
Percent NH Black	−0.06	6.09	0.38	1.23	−0.69	0.00	−0.05	−3.29	−1.09	1.31	0.20	0.00
Percent NH Asian	−0.10 ***	−0.49	0.31	1.02	−0.52	0.00	−0.01	−6.58	−1.32	−3.56	−4.08	0.00
Percent Latino/a	−0.05 *	−2.11	0.32	0.27	−0.84	−0.01	−0.11 **	−0.74	−1.48	−1.07	0.91	0.00
Med HH Inc	0.04 ***	1.02	0.12	0.09	−0.24	−0.01	0.03 **	−0.39	−0.38	0.20	0.18	0.00
Percent College	0.07 **	−3.54	−0.22	−0.38	0.43	0.02	0.01	−0.71	−1.03	1.17	−0.61	0.00
Percent Child	0.00	0.52	−0.33	0.28	−0.01	0.01	0.05	0.85	1.05	−0.41	0.76	0.00
Percent Older	0.08 *	−2.97	0.26	0.01	−0.49	0.00	0.08 *	−2.74	1.73	0.20	0.61	0.00
Pop Den	0.04 ***	0.48	0.14 **	0.13	0.11	0.00	0.05 ***	0.90 **	0.25	−0.11	−0.05	0.00
Adjusted R^2	0.68	0.10	0.75	0.39	0.68	0.50	0.70	0.42	0.59	0.13	0.59	0.91

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; shaded cells show statistically significant results for environmental injustice (orange) and justice (green) ($p \leq 0.05$).

Table A2. Spatial filtering model results by urban area (cities in South and Northeast regions).

Urban Area	Houston						Boston				
Variables	XS	S-L_walk	S-L_bike	XL_walk	XL_bike	XL_drive	XS	S-L_walk	S-L_bike	XL_walk	XL_bike	XL_drive
Intercept	−0.82 ***	−10.54 ***	3.30 **	5.12 **	2.56	10.30 ***	−0.63 ***	1.45	4.08 ***	11.32 ***	6.24 ***	10.98 ***
Percent NH Black	−0.14 ***	0.02	−1.13 ***	0.89 *	−0.36	−0.14 *	−0.03 *	−1.05	−0.18	0.46	−0.08	−0.02 *
Percent NH Asian	−0.17 ***	0.45	-0.22	−0.58	0.60	−0.14	−0.11 ***	−2.57 ***	−0.15	−0.39	−0.05	−0.01
Percent Latino/a	−0.08 ***	−0.14	−0.81 **	−0.01	−0.33	−0.09	−0.10 ***	−1.34 *	−0.21	−0.02	−0.02	−0.01
Med HH Inc	0.06 ***	0.53 *	−0.19*	−0.18	0.17	−0.01	0.03 ***	−0.61 ***	−0.08	−0.46 ***	−0.08	0.00
Percent College	−0.03 *	−0.34	0.24	0.23	−0.09	0.02	0.05 ***	0.05	0.27	0.04	−0.15	−0.02 **
Percent Child	0.05 **	0.24	−0.23	−0.05	−0.27	−0.08	0.15 ***	−0.19	0.49 *	0.02	−0.13	0.00 ***
Percent Older	0.21 ***	1.86	0.04	−0.78	0.20	0.03	0.18 ***	−1.35	−0.26	−1.04	-0.50	−0.04 ***
Pop Den	0.05 ***	0.25 *	0.22 ***	−0.25 ***	0.03	0.01	0.04 ***	0.75 ***	0.12 ***	−0.47 ***	0.11 ***	0.01 ***
Adjusted R²	0.56	0.38	0.76	0.30	0.69	0.77	0.51	0.45	0.69	0.33	0.62	0.98
Urban Area	Raleigh						Providence				
Variables	XS	S-L_walk	S-L_bike	XL_walk	XL_bike	XL_drive	XS	S-L_walk	S-L_bike	XL_walk	XL_bike	XL_drive
Intercept	−0.45 ***	−19.54 *	−2.96	5.06	1.26	10.54 ***	−0.68 ***	1.88	1.20	0.47	3.11 *	9.34 ***
Percent NH Black	−0.01	1.18	1.43	3.11 *	−0.69	0.01	−0.07 *	0.84	−0.39	1.75	0.58	0.04
Percent NH Asian	−0.09 *	3.31	1.73	−2.43	−0.44	0.00	−0.12 **	−1.21	0.18	1.65	0.04	0.09
Percent Latino/a	−0.05	0.17	0.86	1.61	−1.93	0.05	−0.05 *	−0.93	−0.74	1.06	0.10	0.12
Med HH Inc	0.02 **	1.45	0.07	−0.55	0.39	−0.02	0.03 ***	−0.71 *	0.03	0.16	0.08	0.09
Percent College	0.02	−1.16	1.74	3.36 *	−0.99	0.07	0.11 ***	1.93	−0.21	−0.39	−0.24	−0.10
Percent Child	0.03	1.18	0.70	0.16	−0.43	0.03	0.03	2.69	0.85	−0.54	0.26	0.26
Percent Older	0.13 ***	−0.50	1.80	2.06	0.38	0.14 *	0.12 ***	−0.13	0.66	0.20	0.03	0.17
Pop Den	0.04 ***	0.12	0.41 **	0.03	0.13	0.01	0.06 ***	0.54 **	0.27 ***	−0.11	0.10	−0.01
Adjusted R²	0.71	0.29	0.70	0.12	0.59	0.95	0.70	0.42	0.71	0.30	0.64	0.54
Urban Area	Sarasota						Buffalo				
Variables	XS	S-L_walk	S-L_bike	XL_walk	XL_bike	XL_drive	XS	S-L_walk	S-L_bike	XL_walk	XL_bike	XL_drive
Intercept	−0.37 ***	−7.07	3.08	5.91	4.25	10.08 ***	−0.42 ***	0.07	2.25	−5.58 *	4.04 *	9.19 ***
Percent NH Black	−0.03	0.06	−0.20	0.92	0.97	0.01	−0.08 ***	0.17	0.07	−0.46	0.80	0.01
Percent NH Asian	−0.12 *	6.51	−2.74	3.03	−0.83	0.16	−0.12 ***	−3.05	−0.01	0.81	1.10	0.01
Percent Latino/a	−0.03 *	0.63	1.67	1.18	0.17	−0.05	−0.02	0.53	0.17	0.43	0.70	0.02

Table A2. *Cont.*

Urban Area	Houston						Boston					
Med HH Inc	0.02 **	−0.03	−0.22	−0.17	−0.08	−0.06	0.01 *	−0.51	−0.06	0.46	0.02	0.00
Percent College	0.03	0.94	1.08	−1.60	−1.35	0.13	0.05 **	0.30	−0.29	0.71	0.06	0.00
Percent Child	−0.05	5.07	1.35	−1.59	−2.96	0.18	0.00	0.39	−0.61	−0.11	−0.32	−0.02
Percent Older	−0.05 ***	0.33	0.73	−0.22	−1.02	−0.03	0.08 ***	−0.86	0.92	2.30 *	0.82	0.01
Pop Den	0.03 ***	0.33	0.06	−0.34	0.21	0.01	0.05 ***	0.48 **	0.20 ***	0.14	0.01	0.00
Adjusted R^2	0.55	0.38	0.62	0.21	0.66	0.97	0.62	0.43	0.80	0.20	0.66	0.97

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; shaded cells show statistically significant results for environmental injustice (orange) and justice (green) ($p \leq 0.05$).

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