sustainability

MDPI

Review

Models and Methods for Quantifying the Environmental, Economic, and Social Benefits and Challenges of Green Infrastructure: A Critical Review

Yasser Jezzini, Ghiwa Assaf and Rayan H. Assaad *

Department of Civil and Environmental Engineering, Smart Construction and Intelligent Infrastructure Systems (SCIIS) Lab, New Jersey Institute of Technology, Newark, NJ 07102, USA; yj38@njit.edu (Y.J.); ga338@njit.edu (G.A.)
* Correspondence: rayan.hassane.assaad@njit.edu

Abstract: With growing urbanization and increasing climate change-related concerns, green infrastructures (GIs) are recognized as promising solutions for mitigating various challenges and promoting sustainable development. Despite the important role of GIs, a comprehensive synthesis of the quantification of their full range of benefits and challenges is lacking in the current literature. To address this gap, a systematic literature review was conducted on the quantifiable environmental, economic, and social benefits and challenges of GIs. This paper followed the Preferred Reporting Items for Systematic Review (PRISMA) methodology, where 75 relevant articles were reviewed to present the various models and methods that could be used to quantify and assess the impacts of different GI types. The study further investigated existing knowledge trends and patterns, identified research gaps, and suggested future research directions. The results revealed that while existing research studies offer great insights into the impacts of GIs, a more holistic approach is necessary to balance the benefits and challenges of GIs. The findings also offered a comprehensive understanding of a wide range of environmental, economic, and social considerations of both natural and engineered GIs. Ultimately, the performed literature review serves as a comprehensive guide for researchers and practitioners and could be used in estimating and evaluating the benefits and challenges of GI plans and programs as well as in making informed decisions about GI projects.

Keywords: green infrastructure; quantification methods; environmental; social and economic benefits; challenges

Citation: Jezzini, Y.; Assaf, G.; Assaad, R.H. Models and Methods for Quantifying the Benefits and Challenges of Green Infrastructure: A Critical Review. *Sustainability* **2023**, *15*, 7544. https://doi.org/10.3390/su15097544

Academic Editor: Antonio Caggiano

Received: 23 March 2023
Revised: 27 April 2023
Accepted: 28 April 2023
Published: 4 May 2023

1. Introduction

Urbanization is the growth of the population density in cities and urban areas. According to the United Nations [1], about 55% of the global population currently lives in urban areas, and this number is expected to increase to 60% by 2030. In the United States, 83% of the population currently resides in urban areas, and this is expected to grow to 89% by 2050 [2]. This trend is influenced by several factors, including the availability of economic opportunities, access to services and amenities, and the appeal of urban social lifestyles [3]. As urbanization continues to accelerate, cities are becoming home to a larger population. This phenomenon brings cities new opportunities and challenges such as the need for an appropriate infrastructure system and services to support the associated population growth [4,5].

Moreover, urban environments are characterized by the absence of vegetation, the proliferation of paved surfaces, and the disruption of drainage connectivity; all of which increase stormwater runoff [6]. Increased stormwater runoff, inadequate management of flood risk, and poor urban planning all contribute to the exacerbation of urban flooding

[7]. To address these challenges, many cities are now shifting towards green infrastructure (GI) to improve the sustainability and resilience of their urban environments [8].

The use of GI offers a range of environmental, economic, and social benefits. In terms of environmental benefits, the use of GI supports sustainable urban development and ecosystem resilience [9]. Green roofs, bioretention systems, and permeable pavements reduce stormwater runoff and improve water quality by infiltrating, retaining, and detaining water and reducing pollutant loads [10]. In addition to flood management, GI such as trees and vegetation provide shading and cooling through evapotranspiration which reduces surface and air temperatures and mitigates the Urban Heat Island (UHI) effect [11]. GI also supports biodiversity by providing habitat and food for wildlife [12]. Furthermore, urban areas with a high proportion of green spaces serve as effective carbon sinks [13]. This highlights the potential of GI in mitigating carbon dioxide emissions, purifying the air, and addressing climate change.

In addition to its environmental benefits, GI provides a range of economic benefits that contribute to the overall growth of a community. Property values in neighborhoods with access to green spaces tend to be higher than those without them [14]. In addition, the construction and maintenance of GI also stimulate economic development and create job opportunities [15]. Also, GI mitigates the UHI which results in the reduction of energy costs [16]. Moreover, GI provides cost savings through reduced stormwater management costs [17].

In terms of social benefits, parks increase participation in recreational and leisure activities [9]. Furthermore, green spaces help to enhance mental health and well-beingClick or tap here to enter text. Ref. [18] and reduce crime rates [19]. Additionally, GI strengthens community cohesion and social interaction [20].

While GIs (such as trees, parks, and gardens) bring many benefits to the environment and human health, they also have some challenges. One potential challenge is that exposure to green spaces increases the risk of certain health issues, such as allergies and asthma [18]. Trees and plants that provide shade during hot summer days also trap heat during the night, which is detrimental to human health [11]. Moreover, in arid climates, irrigation of GI can exacerbate water scarcity, which creates a trade-off between cooling and carbon storage as well as water scarcity management [15]. Additionally, policies focused on increasing green spaces can lead to the displacement of low-income communities, a phenomenon known as "green gentrification" [21].

That being said, and due to the increased implementation and need for GIs, there is a growing interest in understanding the benefits and challenges of GIs to effectively design, implement, and maintain them in urban areas. Although this has led to a high growth of research in this field, much of the current literature focuses on the qualitative aspects of GI, or on quantifying the benefits or challenges of a single GI type, rather than providing a comprehensive understanding of the overall range of several GI types with their associated benefits and challenges. To this end, and to fill this knowledge gap, the goal of this paper is to conduct a systematic review of the existing literature to better understand and quantify the environmental, social, and economic benefits and challenges of several types of GI. The associated objectives are to (1) investigate the trends and patterns in the existing body of knowledge; (2) identify gaps in the existing research; (3) and suggest directions for future work.

2. Methodology

This paper follows a systematic review methodology based on the Preferred Reporting Items for Systematic Review (PRISMA) framework [22] to examine relevant studies, summarize their findings, and identify research gaps in the literature. The systematic review provides a broader range of paper searching in an effective and transparent manner. The adopted methodology is divided into three steps as shown in Figure 1 and as detailed in the next sub-sections.

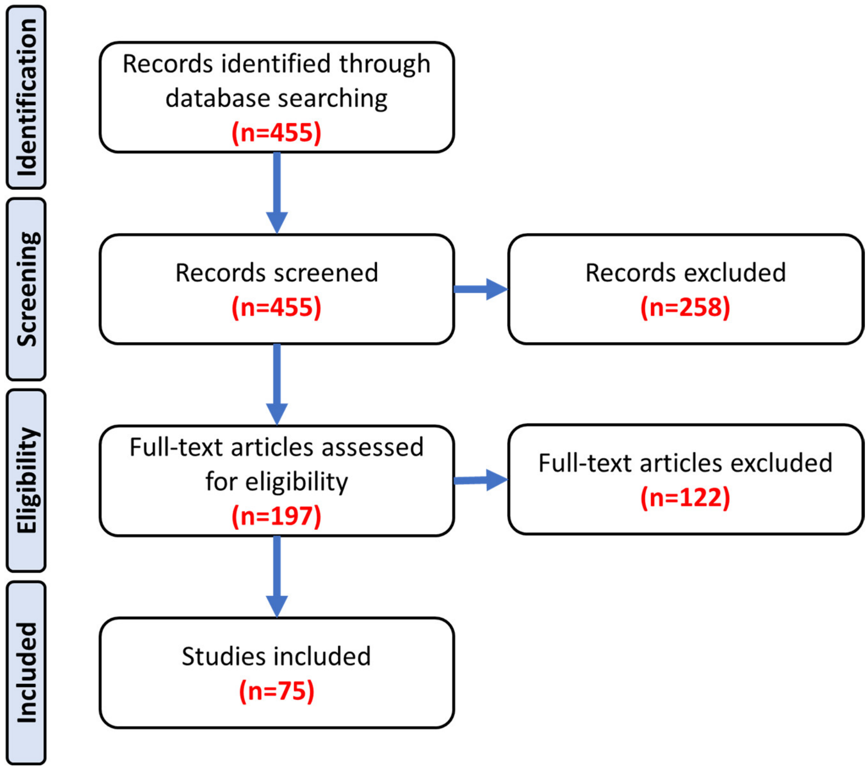

Figure 1. Systematic literature review methodology.

It is worth mentioning that the main goal of this review paper is to provide a guide on quantifying the main benefits and challenges of GIs based on well-established models, methods, or equations extracted from papers published in peer-reviewed journals. It is to be noted as well that many previous literature review studies have already focused on a specific aspect of GI. Hence, there is no need to reinvent the wheel. However, there is a gap in the current body of knowledge as there is no literature review study that was conducted to integrate the different benefits and challenges into one research study. Since GIs provide multi-dimensional benefits and challenges in different aspects including environmental, economic, and social, this creates some difficulties in properly planning and designing GI plans and programs since the effectiveness of such plans need to be quantitatively assessed on multiple facets so that different alternatives could be compared for an optimal plan to be identified and implemented. Therefore, the goal of this paper was to address this research need and knowledge gap by presenting a quantitative guide for decision-makers, urban planners, practitioners, and researchers to facilitate the planning and design of GIs.

2.1. Identification of Articles

The Scopus database was used to retrieve the articles to be reviewed in this paper. The Scopus database was selected because it provides comprehensive coverage of the articles in relevant journals and supports an advanced tool to search papers through a keyword search. A comprehensive search was carried out under the "Title, Abstract, Keywords" field using the following phrase: ("Green infrastructur*" OR "Green urban infrastructur*") AND ("Social*" OR "Economic*" OR "Environment*" OR "Benefit*" OR "Challenge*"). The adapted searching methodology ensured the selection of relevant articles related to social, economic, and environmental challenges and/or benefits of GIs. The selected articles were filtered to those written in English, but no restriction on the publication year was applied to ensure a comprehensive literature review. The first phase (i.e., the identification phase) led to the collection of 455 journal papers.

2.2. Screening of Articles

For the second phase, a preliminary screening was conducted based on the papers retrieved from the first phase to investigate their relevance to the scope of this study. During the screening phase, the focus was primarily on the abstracts due to their concise nature and ability to provide a summary of the main focus, goal, and objectives of the article, including other key information such as obtained results and findings. This allows us to efficiently determine the relevance of each article to the goal and scope of this literature review study. This phase led to the inclusion of 197 journal papers.

2.3. Eligibility of Articles

For the third phase, the full articles were further examined for eligibility. Existing literature on green infrastructure already includes several studies that have undertaken qualitative reviews on various benefits associated with green infrastructure, such as the work done by [15,23]. In fact, while the benefits and challenges of GIs are already known to practitioners and researchers, the quantifications of these benefits and challenges are not widely accessible or known to them. This is due to the lack of comprehensive quantitative literature reviews on the benefits and challenges of GIs. This creates some difficulties in planning and designing GI plans and programs since the effectiveness of such plans needs to be quantitatively assessed so that different alternatives could be compared in order for an optimal plan to be identified and implemented. Therefore, the goal of this paper was to present a quantitative guide for decision-makers, urban planners, practitioners, and researchers to facilitate the planning and design of GI. In relation to that, the authors have focused on models and methods that could be used in order to quantify the benefits and challenges of GIs. Thus, the articles that ultimately passed the eligibility criteria included those that have particularly focused on quantifying the benefits and/or challenges of GIs, whereas qualitative papers were excluded as they were not pertinent to the scope and goal of this literature review. This stage led to the inclusion of a total of 75 articles, where their content was fully reviewed, analyzed, and synthesized. Once the papers were identified, a detailed content analysis was carried out, and the following information was extracted: (1) GI solutions that fall within the focus of the study; and (2) the quantified environmental, economic, and social benefits and challenges of these GI solutions. It is worth mentioning that the equations used for the quantifications of the benefits and challenges of GIs were organized by broad categories to make it clearer to the readers. However, while some equations are correlated, or feed into each other; this is not necessarily the case for all equations. In relation to that, the equations were presented in a table format to better reflect which equations are related to each other and which ones are not.

3. Results

The results section is divided into five sub-sections to examine the following quantifiable impacts of GIs: environmental benefits, social benefits, economic benefits, environmental challenges, and social challenges.

3.1. Environmental Benefits

Based on the performed literature review, it was found that GIs provide several environmental benefits such as air purification, carbon sequestration, stormwater management, water purification, water harvesting, noise pollution reduction, biodiversity conservation, and soil stabilization. These benefits are quantified and detailed in the below subsections.

3.1.1. Air Purification

GIs, including vegetation and trees, can effectively filter and reduce air pollutants such as particulate matter (PM) in the environment. This is due to their ability to trap particles and facilitate pollutant deposition on their large surface areas [24]. Different green spaces have varying abilities to reduce the concentrations of PM with a diameter of 10 μm or less (PM_{10}). The mean PM_{10} reduction rate (in g/m^2/yr) for trees is 3.99, woodland is 2.73, tall shrub is 2.08, short shrub is 2.06, herbaceous is 0.91, private gardens is 0.83, agricultural land is 0.74, farmland is 0.92, forest is 6.2, and grassland is 2.7 [25,26]. Moreover, the average PM with a diameter of 2.5 μm or less ($PM_{2.5}$) removal rate for urban vegetation is 1.6 g/m^2/yr [26]. Additionally, trees reduce $PM_{2.5}$ concentration by up to 64.5 tons annually [13].

Green walls are effective in removing PM from the air as well, where the average number of particulate matters with a diameter of 1 micrometer or less (PM_1), $PM_{2.5}$, and PM_{10} captured on a 100 cm^2 green wall are 122.08 ± 6.9 × 107, 8.24 ± 0.7 × 107, and 4.45 ± 0.33 × 107, respectively [27]. Moreover, green roofs reduce the concentrations of PM, nitrogen dioxide (NO2), sulfur dioxide (SO2), and ozone (O3) by an average of 0.65, 2.33, 1.98, and 4.49 kg/m^2/yr, respectively [28].

Air purification capabilities of GI could also be analytically quantified using multiple measures such as (1) predicted percentage reduction in pollutant concentration (PPR), which could be estimated using Equations (1)–(3) in Table 1; (2) deposited pollutant mass for GI (F), as shown in Equations (4)–(6) in Table 1; (3) total particle number deposition ($ToND$), which could be calculated using Equation (7) in Table 1; and (4) the removal rate of $PM_{2.5}$ ($Q_{i,j}$) (see Equations (8) and (9) in Table 1).

Table 1. Quantified measures of air purification benefit of GI.

Quantified Measure	Equation		Definition	Reference
Predicted percentage reduction in pollutant concentration (PPR) in %	$PPR\ (\%) = \left(\frac{C_{NoGI} - C_{WGI}}{C_{WGI}} \times 100\right)$	(1)	PPR is a common measure to quantify the air purification capabilities of GI, where C_{NoGI} is the pollutant concentration at the area of study without GI (in μg/m^3) and it could be determined using Equation (2); and C_{WGI} is the pollutant concentration at the area of study with GI (in μg/m^3) and can be obtained from Equation (3).	[29]
	$C_{NoGI} = C_b + C_0 e^{(-d \times x)}$	(2)	C_{NoGI} is the pollutant concentration at the area of study without GI (in μg/m^3), where C_b is the background concentration or the constant concertation that pollution concertation converges to after mixing with air, C_0 is the initial concentration of pollutant on the roadway, d is its decay rate, and x is the defined proximity from the roadway (in m) in which the pollutant concentration is being calculated.	
	$C_{WGI} = \left(\left(C_0 e^{(-d \times y)}\right) \times \left(\alpha e^{-\beta \times LAD}\right) \times e^{-d \times z}\right) + C_b$	(3)	C_{WGI} is the pollutant concentration at the area of study with GI (in μg/m^3), where $\alpha e^{-\beta \times LAD}$ is assumed to be the effect of GI on the pollutant concentration reduction as a function of leaf area density (LAD; m^2/m^3), y is the distance (in m) from the roadway (source of pollution) to GI, z is the distance (in m) from GI to the area of study, and α and β are GI-induced reduction factors dependent on the pollutant and its interaction with the vegetation barrier.	

Deposited pollutant mass for GI (F) in g/m^2	$F = V_d . C_p . t . \text{f} . \text{r}$	(4)	F is a measure of the pollutants that are deposited onto vegetation leaves, where V_d is the deposition velocity (in m/s), C_p is the pollutant concentration (in g/m^3), t is the exposure time (in s), f is the leaf-on period indicator and is assumed 0.5 for deciduous trees or 1 for grassland and coniferous trees, and r is the resuspension rate assumed 0.5 for particulate pollutants to account for resuspension of pollutant particles back to the atmosphere. Moreover, V_d depends on the pollutant nature, whether it is a gaseous pollutant (i.e., NO_2) or particulate matter (i.e., PM_{10} and $PM_{2.5}$), and could be calculated using Equations (5) and (6), respectively.	[30]
	$V_d = \frac{1}{R_a + R_b + R_c}$	(5)	V_d is the deposition velocity (in m/s) for gaseous pollutants, where R_a is the aerodynamic resistance (in s/m), R_b is the quasi-laminar boundary layer resistance (in s/m), and R_c is the surface resistance (in s/m).	
	$V_d = V_s + \frac{1}{R_a + R_b + R_a R_b V_s}$	(6)	V_d is the deposition velocity (in m/s) for particulate matter, where R_a is the aerodynamic resistance (in s/m), R_b is the quasi-laminar boundary layer resistance (in s/m), and V_s is the particulate settling velocity (in m/s).	
Total particle number deposition ($ToND$) in #/cm^2	$ToND = ToNC_{intial} \times t \times f \times r \times (\text{f}_{Ait} \times v_{d,Nuc} + \text{f}_{Nuc} \times v_{d,Ait} + \text{f}_{Acc} \times v_{d,Acc})$	(7)	$ToND$ is another measure of the deposition process, where $ToND$ is expressed in terms of the initial total particle number concentration ($ToNC_{intial}$) in #/cm^2, annual deposition time (t =3.1 × 107 s), the fraction of the $ToNCs$ in a specific mode such as nucleation (f_{Nuc}), Aitken (f_{Ait}), and accumulation (f_{Acc}), and dry deposition velocities in a specific mode such as nucleation ($v_{d,Nuc}$) in cm/sec, Aitken ($v_{d,Ait}$) in cm/sec, and accumulation ($v_{d,Acc}$) in cm/sec.	[31]
The removal rate of $PM_{2.5}$ ($Q_{i,j}$) in g/m^2	$Q_{i,j} = \sum_{j=1}^{4} V_{dij} \times C_{ij} \times LAI_{ij} \times T_{ij} \times (1 - R_{ij})$	(8)	$Q_{i,j}$ is a measure of the urban vegetation deposition rate of $PM_{2.5}$, where V_{dij} is the deposition velocity of $PM_{2.5}$ in (m/s), C_{ij} is the concentration of $PM_{2.5}$ in (μg/m^3), LAI_{ij} is the vegetation leaf area index in (m^2/m^2), T_{ij} is the no-rainfall time (in s), R_{ij} is the resuspension rate (in %), i is the grid number (where the area of study is divided into grids), and j is a notation for the seasons in a year.	[26]
	$TQ_{annual} = \sum_{i=1}^{4} mean\_Q_k \times A_m$	(9)	TQ_{annual} is the annual total $PM_{2.5}$ removal (in g), $mean\_Q_k$ is the seasonal mean $PM_{2.5}$ removal rate of vegetation type (k) (in g/m^2), and A_m is the coverage area of vegetation type (k) (in m^2).	

3.1.2. Carbon Sequestration

Carbon sequestration is the capture and storage of carbon dioxide (CO_2) from the atmosphere and is a key process in mitigating climate change. GIs are considered effective techniques in carbon sequestration; Table 2 provides the carbon sequestration rate for different GI types.

Table 2. Carbon storage rate for different GI types.

GI Type	Carbon Storage Value	Unit	Reference
Tree	0.75, 7.69, 28.46	kgC/m^2	[13,25,32]
Woodland	28.46	kgC/m^2	[25]
Tall shrub	14.19	kgC/m^2	
Short shrub	10.23	kgC/m^2	
Herbaceous	0.15	kgC/m^2	
Private garden	0.79	kgC/m^2	
Agricultural land	0.1	kgC/m^2	
Vegetation	18, 26, 30.25, 31.4, 31.6, 60, and 141.4	tC/ha/yr	(Demuzere et al., 2014) [33]
Urban land	4.7, 7.2	tC/ha/yr	[13,33]
Forested wetland	147	tC/ha/yr	[33]
Tidal brackish wetland	92	tC/ha/yr	
Freshwater wetland	95	tC/ha/yr	
Tidal salt wetland	78	tC/ha/yr	
Green roof	165	kgC/m^2/yr	[28]

Moreover, the carbon sequestration monetary value (ψC) in USD/m^2/yr of GI could be calculated using Equation (10) [34].

$$\psi C = C_C \times e_c \times PR_c \times CG \quad (10)$$

where C_C is the mass of the carbon sequestered (in kg/m^2/yr), e_c is the conversion coefficient of carbon mass to CO_2 mass (could be taken as 44/12), PR_c is the cost of carbon sequestration (in USD/kgCO_2), and CG is the green space area (in m^2).

3.1.3. Cooling

The UHI effect is a phenomenon in which urban areas experience higher temperatures compared to their surrounding rural areas [35]. GIs mitigate the UHI effect through their ability to moderate urban air temperatures. For instance, the mean Land Surface Temperature (LST) of urban parks is 1.8 °C lower than the surrounding area on hot days [36]. In addition, a cooling of up to 4 °C is observed over 440 m around the park [35]. Also, urban parks have a cooling effect that extends over an area 5–9 times their area, with a maximum cooling distance of 151.4–300 m [36,37]. Moreover, the combination of green and blue infrastructure together has a cooling effect on the air temperature in the range of 7–12 m around the waterfront boundaries, with an average decrease of 3.3 °C higher than the individual cooling effects of water and forest alone [37].

The mean air temperature is significantly lower in areas with tree canopies compared to non-shaded sites on hot days, with temperature differences ranging from 0.11 to 1.75 °C during the day [38]. Furthermore, air temperature is estimated to drop by 0.02 °C for a 1% increase in the tree canopy cover [11]. Moreover, increasing vegetation cover by 10% and tree canopy by 16% can lower the surface temperatures in urban areas by up to 1 °C [11,39]. In addition, green roofs reduce indoor temperatures by 4–6 °C [39], and green walls reduce the interior surface temperature by more than 2 °C [13].

The cooling effect of GIs could generally be quantified in relation to their cooling capacity, and effect on the LST and air temperature. The next paragraphs detail how such quantifications could be performed.

The cooling capacity of GIs could be quantified by the cooling index (CI), the cooling capacity index (CC_i), the cooling capacity index for large green areas (CC_{ga}), and the heat mitigation index (HM_i), as shown in Equations (11)–(14) in Table 3, respectively. In addition to the previous measures, the cooling capacity of GIs could be also estimated using microclimate regulation measure (MR), universal thermal climate index ($UTCI$), and greening cooling services index, as shown in Equations (15) through (21) in Table 3.

Table 3. Quantified measures of GIs' cooling capacity.

Quantified Measure	Equation		Definition	Reference
Cooling index (CI)	$CI = \frac{T_c \times T_{mean}}{i \times 100}$	(11)	CI is a valuable measure for determining the optimal amount of urban green vegetation necessary to effectively cool summer temperatures, T_c is the tree cover density (in %), T_{mean} is the average summer land surface temperature (in °C), i is a dimensionless empirically-derived constant equals to 5, and 100 is a correction factor.	[40]
Cooling capacity index (CC_i) (based on raster analysis)	$CC_i = 0.6 \times shade + 0.2 \times albedo + 0.2 \times ETI$	(12)	Another method for quantifying the cooling capacity index (CC_i) is through the analysis of raster pixels as indicated by Equation (12). The $albedo$ variable is the fraction of light that is reflected by a surface, the $shade$ variable is extracted from a tree canopy map, and the ETI variable is the evapotranspiration index of each raster pixel.	[41]
Cooling capacity index for large green areas (CC_{ga}) (larger than 2 ha)	$CC_{ga} = \sum_{j \in d\ raduis\ from\ i} g_i \times CC_j \times e^{\left(\frac{-d(i,j)}{d_{cool}}\right)}$	(13)	CC_{ga} is considered as a distance weighted average of the cooling capacities of the surrounding green area pixels within a cooling distance (d_{cool}), where g_i equals 1 if pixel j is green, $d(i,j)$ is distance from pixel i to pixel j.	
Heat mitigation index (HM_i)	$HM_i = \begin{cases} CC_i\ if\ CC_i \geq CC_{parki}\ or\ GA_i < 2ha \\ CC_{ga}\ otherwise \end{cases}$	(14)	HM_i is a metric used to evaluate the effectiveness of GI in mitigating urban heat islands. CC_i is the cooling capacity index calculated based on Equation (12), CC_{ga} is the cooling capacity for large green areas calculated based on Equation (13), and GA_i is the green area around pixel i.	
Microclimate regulation measure (MR) in	$MR = \left(B_t \times \alpha \times l_p + P \times sw\right) \times h \times e$	(15)	The presence of tree canopy cover also contributes to the overall	[34]

kWh/m² of green space/yr (due to tree canopy cover cooling effect)			microclimate regulation, where the tree canopy cover cools the urban area by providing shade and increasing evapotranspiration. As shown in Equation (15), B_t is the trees' biomass (in ton/m²), α is the percentage of leaf biomass in tree biomass (8.73%), l_p is the evapotranspiration intensity (451.9 ton of water/ton of fresh leaves/year), P is the mean annual precipitation in ton/m², sw is the soil evaporation coefficient (5%), $h$is the heat consumed by vaporization of a ton of water (2.26 × 10⁶ kJ), and e (in kWh/ kJ) is the conversion factor from kJ to kWh (1/3600).	
Universal thermal climate index ($UTCI$)	$UTCI = -0.95 \times A_{Gs} - 0.74 \times A_{wb} + 0.10 \times A_{CL} + 35.14$	(16)	$UTCI$ is a measure used to represent human thermal comfort perception; where higher values of $UTCI$ correspond to higher levels of thermal discomfort. $UTCI$ is calculated using Equations (16)–(18) for the main urban area, metropolitan development area, and beyond metropolitan area, respectively; where A_{Gs} is the percentage of greenspace area (in %), A_{wb} is the percentage of the water body area (in %), and A_{CL} is the percentage of constructed land area (in %).	[42]
	$UTCI = -0.45 \times A_{Gs} - 0.21 \times A_{wb} + 1.11 \times A_{CL} + 34.54$	(17)		
	$UTCI = -0.24 \times A_{Gs} - 0.07 \times A_{wb} - 0.53 \times A_{CL} + 34.43$	(18)		
Greening cooling services index ($GCoS$)	$GCoS = 0.5 \times (ECoS + RCoS)$	(19)	$GCoS$ is a measure of the cooling services provided by GIs, where it is the average of the evapotranspiration cooling service ($ECoS$) and the radiative cooling service ($RCoS$) sub-indices as shown in Equations (20) and (21), respectively. Moreover, low index values are an indication of poor evapotranspiration and radiative cooling services, which implies that there is a higher risk of heat exposure.	[43]
	$ECoS = \frac{ET_i}{(\max(ET) - \min(ET))}$	(20)	$ECoS$ is a measure of the cooling capacity of GIs based on the amount of water released into the atmosphere through evapotranspiration (ET) in mm/day on the hottest day of the year, where	

			$max(ET)$ and $min(ET)$ are the maximum ET and minimum ET, respectively.
	$RCoS = \frac{(max(TS_i) - min(TS))}{(max(TS) - min(TS))} \times vf_i$	(21)	$RCoS$ is a measure of a plant's ability to lower the surface temperature through shading and it is calculated based on the maximum hourly soil temperature (TS) in °C, on the hottest day of the year, and the vegetation percentage (vf_i) in %. Moreover, $max(TS)$ and $min(TS)$ are the maximum TS and minimum TS, respectively.

More specifically, taking into consideration the parks, the maximum park cooling intensity (PCI_{max}) and the park cooling distance (PCD_p) are two commonly used measures to quantify the park's cooling capacity as shown in Equations (22) and (23) in Table 4, respectively. Moreover, the park's cooling intensity (PCI_{rp}) could be estimated using Equations (24)–(26) in Table 4. In addition to the park's cooling intensity, the park's ability to provide cooling could be quantified through three key measures: the maximum park cooling distance (MCD) shown in Equation 27 in Table 4, the local cool island intensity ($MLCII$) shown in Equation (28) in Table 4, and the maximum park cooling area (MCA) shown in Equation (29) in Table 4. Also, the park's ability to provide cooling could be quantified using LST based on Equation (30) in Table 4.

Table 4. Quantified measures of parks' cooling capacity.

Quantified Measure	Equation		Definition	Reference
Maximum park cooling intensity (PCI_{max}) in °C	$PCI_{max} = \gamma_p + \gamma_0 \times NDVI_{rp}$	(22)	PCI_{max} is a commonly used index to estimate the maximum temperature difference between a park and its surrounding environment, where γ_p is a parameter expressing the temperature difference between the park and its wider surrounding, γ_0 is a NDVI-related coefficient, and the $NDVI_{rp}$ is the normalized difference vegetation index within each ring buffer assumed around the park.	[44]
Park cooling distance (PCD_p) in m	$PCD_p = \beta_0 + \beta_1 \times {Area_p}^{\delta} + \beta_2 \times SI_p + \beta_3 \times Altitude_p + \beta_4 \times Longitude_p$	(23)	PCD_p is a measure of the maximum distance (in m) within which the cooling effect of a park could still be detected, where $Area_p$ is the area of the park (in ha), SI_p is the park's shape index (dimensionless), $Altitude_p$ is the park's mean altitude (in m), and $Longitude_p$ is the park's longitude (UTM easting in km).	[44]

		Furthermore, β_0, β_1, β_2, β_3, β_4, and δ are parameters to be estimated.	
Park cooling intensity (PCI_{rp}) in °C	$if\ Dist_{rp} < PCD_p$ $PCI_{rp} = a + b \times Dist_{rp} + c \times Dist_{rp}^2 + \varepsilon_{rp}$ $if\ Dist_{rp} \geq PCD_p$ $PCI_{rp} = PCI_{max} + \varepsilon_{rp}$ (24) $a = PCI_{max} + c \times PCD_p^2$ (25) $b = -2 \times c \times PCD_p$ (26)	PCI_{rp} is the park cooling intensity taking into consideration the proximity to multiple buffers around the park's edge, where the ring buffer zones are represented by the subscript r, $Dist_{rp}$ is the distance between the park and the ring buffer (in m), ε_{rp} is the residual error, and *a* and *b* are coefficients calculated using Equations (25) and (26). Moreover, c is a coefficient to be estimated.	[44]
Maximum park cooling distance (MCD) in m	$MCD = 83.087 \times {Area_p}^{0.4547}$ (27)	MCD is the maximum distance (in m) at which the park can provide cooling, where $Area_p$ is the park's area (in ha).	[45]
Local cool island intensity ($MLCII$) in K	$MLCII = 0.394 \times ln(Area_p) + 2.196$ (28)	$MLCII$ is the maximum intensity of the cooling effect within the immediate area surrounding the park, where $Area_p$ is the park's area (in ha).	[45]
Maximum park cooling area (MCA) in ha	$MCA = 2.136 \times Area_p + 5.352$ (29)	MCA is the maximum area (in ha) over which the park's cooling effect is felt, where $Area_p$ is the park's area (in ha).	[45]
Land surface temperature (LST)	$LST = -0.603 \times ln(Area_p) + 308.509$ (30)	Parks' ability to provide cooling could also be quantified using LST (in K), where $Area_p$ is the park's area (in ha).	[45]

Considering the cooling impact of GIs on the LST, the cooling effect of trees and vegetation is reflected by Equations (31) and (32) in Table 5. Another quantification of the cooling effect of tree canopy is generally reflected by LST and the maximum air temperature T_{air}, which could be estimated using Equations (33) and (34) in Table 5, respectively. Generally, to assess the efficiency of GIs in mitigating UHI, the % reduction of UHI is calculated as shown in Equation (35) in Table 5.

Table 5. Quantified measures of GIs' cooling effect in relation to their effect on LST and air temperature.

Quantified Measure	Equation	Definition	Reference
Land surface temperature (LST) in °C (in the presence of tree canopy cover)	$LST = -0.087 \times tc + 38$ (31)	The cooling effect of trees is demonstrated by the negative association of the LST (°C) and the percentage of tree canopy cover (tc) in %.	[46]

Land surface temperature (LST) in °C (in the presence of vegetation)	$LST = -13 \times NDVI + 40$	(32)	The cooling effect of vegetation is demonstrated by the negative association of the LST (°C) and the normalized difference vegetation index $NDVI$(see Equation (66)).	[46]
Land surface temperature (LST) in °C (in the presence of tree canopy cover)	$LST = \beta_{0e1} + \beta_{1e1} \times T_c + \beta_{2e1} \times E_{tree}$	(33)	The cooling effect of tree canopy is generally reflected by LST, where T_c is the tree cover density and E_{tree} is the amount of water evaporated from tree canopies in mm/day. Moreover,β_{0e1}, β_{1e1}, and β_{2e1} are coefficients to be estimated.	[40]
Maximum air temperature (T_{air}) in °C (in the presence of tree canopy cover)	$T_{air} = \beta_{0e2} + \beta_{1e2} \times LST + \beta_{2e2} \times Latitude$	(34)	The cooling effect of tree canopy is also reflected by T_{air}, where $Latitude$ is the latitude of the area of study. Moreover, β_{0e2}, β_{1e2}, and β_{2e2} are coefficients to be estimated.	[40]
Percentage reduction of urban heat island (in %)	$if\ T_{sealed} > T_{GI}$ $\%\ \text{reduction of UHI} = \left(1 - \frac{(T_{GI} - T_{rural\ surrounding})}{(T_{sealed\ area} - T_{rural\ surrounding})}\right) \times 100$ $if\ T_{sealed} \leq T_{GI}$ $\%\ \text{reduction of UHI} = 0$ $if\ T_{GI} \leq T_{rural\ surrounding}$ $\%\ \text{reduction of UHI} = 100$	(35)	Percentage reduction of urban heat island is a measure used to evaluate the effectiveness of GI in mitigating urban heat islands, where T_{GI} is the temperature of the GI, $T_{rural\ surrounding}$ is the temperature of GI in the rural surrounding, and $T_{sealed\ area}$ is the temperature of the built area (i.e, structures and roads).	[47]

3.1.4. Stormwater Management

Stormwater management is the reduction of rainwater runoff and the improvement of water quality. On average, GIs lead to a 33% reduction in combined sewer flow volume and a 61% reduction in peak flow during storms [48]. Moreover, replacing 10 ft^2 of impervious surface with pervious surface reduces stormwater footprint by about 1.4% [49]. As for rain gardens, their rainfall volume retention ranges from 19% to 70%, with the reduction rate estimated at 1.5–9 mm/day [50]. Furthermore, green roofs retain anywhere from 11% to 77% of total rainfall volume per year, with a median of 57%, and have a volume reduction rate of 0.5–3.5 mm/day [50]. As for vegetated façades, they have a retention rate of 33%–81% [7]. Similarly, permeable pavements reduce the runoff by 50%–93% [47]. In addition, trees play an important role in reducing runoff by intercepting incoming precipitation up to 16,615 L/yr [49].

Generally, the storm management impact of GI can be quantified using several measures such as percent flow capture, surface runoff, runoff retention, rainwater storage capacity, and runoff control. These measures of the GI's effectiveness in managing stormwater are presented in Table 6 through Equations (36)–(46). Specifically, the green spaces' runoff reduction and the green roofs' retention capacity give a better estimation of green spaces and green roofs' efficiencies in mitigating stormwater, relatively. These two measures could be calculated using Equations (47)–(50), as shown in Table 6. Moreover, the actual runoff abatement for (ARA) for single and multiple GIs could be calculated using Equations (51) and (52) (see Table 6), respectively.

Table 6. Quantified measures of stormwater management benefit of GI.

Quantified Measure	Equation	Definition	Reference
$Percent\ flow\ captured$ in % (for infiltration-based GIs)	$Percent\ flow\ captured = \frac{A_{GI}(d_{inf} + \Delta\theta \times d_{media})}{A_{sub-basin} \times d_{Runoff}}$ (36)	A_{GI} is the area of the GI (in m²), d_{inf} is the infiltration depth (in m), $\Delta\theta$ is the moisture content for the different layers in the GI, d_{media} is the entire media depth (in m), $A_{sub-basin}$ is the area of the sub-basin in (m²), d_{Runoff} is the runoff depth (in m), and d_{GI} is the depth of the GI (in m).	[51]
$Percent\ flow\ captured$ in % (for storage-based GIs)	$Percent\ flow\ captured = \frac{A_{GI} \times d_{GI}}{A_{sub-basin} \times d_{Runoff}}$ (37)		
Surface runoff (P_e) in mm	$P_e = \frac{(P - 0.2 \times S)^2}{P + 0.8 \times S}$ (38)	P (in mm) is the mean annual precipitation and S (in mm) denotes the maximum potential retention of catchment and could be calculated using Equation (39).	[25,52]
	$S = \frac{2540}{CN} - 25.4$ (39)	CN, the curve number, is a dimensionless parameter used in hydrology to estimate the amount of runoff from a drainage basin. CN is dependent on the land cover and soil type, where higher values indicate a higher potential for runoff.	[25]
Runoff retention (RM) in L/m²	$RM = (1 - Q) \times P$ (40)	P (in mm) is the mean annual precipitation and Q is a dimensionless runoff coefficient that could be calculated using Equation (41).	[25,52,53]
	$Q = \frac{P_e}{P}$ (41)	P_e (in mm) is the surface runoff (see Equation (38)) and P (in mm) is the mean annual precipitation.	
Rainwater storage capacity of GI (S_{rw}) in mm	$S_{rw} = S_{ca} \times r_{green} + S_{so} \times r_{soil}$ (42)	r_{green} and r_{soil} are the vegetation and soil proportions of the GI, respectively; S_{ca} is the maximum canopy storage capacity (in mm) and is calculated based on Equation (43); and S_{so} is the soil rainwater storage capacity (in mm) and could be calculated as shown in Equation (44).	[54]
	$S_{ca} = -0.00575 \times LAI^2 + 0.498 \times LAI + 0.935$ (43)	LAI is the leaf area index (see Equations (78) and (79)).	
	$S_{so} = H \times \left(1 - \frac{BD}{d_s}\right) \times 100$ (44)	H is the soil depth (in mm), BD is the bulk density of the soil (in	

			g/cm³), and d_s is the particle density of the soil (in g/cm³).	
Rainwater runoff reduction by green spaces (RM_{gs}) in ton/yr	$RM_{gs} = P \times AG \times \rho_w \times \left(RI_{im} - RI_g\right)$	(45)	P is the average annual precipitation (in m/yr), AG is the area of the green space (in m²), RI_{im} is the runoff coefficient for impervious surfaces, RI_g is the runoff coefficient for the green space, and ρ_w is the water density assumed equal to 1 ton/m³.	[34]
Retention capacity (R) in % (for green roofs)	$\ln(R) = 6.336 + -0.045 \times Rdep - 12.138 \times AVMC$	(46)	R_{dep} is the rainfall depth (in mm), and $AVMC$ is the antecedent volumetric moisture content (in m³/m³).	[55]
	$\ln(R) = 3.507 - 0.044 \times Rdep + 0.013 \times ADWP$	(47)	R_{dep} is the rainfall depth (in mm), and $ADWP$ is the antecedent dry weather period (in h).	
	$\ln(R) = 2.059 + (-0.043)(Rdep) + (0.017)\,(ADWP) + (1.400)(WS) + (0.004)(SR)$	(48)	R_{dep} *is the* rainfall depth (in mm), $ADWP$ is the antecedent dry weather period (in h), WS is the mean wind speed (in m/s), and SR is the solar radiation (in W/m²).	
Runoff control rate (R_r) in %	$R_r = \left(1 - \frac{V_a}{V_t}\right) \times 100\%$	(49)	R_r could be calculated using Equation (49), where V_a is the runoff after installation of the GI (in m³), V_t is the total runoff of the storm event (in m³).	[56]
	$R_r = \left(\frac{P - R}{P}\right) \times 100\%$	(50)	R_r could be also estimated using Equation (50), where P is the total rainfall (mm), and R is the total runoff (in m).	[57]
Actual runoff abatement (ARA) in m² (for one GI)	$if\ Q_k \times A_k - C_{ab_{n,k}} \geq 0$ $ARA_{n,k} = C_{ab_{n,k}},$ $if\ Q_k \times A_k - C_{ab_{n,k}} < 0$ $ARA_{n,k} = Q_k \times A_k,$	(51)	ARA refers to the measurable reduction in stormwater runoff volume. The ARA of one GI type, n, placed on parcel k is calculated as per Equation (51), where C_{ab} is the runoff abatement capacity of the GI (in m³), Q is the runoff depth (in m), and A is the parcel's area (in m²).	[58]
Actual runoff abatement (ARA) in m² (for multiple GIs)	$if\ Q_k \times A_k - ARA_{n,k} - C_{ab_{m,k}} \geq 0$ $ARA_{m,k} = C_{ab_{m,k}},$ $if\ Q_k \times A_k - ARA_{n,k} - C_{ab_{m,k}} < 0$ $ARA_{m,k} = Q_k \times A_k - ARA_{n,k},$	(52)	When considering multiple GI types, having GI type n implemented, followed by implementing GI type $m$on parcel k, ARA is then calculated based on Equation (52), where C_{ab} is the runoff	[58]

			abatement capacity of the GI (in m³), Q is the runoff depth (in m), and A is the parcel's area (in m²).	

3.1.5. Water Purification

GIs have the ability to remove sediments and nutrients from stormwater runoff and purify water. In fact, up to 15% of nutrients and sediments are removed when GI practices are implemented on up to 1% of the sub-catchment area [59]. Generally, GIs lead to a reduction between 65 and 100% in total phosphorous (TP) and total suspended solids (TSS) [13].

The efficiency of pollutant removal depends on the type of GI used, whether it is infiltration-based or storage-based. Equations (53) and (54) in Table 7 show the percent pollutant removal (%) for infiltration-based and the percent dissolved pollutant removal (%) for storage-based GI, respectively. Furthermore, Equations (55) and (56) in Table 7 are used to calculate the percent colloid removal (%) for storage-based GI. In addition, the TSS removal in grass swales and grass filter strips could be estimated based on Equations 57 and 58, as shown in Table 7. Furthermore, the pollution retention rate (P_r) could be calculated as shown in Equations (59) and (60) (see Table 7), respectively.

Table 7. Quantified measures of water purification benefit of GI.

Quantified Measure	Equation		Definition	Reference
Percent pollutant removal (in %) (for infiltration-based GI)	$Percent\ pollutant\ removal\ (\%) = \frac{k \times d_{media} \times A_{GI}}{P_{LR}}$	(53)	The efficiency of pollutant removal depends on the type of GI used, whether it is infiltration-based or storage-based. For infiltration-based GI it could be calculated using Equation (53), where k is the decay rate value for the pollutant (in kg/m³/s), d_{media} is the entire media depth (in m), A_{GI} is the area of the GI (in m²), and P_{LR} is the pollutants loading rate (in kg/s).	[51]
Percent dissolved pollutant removal (in %) (for storage-based GI)	$Percent\ dissolved\ pollutant\ removal\ (\%) = \frac{k \times d_{GI} \times A_{GI}}{P_{LR}}$	(54)	Percent dissolved pollutant removal (%) is a measure of the efficiency of pollutant removal in a storage-based GI, where k is the decay rate value for the pollutant (in kg/m³/s), d_{GI} is the depth of the GI (in m), A_{GI} is the area of the GI (in m²), and P_{LR} is the pollutants loading rate (in kg/s).	[51]
Percent colloid removal (in %) (for storage-based GI)	$Percent\ colloid\ removal\ (\%) =$	(55)	Percent colloid removal (%) refers to the percentage of colloidal particles (e.g., small suspended solids or	[51]

	$\frac{\frac{v}{D}\left\{\left(10.36^2+1.049(1-C_S)^{4.7}\left[\left[\frac{g\times R}{v^2}\right]^{\frac{1}{3}}D\right]^3\right)^{\frac{1}{2}}-10.36\right\}\times A_{GI}}{Q_{Runoff}}$		pollutants) that are removed from stormwater runoff by a GI, where v is the kinematic viscosity of water (in m^2/s), D is the average diameter of the grains (in m), C_s is the volumetric sediment concentration, g is the gravitational acceleration (in m/s^2), R is the submerged specific gravity of the grains that could be calculated using Equation (56), and Q_{Runoff} is the runoff flow (in m^3/s).	
	$R=\frac{\rho_s-\rho_w}{\rho_w}$	(56)	R is the submerged specific gravity of the grains, where ρ_w is the water density (in kg/m^3) and ρ_s is the density of the grains (in kg/m^3).	
TSS removal (T_{rs}) (in grass swales and grass filter strips)	$T_{rs}=Exp\left[\left(-1.05\times 10^{-3}\left(\frac{V\times R_s}{v}\right)\right)^{0.82}\left(\frac{V_s\times L}{Vh}\right)^{-0.91}\right]$	(57)	T_{rs} is a measure of TSS trapping efficiency, where V is the average flow velocity, R_s is the flow area hydraulic radius, V_s is the particle settling velocity, L is the length of the grass section, v is the kinematic viscosity, and h is the flow depth.	[60]
TSS removal (T_{rs}) (in grass swales and grass filter strips for smaller sediment particles (0–180 μm) and lower concentrations of sediment in the inflow (670–3920 mg/L))	$T_{rs}=\frac{\left(\frac{x\times V_s}{hV}\right)^{0.69}}{\left(\frac{x\times V_s}{hV}\right)^{0.69}+4.95}$	(58)	When considering smaller sediment particles (0–180 μm) and lower concentrations of sediment in the inflow (670–3920 mg/L), the quantification described in Equation (57) is no longer effective. In such cases, Equation (58) is recommended to be used as it is considered more representative. As shown in Equation (58), x is the distance from the inlet edge to the point of study "X" along the grass section.	[60]
pollution retention rate (P_r) in %	$P_r=\left(1-\frac{S_a}{S_t}\right)\times 100\%$	(59)	P_r is a measure of the GI effectiveness in reducing pollutant load, where S_a is the outfall pollutant load (in kg) after installation of the	[56]

		GI, and S_t is the outfall pollutant load (in kg) before installing GI.	
$P_r = \frac{M_{NR} - M}{M_{NR}} \times 100\%$	(60)	P_r could be also calculated using Equation (60), where M_{NR} is the pollutant mass throughout the runoff process (in mg), and M is the pollutant mass throughout the outflow (in mg).	[57]

3.1.6. Water Harvesting

GI practices such as green roofs, permeable pavements, and rain gardens not only reduce stormwater volume but also provide an opportunity for the captured water to be used again. Some GI systems, known as water harvesting systems, are specifically designed to capture, store, and reuse rainwater for non-potable purposes such as irrigation and toilet flushing. These systems are effective to conserve water, particularly in areas with limited water resources or water use restrictions. For instance, it is reported in the literature that a barrel with a capacity of 600 L could save 7.25 m^3 of water per house per month, assuming an average of 12 rainy days per month [28].

3.1.7. Noise Pollution Reduction

GIs also reduce noise pollution in urban environments by providing barriers and absorbent surfaces that can attenuate sound waves. The noise reduction rate of urban green spaces varies based on the type of land cover vegetation. Figure 2 presents the range of the noise reduction rate for different urban green space (UGS) vegetation [25].

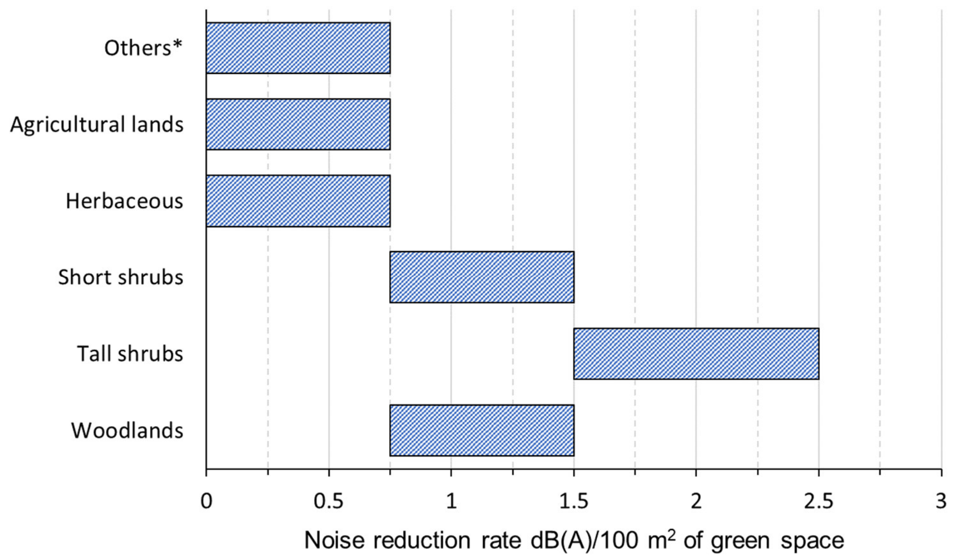

Figure 2. The noise reduction rate provided by different UGS components (Others* in the figure is defined as the allotments or community growing spaces, bowling greens, camping or caravan parks, cemeteries, golf courses, sports facilities, playing fields, and tennis courts).

Moreover, the noise reduction provided by a given area of green spaces (NR), in dB(A)/ha, could be estimated based on Equation (61) [34].

$$NR = -3.77\log V + 3.04\log D + 0.83\log H + 1.02\log W + 2.75 \quad (61)$$

where V is the visibility of the tree community in the study location (in m), D is the length of the tree (in m), H is the average height of the trees (in m), and W is the width of tree community (in m); where the visibility of tree community is the distance that an object is obscured by the vegetation and which provides an indirect indication of the density of the trees.

3.1.8. Biodiversity Conservation

Measuring the benefits of GI on urban biodiversity is essential for city planners as they seek to find ways to support ecosystem services and protect biological diversity [12]. GIs can support biodiversity in urban environments by providing habitat, connecting fragmented habitats, reducing the impact of development, and providing food and shelter. For instance, planting with a 2–9% flower cover is considered to be the most effective in promoting native plants and invertebrate biodiversity [61]. Furthermore, biodiversity conservation could be quantified using multiple measures such as lichen species richness, Simpson's index of diversity (ID), land use mix index ($LUMI$), integral index of connectivity (IIC), and normalized difference vegetation index ($NDVI$), as shown by Equation (62) through Equation (66) in Table 8, respectively.

Table 8. Quantified measures of biodiversity conservation benefit of GI.

Quantified Measure	Equation		Definition	Reference
Lichen species richness	$Lichen\ species\ richness = 2.5 \times \log(Area) + 33.79 \times NDVI_b - 6.47$	(62)	The lichen trees richness is defined as the total number of lichen species in a green space, where $Area$ is the green space area (in m[2]), and $NDVI_b$ is the average NDVI (see Equation (66)) for a 100 m buffer around the green space centroid with the green space area included.	[62]
Simpson's index of diversity (ID)	$ID = 1 - \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}$	(63)	ID is a measure of species diversity in the ecosystem, where it is unitless and ranges between 0 and 1. A higher value for ID indicates heterogeneity (i.e., higher diversity), while a lower value indicates a lower degree of diversity (homogeneity). As shown in Equation (63), S is the species number, n_i is the frequency of specimens of i^{th} species, and N is the specimens' total number regardless of species.	[63]
Land use mix index ($LUMI$)	$LUMI = \left[\frac{\sum_1^n (p_i)\ln(p_i)}{\ln(n)}\right]$	(64)	$LUMI$ could be used as a measure that assesses the distribution of land use and land cover classes across a landscape, where values close to 1 indicate a blend of various similarly sized land cover classes across the landscape, while values close to 0 indicate a dominance of a particular land cover class. As shown in Equation (64), p_i is the proportion of land cover of type "i", and n is the total number of land cover classes.	[64]

Integral index of connectivity (IIC)	$IIC = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\frac{A_i \times A_j}{1 + nl_{ij}}}{A_L^2}$	(65)	IIC is used to prioritize green and blue spaces, such as habitats and ecological corridors, where IIC evaluates the role of each core area in maintaining and improving the connectivity of the GI network. IIC with higher values indicates more connectivity between GI core area. As shown in Equation (65), N is the total number of GI elements in the area of study, A_i and A_j are the areas of the GI elements, nl_{ij} is the number of shortest path links between i and j, and A_L is the total area of the landscape (including habitat and non-habitat areas).	[65]
Normalized difference vegetation index ($NDVI$)	$NDVI = \frac{NIR - RED}{NIR + RED}$	(66)	$NDVI$ could be used to quantify biodiversity by considering the difference between near-infrared (NIR) and red light (RED), as shown in Equation (66). Since vegetation generally reflects NIR and absorbs RED, a higher $NDVI$ value indicates dense green vegetation.	[66]

3.1.9. Soil Stabilization

Trees and vegetation cover stabilize the soil due to their roots that contribute to structural reinforcement of the deeper soil layers [67]; which helps to prevent erosion and landslides. To evaluate the soil stability, a slope stability safety factor, $FS(l,t)$, could generally be obtained based on Equation (67) in Table 9 [68].

Table 9. Quantified measures of soil stabilization benefit of GI.

Quantified Measure	Equation		Definition	Reference
Slope stability safety factor ($FS(l,t)$)	$FS(l,t) = \frac{B + \left(A - \sum_{k=1}^{l} h(k) \times m(k,t)\right) \times \frac{tan(\Phi(l}{tan(\beta}}{A}$	(67)	$FS(l,t)$ values larger than one indicate a stable soil column at depth l and time t. As shown in Equation (67), $h(k)$ is the depth of layer soil layer k (in m), $\Phi(L)$ is the internal friction angle for the entire soil depth L (in °), β is the soil column slope angle (in rad), $m(k,t)$ is the soil moisture of layer k at time t and could be calculated as per Equation (68), A is the effective normal stress and could be obtained using Equation (69), and B is the resisting force cohesion	[68]

		angle which is calculated using Equation (70).
$$m(k,t) = \frac{\theta(k,t)}{\theta_{sat}(k)}$$	(68)	$m(k,t)$ is the soil moisture of layer k at time t, where $\theta(k,t)$ is the water content of the soil in layer k at time, and $\theta_{sat}(k)$ is the saturated water content of layer k.
$$A = \gamma_w^{-1} \times \left(q + \sum_{k=1}^{l} h(k) \times \left[m(k,t) \times \left(\gamma_{sat}(k) - \gamma(k)\right) + \gamma(k)\right]\right)$$	(69)	A is the effective normal stress, where γ_w is the water-specific weight (in kN/m^3), q is the pressure developed due to the vegetation weight (in kN/m^2), $h(k)$ is the depth of layer soil layer k (in m), $m(k,t)$ is the soil moisture of layer k at time t, γ_{sat} is the saturated soil specific weight (in kN/m^3), and γ is the dry soil specific weight (in kN/m^3).
$$B = \frac{2 \times \left(C_s(l) + C_r(l)\right)}{\gamma_w \times sin(2 \times \beta)}$$	(70)	B is the resisting force cohesion angle, where $C_s(l)$ and $C_r(l)$ are the soil and root cohesion (in Pa), respectively. Moreover, γ_w is the water-specific weight (in kN/m^3) and β is the soil column slope angle (in rad).

3.2. Economic Benefits

In addition to the multiple environmental benefits discussed in the previous section, GIs have numerous economic benefits such as energy saving, property value enhancement, built environment lifetime enhancement, and maintenance cost reduction. These quantification models and methods for these are detailed in the next subsections.

3.2.1. Energy Saving

The use of GIs significantly reduces energy consumption. For instance, green roofs reduce energy consumption in buildings through their ability to regulate temperature and provide insulation. Green roofs save 76.65 kWh/m^2/yr of cooling energy on hot days and 0.02 kWh/m^2/yr of heating energy on cold days [16]. Additionally, thermally insulated green roofs lead to significant reductions in total life cycle energy consumption ranging from 8 to 31% [69]. Generally, green walls and green roofs contribute to energy savings from 32% to 100% in buildings [13]. Moreover, the usage of rain barrels is estimated to lower energy consumption by 3 to 4 kWh/m^3 of desalinated seawater produced [39]. Trees also provide energy savings, where 96 trees can save a total of $950.60 in energy costs annually [49]. In addition, grove can save 63.98 kWh/m^2/yr cooling and 12.09 kWh/m^2/yr heating. Moreover, greenways save 176.97 kWh/m^2/yr in cooling demands and 15.46 kWh/m^2 in heating demands [16].

The annual energy saving of green roof (AES), in kWh/m^2/yr, could be calculated using Equation (71) [28].

$$AES = C_{days} \times \left[\left(\frac{1}{R_{conv\,roof}} \right) - \left(\frac{1}{R_{green\,roof}} \right) \right] \times \frac{24\,hr}{day} \times 0.00315 \quad (71)$$

where C_{days} (in °F×days) is the annual number of cooling degree days, $R_{conv\,roof}$ (in SF×°F×hrs/BTU) is the thermal resistance for conventional roofs, $R_{green\,roof}$ (in SF×°F×hrs/BTU) is the thermal resistance for green roofs, and 0.00315 is a conversion factor that is used to convert the units from BTU/SF to kWh/m^2. The annual cooling degree days are calculated by subtracting the balance temperature from the mean daily temperature and only adding the positive values over a full year.

Furthermore, the presence of GIs has an impact on electricity usage, where this impact is influenced by various socioeconomic factors such as income, education level, and neighborhood quality of life. The relationship between the average rise in electricity demand ($Elec_{inc}$), in kWh/day/residential household, as a function of GI's properties and several socioeconomic factors is shown in Equation (72) [70].

$$\begin{aligned} Elec_{inc} = (-3.110)Edu + (-1.645)Prop_{GS} + (-4.944)PD + (-0.120)LST + (-0.002)Age + (0.013)Gen \\ + (-0.002)Pop_{Ind} + 9.103 \end{aligned} \quad (72)$$

where Edu is the proportion of people with university degree and above (in %), $Prop_{GS}$ is the ratio of greenspaces' area to the neighborhood's area, PD is the population density (in Person/km^2), LST is the average land surface temperature (in °C), Age is the ratio of population above age 65 to population below 15, Gen is the male to female ratio, and Pop_{Ind} is the population of indigenous people (in Person).

3.2.2. Property Value Enhancement

GIs can have a positive impact on property value by improving the appearance and livability of a neighborhood. For example, the creation of an urban riparian park covering an area of 200 m^2 and having an estimated storage capacity of 882 m^3 may lead to a 2.5% annual increase in the property values of nearby properties during the first 5 years [71].

3.2.3. Built Environment Lifetime Enhancement

GIs have also the ability to protect the built environment. This effect is seen in the role of GIs in preserving the integrity of built spaces. Green vegetation decreases steel recession by up to 37% [72]. Also, green roofs extend the lifespan of roofs due to their ability to protect the membrane from weather conditions. Conventional roofs typically have a lifespan of 10–20 years, whereas green roofs are expected to last 40–55 years [28].

3.2.4. Maintenance Cost Reduction

One of the benefits of using GIs is that they are more cost-effective than traditional grey infrastructure. For instance, properly sited GIs are 5% to 30% cheaper to construct and approximately 25% cheaper to maintain over their lifespan compared to traditional grey infrastructure [51].

3.3. Social Benefits

In addition to the environmental benefits as well as the economic benefits presented in the previous two sections, GIs also provide a range of social benefits, such as recreational opportunities, human health and well-being enhancement, crime rate reduction, food and medical supply, and cultural services discussed in the next subsections.

3.3.1. Recreation Opportunities

Green spaces offer a range of recreational activities that promote physical activity, social interaction, and stress relief [73]. In this context, recreation is defined as the potential of everyday outdoor activities of short duration, such as walking, exercise, and relaxation

[74]. The basis of quantifying the supply of these recreational opportunities is known as the recreation index score [25] and is based on the fact that people: (1) tend to prefer a landscape with vegetation over one with water, (2) value a high level of naturalness, and (3) appreciate variation and an open structure in the landscape [74]. Figure 3 provides the recreation index value (index value/m²) of different UGS components [25].

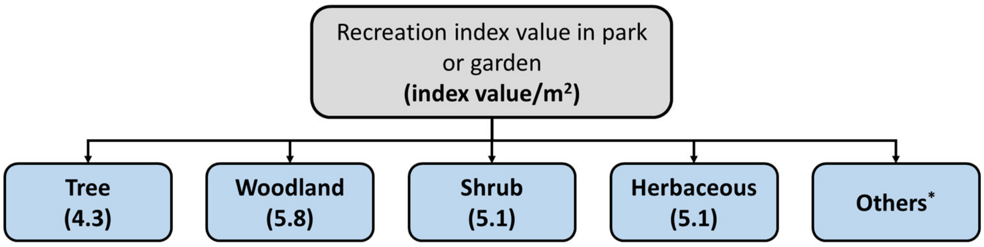

Figure 3. Recreation index score for UGS components (Others* in the figure is defined as the allotments or community growing spaces, bowling greens, camping or caravan parks, cemeteries, golf courses, sports facilities, playing fields, and tennis courts).

Moreover, people who have easy access to parks and other green spaces tend to report higher levels of satisfaction with their neighborhood and a greater sense of community. The accessibility of parks is evaluated using three indices: (1) the average daily green access (AAR), (2) the average daily travel distance from the origin to park (AOD), and (3) the average daily time spent in the park (ATT). These indices could be calculated using Equations (73)–(75), respectively, as shown in Table 10.

Table 10. Quantified measures of recreational opportunities promoted by GIs.

Quantified Measure	Equation	Definition	Reference
Average daily green access (AAR)	$AAR = \frac{\sum_t^T \sum_k^K A_k}{KT}$ (73)	AAR could be estimated using Equation (73), where A_k is the daily number of visits of person k, t is the activity duration per day, K is the total number of visitors, and T is the total activity duration.	[75]
Average daily travel distance from origin to park (AOD)	$AOD = \frac{\sum_t^T \sum_k^K D_k}{KT}$ (74)	AOD could be estimated using Equation (74), where D_k is the daily travel distance of person k from the origin to the park, t is the activity duration per day, K is the total number of visitors, and T is the total activity duration.	[75]
Average daily time spent in the park (ATT)	$ATT = \frac{\sum_t^T \sum_k^K E_k}{KT}$ (75)	ATT could be estimated using Equation (75), where E_k is the daily time spent in the park of person k, t is the activity duration per day, K is the total number of visitors, and T is the total activity duration.	[75]

3.3.2. Human Health and Well-Being Enhancement

Many studies mentioned a link between GI and human health, yet researchers rarely quantified this benefit. NDVI was found to be directly and positively correlated with citizens' mental well-being and other factors that may contribute to mental well-being, such as time spent on walking for recreation, neighborhood social cohesion, perceived level of pollution, and satisfaction with green spaces. In addition, NDVI is negatively correlated with perceived stress levels [20]. Moreover, after greening tram lines, pedestrian streets, avenues, and small streets, the mean perception of stress could generally decrease from 4.87 to 4.03, happiness could increase from 5.46 to 6.38, and safety could increase from 6.02 to 6.71 [76].

According to [18] Click or tap here to enter text., the relationship between NDVI and the odds ratio of reporting good health (OR) is an inverse U-shaped relationship, where OR increases as NDVI values increase from 0 to 0.40. However, beyond this point, OR decreases as NDVI values continue to increase. Thus, older people living in areas with an NDVI of around 0.40 have the highest likelihood of reporting good health [18]Click or tap here to enter text..

3.3.3. Crime Rate Reduction

The relationship between GI and crime rates is an area of growing research interest. GIs are associated with less violence, and a higher percentage of green spaces is associated with lower rates of crime. For instance, an increase of 1% in the total area of green spaces is associated with a 1.2% decrease in violent crime (with a 95% confidence interval of 0.7 to 1.7%) and a 1.3% decrease in property crime [19]. Moreover, increasing the tree cover lowers violent crime by 0.4% [19].

3.3.4. Food and Medical Supply

GIs also contribute to food production in urban environments through the use of urban agriculture practices such as community gardens. In fact, it is estimated that approximately 22% of community gardeners are selling the produce they grow [77]. For instance, allocating up to 52% of the land in community gardens for food production-related purposes could produce enough fruits and vegetables to meet 2% of the demand of local residents [77]. Generally, 88% of the species found in community gardens are edible, with a median of 26 species [77]. Also, food plants could be cultivated for 80% or more of the gardens' surface area [78]. Furthermore, woody species (i.e., trees and shrubs) are the second most commonly used GI for food-related purposes, where 33% of trees and 37% of shrubs generally have at least one edible use [79].

Considering the medical supply, the majority of woody species have medicinal uses, making up 37% of total uses [79]. More specifically, 36% of trees and 38% of shrubs have at least one medicinal use [79].

3.3.5. Cultural Services

The cultural services of GI refer to the non-material benefits that GIs can provide to communities. These benefits can include opportunities for education, recreation, stress relief, and the creation of a sense of place. The land rent method could be used to estimate the cultural benefits provided by green spaces as shown in Equation (76) [34].

$$CEB = L_{rent} \times A_{greenspace} - GI_{regulatingbenefits} \quad (76)$$

where CEB is the estimation of the cultural benefits provided by GI (in USD/m^2), L_{rent} is the land rent (in USD/m^2), $A_{greenspace}$ is the area of the green space (in m^2), $GI_{regulatingbenefits}$ is the monetary value of the benefits that could be felt by humans (in USD/m^2), such as cooling and noise reduction.

3.4. Environmental Challenges

While GIs have multiple environmental, economic, and social benefits as detailed in the previous sections, they could also have negative impacts on the environment, including biogenic volatile organic compounds (BVOC) emissions, heat-trapping, and increased water consumption. These environmental challenges are discussed and quantified in the following subsections.

3.4.1. BVOCs Emission

Trees emit BVOCs that contribute to the formation of ozone and particulate matter in the atmosphere. This process can affect the concentration of ozone in the air [80]. Moreover, the monetary value of BVOC emission of green spaces per urban area ($\psi BVOC$) could be estimated in USD/m²/yr using Equation (77) [34].

$$\psi BVOC = Em_{BVOC} \times PR_{voc} \times CG \tag{77}$$

where Em_{BVOC} is the average BVOC emission intensity for green spaces where it is 3 gC/m²/yr in temperate regions, whereas it is 3.3 gC/m²/yr in subtropical regions; PR_{voc} is the environmental cost per unit of VOC emission (0.77 USD/kg); and CG is the green space surface area (in m²).

3.4.2. Heat-Trapping

Green roofs could also contribute to cooling via insulation which leads to the trapping of heat in certain circumstances. For instance, a green roof with Sedum vegetation could increase the daily air-conditioning electricity consumption by 14.66 kW [17]. Similarly, while a tree canopy provides cooling during the day by shading surfaces and releasing moisture into the air, it traps heat at night and reduces wind circulation at night. In fact, tree canopies store heat in which the air temperature could generally increase by 0.28–1.68 °C [38]. Also, a decrease of 1 Leaf Area Index (LAI) lowers mean air temperature by 0.19–0.31 °C, due to improved ventilation flow [37]. LAI could be quantified using Equations (78) and (79) [27].

$$LAI = \frac{Mean\ surface\ area\ of\ a\ leaf\ \times Mean\ number\ of\ leaves\ per\ quadrat}{Total\ surface\ area\ of\ quadrat} \tag{78}$$

$$V_{LAI} = 0.3361 \times e^{5.9127 \times V_{NDVI}} \tag{79}$$

where V_{LAI} is the value of leaf area index of each rater pixel, and V_{NDVI} is the NDVI of each raster pixel.

3.4.3. Water Consumption

GI practices such as green roofs, rain gardens, and parks could increase water consumption due to irrigation. In general, vegetation irrigation is estimated to be 0.023 m³/m² in the cold season and 0.313 m³/m² in the warm season [81]. In fact, green roofs result in a significant increase in total life cycle water consumption ranging from 279 to 835% [69]. As for wetland water consumption, it is estimated to have an irrigation cost of 215 L/m²/day [82]. The vegetation water consumption (in mm) could be calculated using Equation (80) [83].

$$Vegetation\ water\ consumption = R + I - D \pm \Delta S \tag{80}$$

where R is the precipitation (in mm), I is the irrigation (in mm), D is the drained water (in mm), and ΔS is the difference in soil water moisture before and after irrigation or rainfall events (in mm).

Moreover, the soil water balance method could be used to determine the water needs of individual plant species by measuring the soil moisture content, as shown in Equation (81) [84].

$$P + I = Dp + ET + \Delta S + R_S \tag{81}$$

where P is the rainfall (in mL), I is the irrigation (in mm), Dp is the drained water (in mL), ET is the evapotranspiration of vegetation (in mL), ΔS is the difference in soil water moisture before and after irrigation or rainfall events (in mm), and R_S is the surface water runoff (in mL).

3.5. Social Challenges

In addition to the environmental challenges of GI provided in the previous section, GIs also possess some social challenges such as gentrification and pollen exposure risk as further detailed in the next subsections.

3.5.1. Gentrification

Investments in GIs are found to be correlated with higher housing costs leading to the displacement of vulnerable populations in the affected areas [85,86]. This phenomenon is known as green gentrification [87]. For instance, gentrified census tracts tend to have a higher implementation of Green Stormwater Infrastructure (GSI) projects, compared to non-gentrified low-income census tracts [21]. Moreover, the funding allocated for GSI projects in gentrified census tracts was found to be up to five times higher than in non-gentrified low-income census tracts [21]. Furthermore, areas that are located closer to GSI projects have higher rental prices compared to the average rental prices in the city [21].

3.5.2. Pollen Exposure Risk

Trees in urban green spaces could cause respiratory irritation and increase the risk of asthma and allergic rhinitis in allergy sufferers, particularly in areas with high concentrations of allergenic trees and large grass areas. The Aerobiological Index of Risk for Ornamental Trees ($AIROT$) could be used to evaluate the potential risk of pollen exposure from urban GIs on individual streets by providing a single value for the entire street in a given city. Moreover, the modified AIROT ($AIROT_m$), calculated using Equation (82), is designed to be applied across entire cities and provides a value for each street or avenue; also, the modified $AIROT$ could be calculated for housing application in specific, which is denoted as $AIROT_{mb}$ and is calculated using Equation (83) [88,89].

$$AIROT_m = \sum_{i=1}^{n} \frac{PDd_i \times PD_{wi} \times N_i \times M_i \times SH_i \times H_i}{ST} \quad (82)$$

where PDd_i is the potential dispersibility for distance, PD_{wi} is the potential dispersibility for wind, N_i is the normalized density of trees, M_i is the maturity degree for each specimen, SH_i is the incidence and presence of high buildings and narrow streets, H_i is the height above sea level, and ST is the entire surface of the measured area.

$$AIROT_{mb} = \sum_{i=1}^{n} \frac{PDd_i \times PD_{wi} \times (Nf_i \times \alpha_i) \times M_i \times SH_i \times H_i}{ST} \quad (83)$$

where Nf_i is the number of vegetation specimen par façade, and α_i is the pollen production. Moreover, the subscript i is the number of measuring points.

3.6. Summary of Benefits and Challenges Based on GI Techniques

The above sections provided an overall quantification of several benefits and challenges associated with GIs. The following subsection visually summarizes the variables (or inputs) needed to estimate or quantify the different benefits and challenges of GIs (i.e., outputs), categorized by individual GI techniques.

3.6.1. Green Lands

The term "green lands" includes green spaces, vegetation, and grassland covers. Green lands are widely used in practices as well as studies by researchers due to their natural green characteristics. Based on the information presented in the previous sections, Figure 4 provides a summary of the variables needed to quantify the benefits and challenges of these GIs.

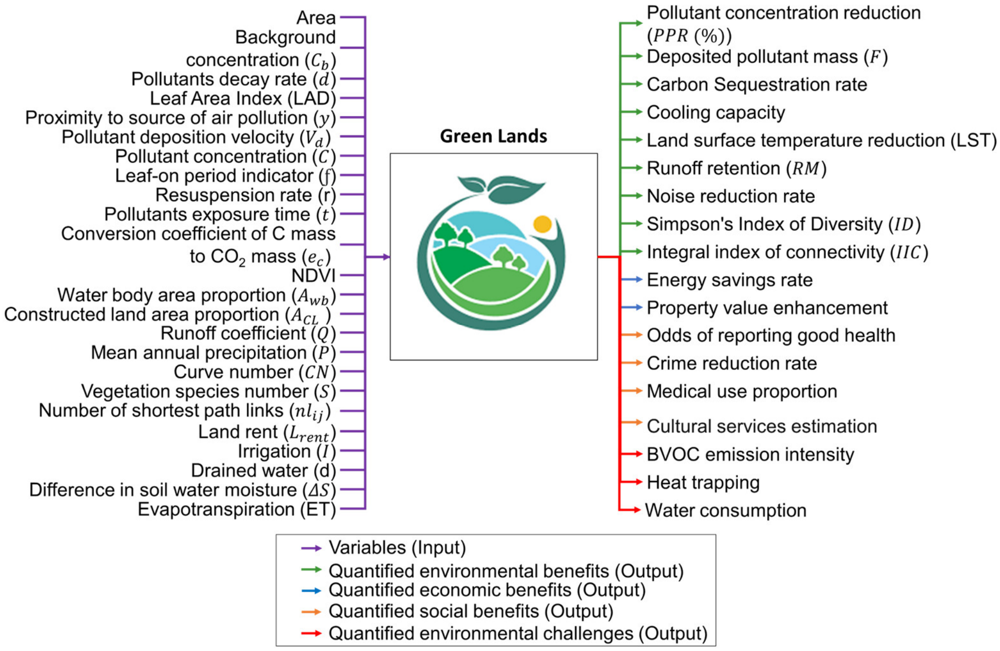

Figure 4. Green lands' quantified impacts.

3.6.2. Forests and Trees

Forests are ecosystems that are characterized by the presence of trees and other woody vegetation. Based on the information presented in the previous sections, Figure 5 provides a summary of the variables needed to quantify the benefits and challenges of these GIs.

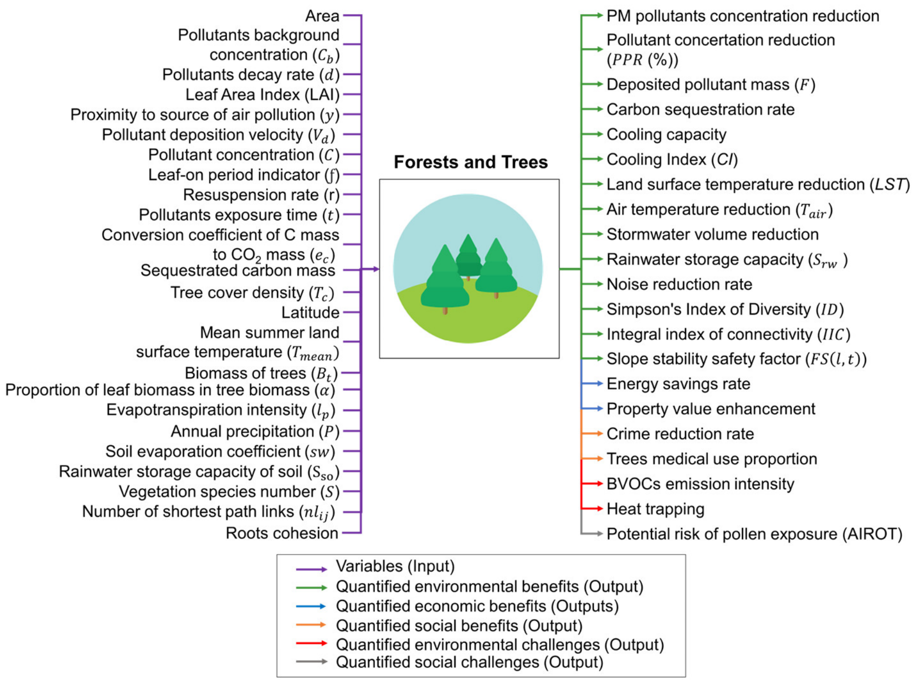

Figure 5. Forests and trees' quantified impacts.

3.6.3. Parks

Parks provide a place for people to experience nature, participate in physical activities, and escape from their daily routines. Based on the information presented in the previous sections, Figure 6 provides a summary of the variables needed to quantify the benefits and challenges of these GIs.

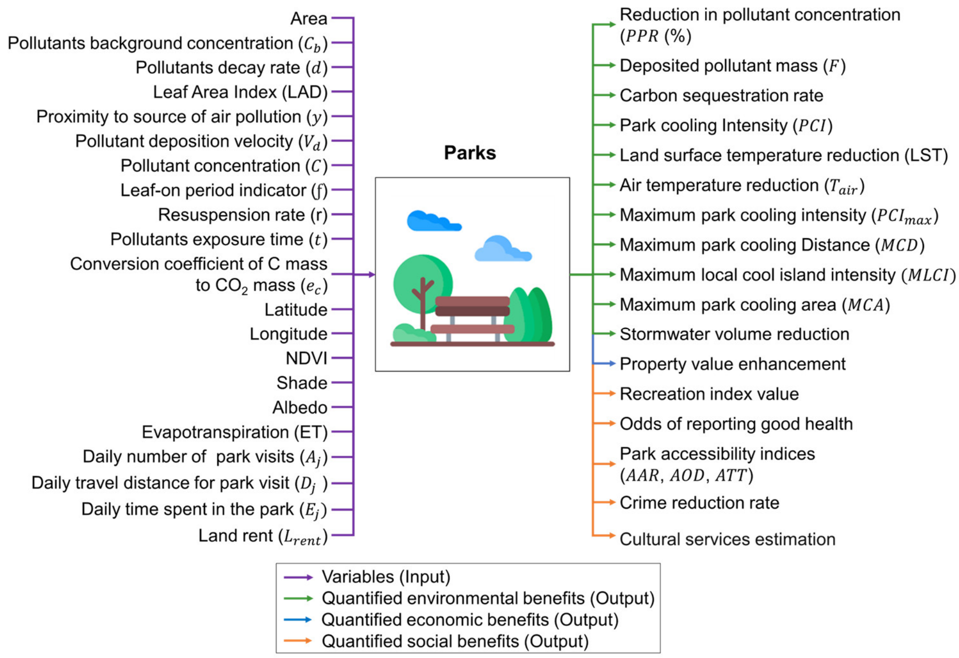

Figure 6. Parks' quantified impacts.

3.6.4. Rain Gardens

Rain gardens, also known as bioretention systems, are a widely used practice for reducing non-point source pollution in urban areas. These GIs utilize both physical and chemical properties as well as biological features to remediate contaminants, store runoff water, and promote nutrient cycling [90]. Based on the information presented in the previous sections, Figure 7 provides a summary of the variables needed to quantify the benefits and challenges of these GIs.

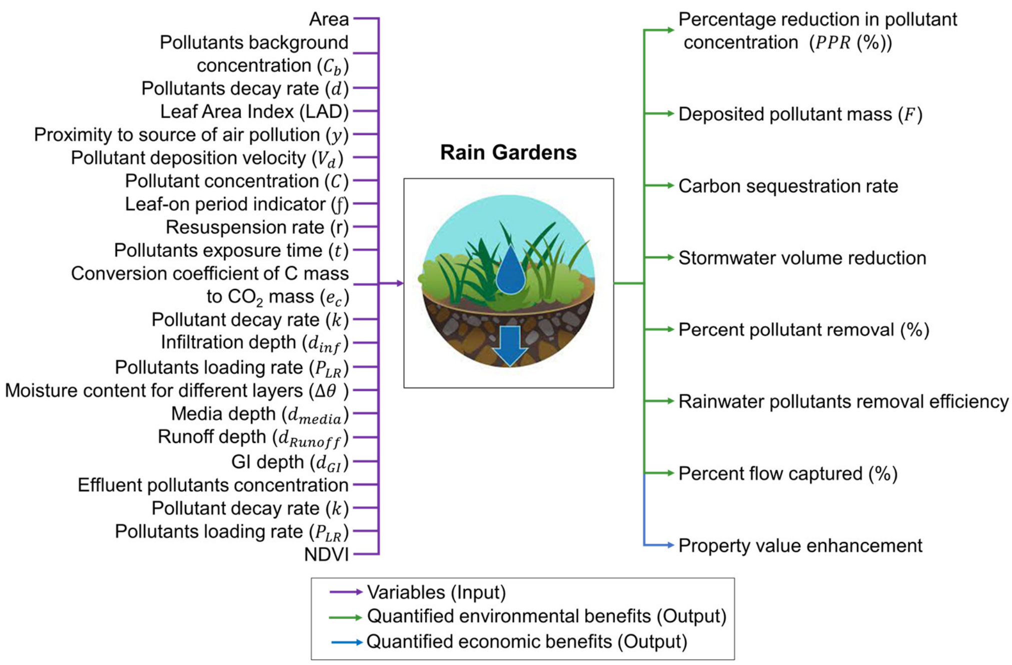

Figure 7. Rain gardens' quantified impacts.

3.6.5. Wetlands

Wetlands (being constructed and natural) are recognized as valuable natural resources throughout human history [91]. They serve as natural water filters that trap pollutants and sediment to improve water quality. Based on the information presented in the previous sections, Figure 8 provides a summary of the variables needed to quantify the benefits and challenges of these GIs.

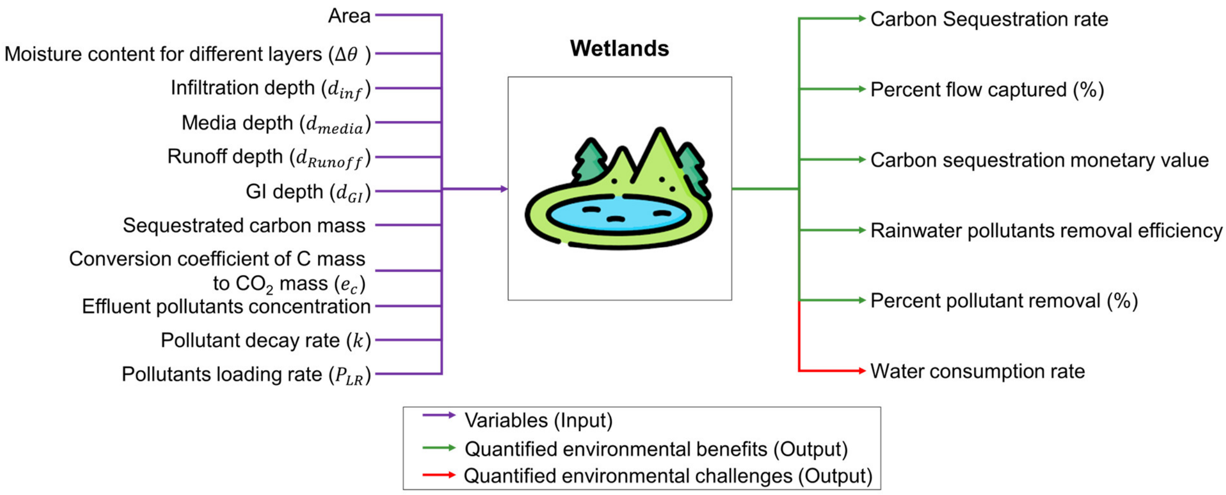

Figure 8. Wetlands' quantified impacts.

3.6.6. Green Roofs

Green roofs, also referred to as living roofs or rooftop gardens, are made up of various elements including plants, a substrate to supply nutrients, a water system to aid plant growth, and a drainage system to eliminate excess rainwater [92]. Based on the information presented in the previous sections, Figure 9 provides a summary of the variables needed to quantify the benefits and challenges of these GIs.

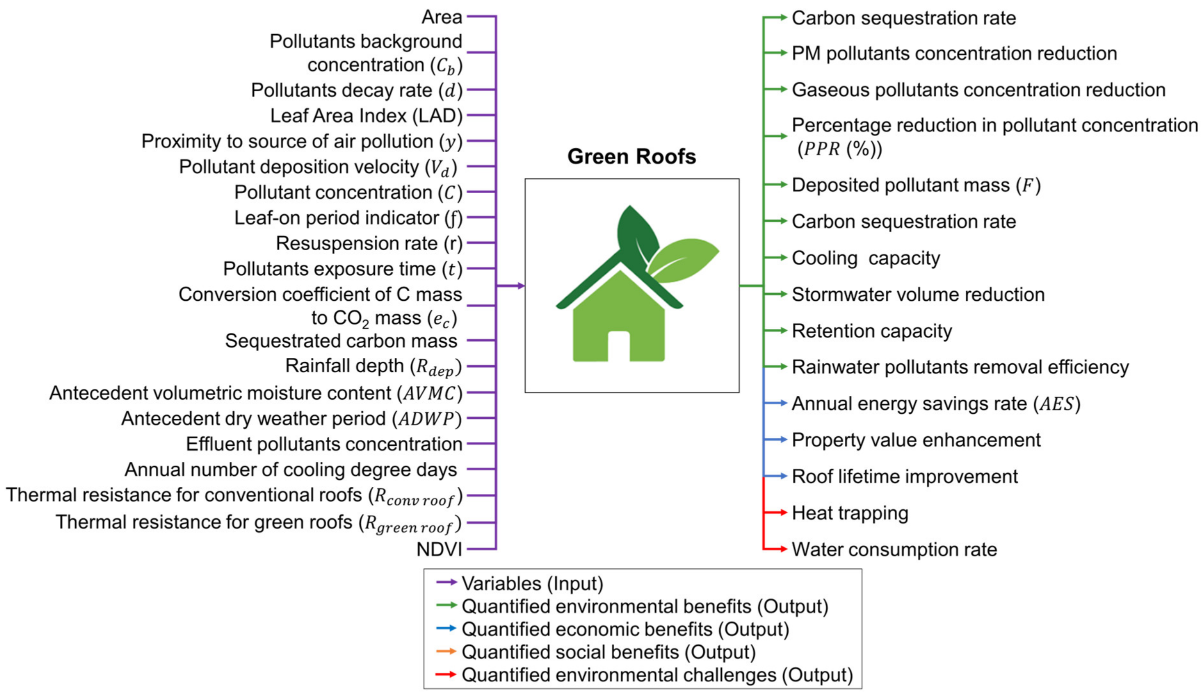

Figure 9. Green roofs' quantified impacts.

3.6.7. Green Walls

Green walls, also known as green facades, are utilized in building design not only for their aesthetic appeal but also for the environmental and economic benefits they provide [93]. Based on the information presented in the previous sections, Figure 10 provides a summary of the variables needed to quantify the benefits and challenges of these GIs.

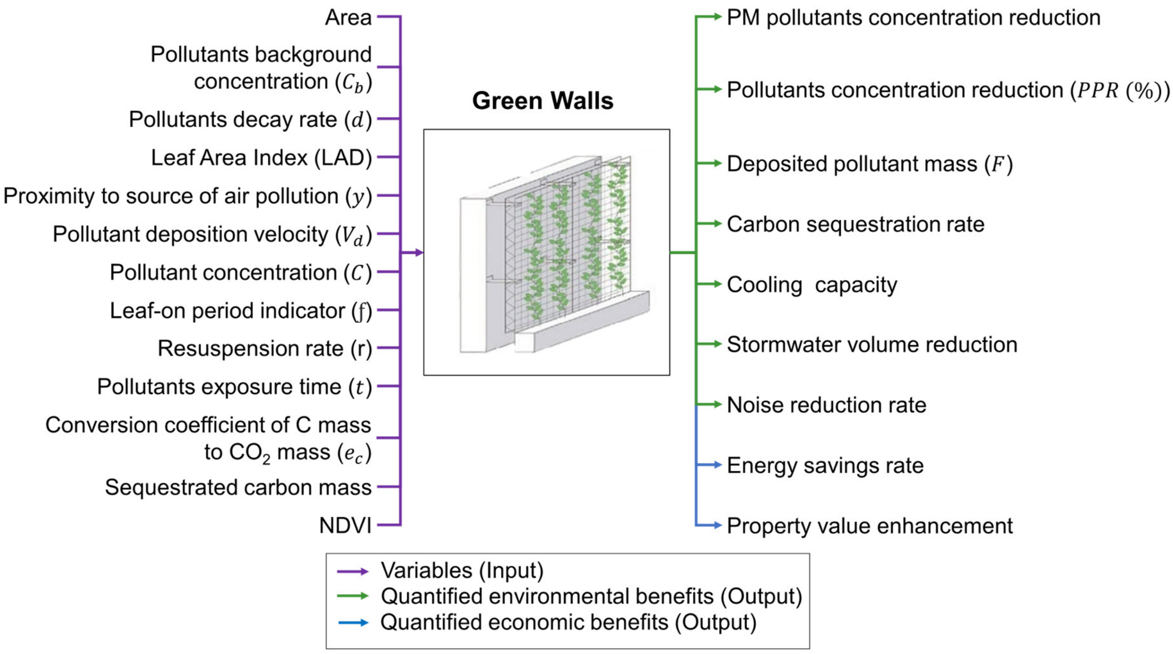

Figure 10. Green walls' quantified impacts.

3.6.8. Permeable Pavements

Permeable pavements have a porous top layer that allows water to pass through, and a drainage layer underneath that filters surface runoff [94]. Based on the information presented in the previous sections, Figure 11 provides a summary of the variables needed to quantify the benefits and challenges of these GIs.

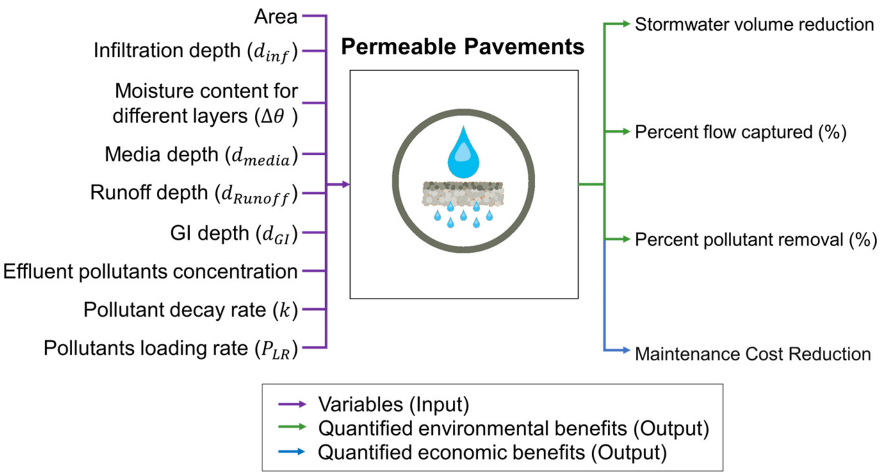

Figure 11. Permeable pavements' quantified impacts.

4. Discussion

While GI techniques are designed to have positive impacts on urban areas and the environment, they could also have negative impacts. Despite the extensive focus on the benefits of GIs in the literature (which often concentrated on quantifying the environmental, social, and economic aspects of GIs), the negative impacts of GIs are often overlooked where less attention is directed by researchers and practitioners. In this section the results are discussed to investigate the trends and patterns in the existing body of knowledge; identify gaps in the existing research; and suggest directions for future work.

4.1. Quantified Benefits of GIs

The benefits of GIs are diverse and include environmental, social, and economic impacts. Figure 12 represents the distribution of the benefits (i.e., environmental, economic, and social). It is worth mentioning that the sum in Figure 12 is not equal to 100% since some of the existing studies in the literature have focused on more than one benefit (i.e., a single article could have quantified one or more benefits).

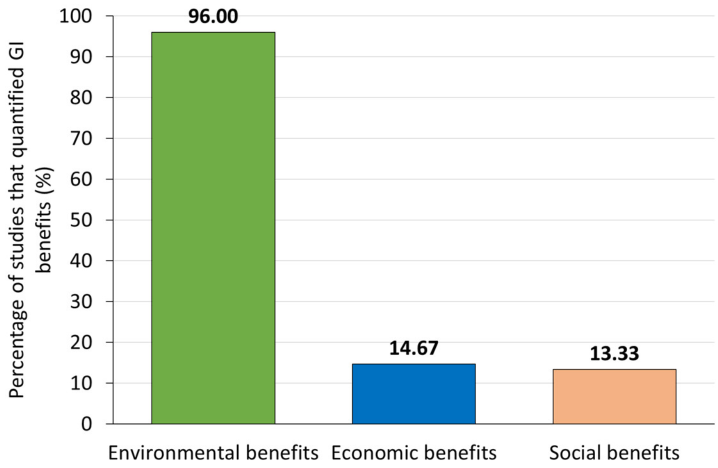

Figure 12. Distribution of GI quantified benefits.

As shown in Figure 12, the environmental benefits of GIs are often predominantly quantified by existing studies (96% of the reviewed articles); which shows that most of the research efforts were directed towards the environmental aspects of GIs with less focus on the economic and social benefits (14.67% and 13.33% of the reviewed articles, respectively). This could be because GI systems are primarily designed to address environmental challenges. Therefore, future research studies are recommended to delve more into the economic and social benefits of GIs.

Furthermore, little to no studies have quantified the socioeconomic benefits of GIs such as improved quality of life, increased sense of community, and property value enhancements. One reason behind this could be that these benefits are considered indirect and difficult to measure. In addition, since the benefits of GIs generally are realized over a long period, it might be difficult to accurately measure their value. Moreover, since there may be other factors that influence the socioeconomic impacts of GIs (such as economic trends or changes in land use patterns), this makes it challenging to accurately quantify the socioeconomic impacts of GIs. Thus, to accurately measure and quantify the holistic impacts of GIs, it is often necessary to use a combination of both quantitative and qualitative methods, which future studies might need to consider when studying GIs.

Moreover, the literature showed that even within a single category of benefits, there is some bias toward quantifying certain benefits over others. Figure 13 represents this variation and visualizes the detailed statistics about the quantified benefits in the literature within each category; where it is to be noted that a single study could have quantified one or more benefits.

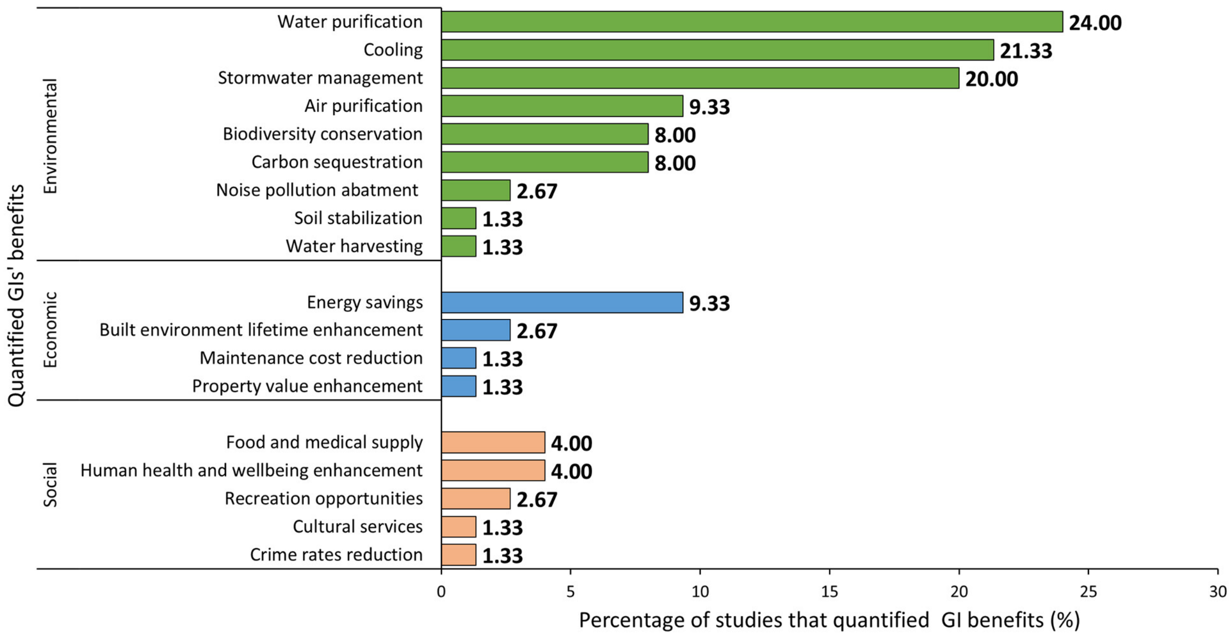

Figure 13. Distribution of the quantified benefits of GIs.

Within the environmental benefits, Figure 13 shows that water purification (24%) was the most quantified environmental benefit in the literature; whereas soil stabilization (1.33%) and water harvesting (1.33%) are the least quantified environmental benefits. This indicates that some environmental benefits of GIs are easier to quantify than others because they can be measured directly through monitoring and measurement techniques. These types of benefits are often referred to as "tangible" benefits since they can be quantified using numerical data [95]. Other environmental benefits of GI may be more difficult to quantify because they are less tangible or because they involve subjective experiences and perceptions.

Furthermore, Figure 13 shows that within the economic benefits, the energy savings benefit is the most quantified in the literature (9.33%) compared to property value enhancement and maintenance cost reduction (1.33% each). This reflects the high interest in energy saving to address climate change and reduce the burning of fossil fuels which is a major contributor to greenhouse gas emissions [96]. While there is evidence that GIs have a positive impact on property values, it is generally difficult to quantify such impacts since property values are determined by a variety of factors such as location, size, and condition, making it difficult to isolate the specific impact of GIs. Moreover, the maintenance of GIs is usually a long-term process which makes it hard to track and quantify their costs and related aspects.

Finally, Figure 13 shows that, among the social benefits, "food and medical supply" as well as "human health and mental well-being enhancement" are the most quantified in the literature (4.00% each), whereas cultural services and crime rate reduction are the least quantified (1.33% each). This, again, shows a bias toward quantifying certain benefits in the literature as compared to other equally important benefits. It is also worth mentioning that, while GIs' benefits on human health and mental well-being may be challenging to quantify, they are closely related to other benefits that have been measured in the literature, such as recreational opportunities, air and water purification, heat stress reduction, and noise pollution reduction [97]. Furthermore, the literature review reveals a gap in terms of quantifying other key social benefits of GIs such as environmental education and the feeling of community belonging which are also considered valuable contributions of GIs [9,98].

4.2. Quantified Challenges of GIs

A similar analysis is performed for the quantified challenges of GI, as represented in Figure 14.

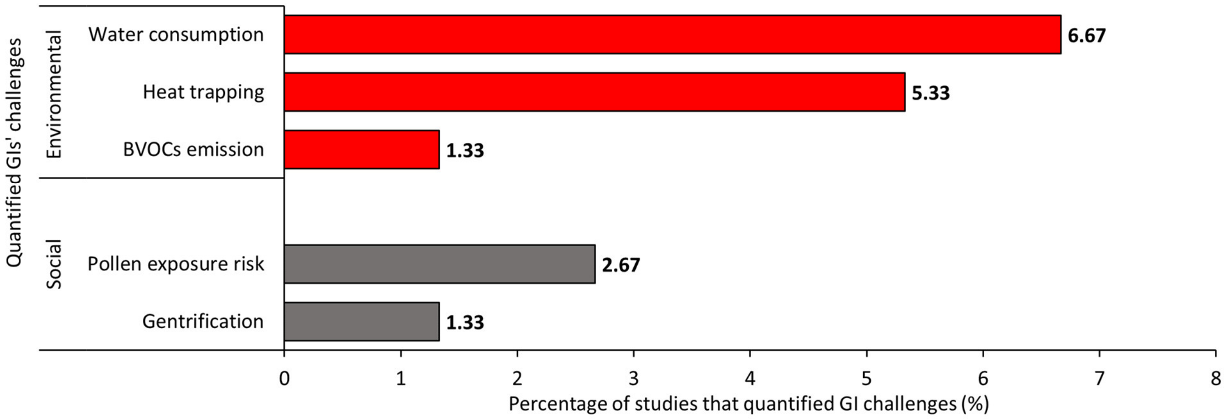

Figure 14. The distribution of quantified challenges based on the number of studies.

According to Figure 13, the relative distributions of the quantified challenges of GIs indicate that the environmental challenges were the most quantified in the literature (13.33%), whereas the social challenges were less quantified (4.00%), and little to no studies quantified the economic challenges of GIs. Moreover, among the environmental challenges, water consumption was the most quantified (6.77%), whereas BVOC emission was the least quantified environmental challenge in the literature (1.33%), as shown in Figure 13. As for the social category, some challenges were more quantified than others where pollen risk exposure was the most quantified (2.67%) and gentrification was the least quantified social challenge (1.33%). It is worth mentioning that, the quantification of gentrification is challenging due to its multi-dimensional complexity [99].

Overall, Figure 14 shows that the social challenges of GI are less understood compared to the environmental challenges. The tangential focus on quantifying the challenges of GI can be problematic, as this makes it difficult to fully understand and address the different aspects of GIs. In fact, to ensure that GIs are effective and sustainable in the long term, it is important to carefully consider and quantify both their benefits as well as challenges, which would help in identifying opportunities for improvement and optimizing their performance as well as related policies and regulations.

Finally, some of the quantified challenges could be addressed through adaptive measures provided in the literature. For instance, since GIs (such as trees) could trap heat and reduce wind ventilation, especially at night [38], it is recommended to plant trees with a larger separating distance to enable wind circulation [100]. Further, to address the water consumption challenge, the use of high concentrations of humic acid (200 mg/L) could increase the water use efficiency by approximately 40%; this level of humic acid reduces the evapotranspiration rate by 10–15 mL/day [84]. Since the release of BVOCs and pollen from trees has a significant negative impact on air quality and human health, it is important to further consider species that do not emit BVOCs when designing GIs [101].

4.3. GI Types

To better understand which GIs were the most studied by previous literature and which ones need further consideration, Figure 15 presents the percentage of previous studies that focused on each GI type. It is worth mentioning that within the reviewed papers, one study may have focused on one or more GI types.

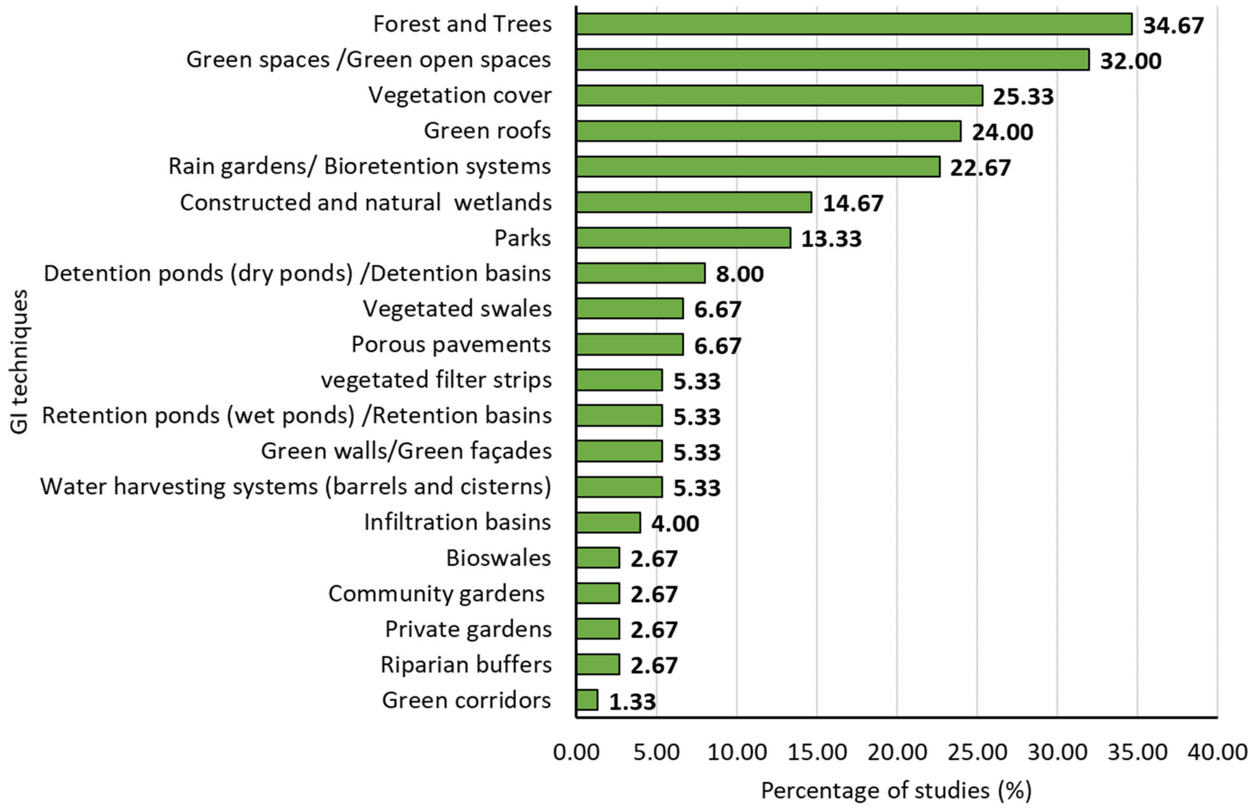

Figure 15. The focus of previous studies on different GI types.

Figure 15 shows that there is a significant emphasis on natural GI solutions such as forests, trees, green spaces, and vegetation cover. This could be due to the fact that these types of natural green spaces are widely available in various countries and their effects are more observable due to their larger areas. Other common GI types whose benefits and challenges were quantified include green roofs, rain gardens, and wetlands. On the other hand, the GI types whose benefits and challenges were least studied include bioswales, community gardens, private gardens, riparian buffers, and green corridors. Therefore, future studies are recommended to focus on these least-studied GIs.

5. Contributions and Implications

The performed literature review in this paper contributes to the body of knowledge by the development of a comprehensive guide and reference for researchers and practitioners that could be used to help them in quantifying the environmental, social, and economic benefits and challenges of GIs. The provided information in this paper is valuable for policymakers, practitioners, and researchers looking to advance the GI-related field and make informed decisions about GI projects.

Providing quantifications of GI's benefits and challenges is useful to practitioners in several ways. First, it helps practitioners to understand the potential benefits that are gained from implementing GIs. This is particularly useful for practitioners working in the planning and design of green cities; where they can use the information provided in this paper to make informed decisions about the types of GI interventions that are most effective in a given area. Moreover, the reported information in this study helps practitioners to better understand the potential negative impacts of their GI strategies. This information is useful to investigate ways and methods to mitigate these challenges and ensure the long-term success of GI interventions on different levels: environmentally, economically, and socially.

Policymakers could also benefit from the quantification of GI's benefits and challenges presented in this paper. By understanding the potential benefits and challenges associated with different types of GI interventions, policymakers may develop successful policies and programs to support the implementation of GI in different contexts. Furthermore, the presented quantification helps policymakers understand the trade-offs that may be involved when selecting different GIs, and it informs the development of effective policies and programs that achieve the required environmental, social, or economic goals.

For researchers, the quantification models and methods of GI's benefits and challenges summarized in this paper can provide valuable data that could be used to further advance the understanding of the ways GIs are used to support environmental, social, and economic purposes. This information could be used to guide the development of tools and methods for assessing the impacts of GIs on different aspects of the built and natural environments as well as to develop new research directions that are needed to better understand the different aspects and multi-dimensional characteristics of GIs. Additionally, this paper helps researchers to identify the current trends and gaps in the body knowledge as well as areas where additional research might be required.

6. Conclusions and Future Work

This paper conducted a systematic review of existing literature where 75 articles were comprehensively reviewed and critically analyzed with a focus on models and methods that were used and developed by existing studies to quantify the different environmental, economic, and social benefits and challenges of GIs.

The following environmental benefits were analyzed and discussed in the paper: air purification, carbon sequestration, cooling, stormwater management, water purification, water harvesting, noise pollution reduction, biodiversity conservation, and soil stabilization. As for the economic benefits, they included energy savings, property value enhancement, built environment lifetime enhancement, and maintenance cost reduction. The following social benefits were examined in the paper: recreation opportunities, human health and well-being enhancement, crime rate reduction, food and medical supply, and cultural services.

As for the challenges, those related to environmental concerns included BVOC emissions, heat-trapping, and water consumption. The following social challenges were also analyzed and discussed in the paper: gentrification and pollen exposure risk.

The results also indicated that most of the literature quantified the environmental benefits of GIs (96%), whereas fewer studies focused on quantifying their social and economic benefits (28%). As for GI-related challenges, the environmental challenges were the most quantified in the literature (13.33%), followed by the social challenges (4%), and little-to-no studies quantified the economic challenges. The results showed that the literature heavily focused on different GI types, where forests and trees were the focus of over 34% of the studies, whereas green corridors were the focus of less than 2% of the studies.

Overall, the results showed that the GIs' benefits are pronominally quantified compared to their challenges. One area that could be the potential focus of future research studies could be the social and psychological benefits of GIs. While some studies have shown that green spaces can have a positive impact on mental health and social interactions, more research is needed to have an in-depth understanding of these effects. This could include studies on the impact of different types of green spaces on different sects of the population, as well as the long-term effects of green spaces on mental and physical health. Another potential area of future research focus could be on understanding the long-term effectiveness of different GI approaches. While many studies have shown that GIs can provide a range of benefits, there is still a need for more research on the durability and sustainability of these benefits over time. Other areas of research could include exploring the potential negative impacts of GIs on wildlife and biodiversity, as well as the potential for GIs to contribute to gentrification and displacement in urban areas.

This paper presents a comprehensive literature review that contributes to the growing body of research on GI by providing a comprehensive guide and reference for researchers, practitioners, and policymakers seeking to quantify the environmental, social, and economic benefits and challenges of GIs. The information provided supports the development of successful GI-related policies and programs, enabling planners and policymakers to make informed decisions regarding GI projects in a way that maximizes benefits and mitigates the risk of unintended consequences. This ensures the long-term success of GI interventions on environmental, social, and economic levels. Furthermore, researchers can benefit from the summarized models and methods, which offer valuable data for advancing the understanding of GI's multi-dimensional characteristics and assessment tools. Additionally, this paper helps identify current trends, knowledge gaps, and areas requiring further research, thus promoting the development of new research directions.

Future research work could also be conducted by focusing on a certain benefit or challenge of GI so that more in-depth analysis and quantification of each aspect could be achieved for interested stakeholders. This includes, for example, focusing on the flood mitigation benefits of GIs (which might be of interest to flood risk managers and agencies) or on the impact of GIs on property values that could be affected by different factors and variables (which might be of interest to urban planners and developers), among other aspects of interest.

Author Contributions: Conceptualization, R.H.A.; methodology, R.H.A., Y.J., and G.A.; formal analysis, Y.J.; data curation, Y.J.; writing—original draft preparation, Y.J. and G.A.; writing—review and editing, R.H.A.; supervision, R.H.A.; project administration, R.H.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. United Nations, Department of Economic and Social Affairs. *World Urbanization Prospects The 2018 Revision*; United Nations: New York, NY, USA, 2018.
2. Center for Sustainable Systems, University of Michigan. U.S. Cities Factsheet. In *Built Environment*; Pub. No. C.-06; Center for Sustainable Systems, University of Michigan: Ann Arbor, MI, USA, 2022.
3. Awumbila, M. Drivers of Migration and Urbanization in Africa: Key Trends and Issues. In Proceedings of the UN Expert Group Meeting on Sustainable Cities, Human Mobility and International Migration, New York, NY, USA, 7–8 September 2017.
4. Buckley, R.M.; Annez, P.C.; Spence, M. *Urbanization and Growth*; World Bank Publications: Washington, DC, USA, 2008.
5. Parr, T.B.; Smucker, N.J.; Bentsen, C.N.; Neale, M.W. Potential Roles of Past, Present, and Future Urbanization Characteristics in Producing Varied Stream Responses. In *Freshwater Science*; University of Chicago Press: Chicago, IL, USA, 2016; pp. 436–443. https://doi.org/10.1086/685030.
6. Dhakal, K.P.; Chevalier, L.R. Managing Urban Stormwater for Urban Sustainability: Barriers and Policy Solutions for Green Infrastructure Application. *J. Environ. Manag.* **2017**, *203*, 171–181. https://doi.org/10.1016/j.jenvman.2017.07.065.
7. Xie, L.; Shu, X.; Kotze, D.J.; Kuoppamäki, K.; Timonen, S.; Lehvävirta, S. Plant Growth-Promoting Microbes Improve Stormwater Retention of a Newly-Built Vertical Greenery System. *J. Environ. Manag.* **2022**, *323*. https://doi.org/10.1016/j.jenvman.2022.116274.
8. Sarni, W. The Case for Green Infrastructure in LAC Conclusions from Stockholm World Water Week 2018; 2019. Available online: http://www.iadb.org (accessed on 20 December 2022).
9. Tzoulas, K.; Korpela, K.; Venn, S.; Yli-Pelkonen, V.; Kaźmierczak, A.; Niemela, J.; James, P. Promoting Ecosystem and Human Health in Urban Areas Using Green Infrastructure: A Literature Review. In *Landscape and Urban Planning*; Elsevier: Amsterdam, The Netherlands, 2007; pp. 167–178. https://doi.org/10.1016/j.landurbplan.2007.02.001.

10. Venkataramanan, V.; Lopez, D.; McCuskey, D.J.; Kiefus, D.; McDonald, R.I.; Miller, W.M.; Packman, A.I.; Young, S.L. Knowledge, Attitudes, Intentions, and Behavior Related to Green Infrastructure for Flood Management: A Systematic Literature Review. *Sci. Total Environ.* **2020**, *720*, 137606. https://doi.org/10.1016/j.scitotenv.2020.137606.
11. Norton, B.A.; Coutts, A.M.; Livesley, S.J.; Harris, R.J.; Hunter, A.M.; Williams, N.S.G. Planning for Cooler Cities: A Framework to Prioritise Green Infrastructure to Mitigate High Temperatures in Urban Landscapes. *Landsc. Urban Plan* **2015**, *134*, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018.
12. Filazzola, A.; Shrestha, N.; MacIvor, J.S. The Contribution of Constructed Green Infrastructure to Urban Biodiversity: A Synthesis and Meta-analysis. *J. Appl. Ecol.* **2019**, *56*, 2131–2143. https://doi.org/10.1111/1365-2664.13475.
13. Demuzere, M.; Orru, K.; Heidrich, O.; Olazabal, E.; Geneletti, D.; Orru, H.; Bhave, A.G.; Mittal, N.; Feliú, E.; Faehnle, M. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *J. Environ. Manag*. **2014**, *146*, 107–115. https://doi.org/10.1016/j.jenvman.2014.07.025.
14. Byrne, J.A.; Lo, A.Y.; Jianjun, Y. Residents' Understanding of the Role of Green Infrastructure for Climate Change Adaptation in Hangzhou, China. *Landsc. Urban Plan* **2015**, *138*, 132–143. https://doi.org/10.1016/j.landurbplan.2015.02.013.
15. Choi, C.; Berry, P.; Smith, A. The Climate Benefits, Co-Benefits, and Trade-Offs of Green Infrastructure: A Systematic Literature Review. *J. Environ. Manag.* **2021**, *291*, 112583. https://doi.org/10.1016/j.jenvman.2021.112583.
16. Wang, Y.; Ni, Z.; Hu, M.; Li, J.; Wang, Y.; Lu, Z.; Chen, S.; Xia, B. Environmental Performances and Energy Efficiencies of Various Urban Green Infrastructures: A Life-Cycle Assessment. *J. Clean Prod.* **2020**, *248*. https://doi.org/10.1016/j.jclepro.2019.119244.
17. Jim, C.Y. Assessing Climate-Adaptation Effect of Extensive Tropical Green Roofs in Cities. *Landsc. Urban Plan* **2015**, *138*, 54–70. https://doi.org/10.1016/j.landurbplan.2015.02.014.
18. Huang, B.; Yao, Z.; Pearce, J.R.; Feng, Z.; Browne, A.J.; Pan, Z.; Liu, Y. Non-linear association between residential greenness and general health among old adults in China. *Landsc. Urban Plan.* **2022**, *223*, 104406. https://doi.org/10.1016/j.landurbplan.2022.104406.
19. Venter, Z.S.; Shackleton, C.; Faull, A.; Lancaster, L.; Breetzke, G.; Edelstein, I. Is Green Space Associated with Reduced Crime? A National-Scale Study from the Global South. *Sci. Total Environ.* **2022**, *825*. https://doi.org/10.1016/j.scitotenv.2022.154005.
20. Liu, Y.; Wang, R.; Grekousis, G.; Liu, Y.; Yuan, Y.; Li, Z. Neighbourhood Greenness and Mental Wellbeing in Guangzhou, China: What Are the Pathways? *Landsc. Urban Plan* **2019**, *190*. https://doi.org/10.1016/j.landurbplan.2019.103602.
21. Walker, R.H. Engineering Gentrification: Urban Redevelopment, Sustainability Policy, and Green Stormwater Infrastructure in Minneapolis. *J. Environ. Policy Plan.* **2021**, *23*, 646–664. https://doi.org/10.1080/1523908X.2021.1945917.
22. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Liberati, A.; Altman, D.G. Reprint-Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement; 2009. Available online: http://www.annals.org/cgi/content/full/151/4/264 (accessed on 27 April 2023).
23. Berardi, U.; GhaffarianHoseini, A.; GhaffarianHoseini, A. State-of-the-Art Analysis of the Environmental Benefits of Green Roofs. *Appl. Energy* **2014**, *115*, 411–428. https://doi.org/10.1016/j.apenergy.2013.10.047.
24. Tomson, M.; Kumar, P.; Barwise, Y.; Perez, P.; Forehead, H.; French, K.; Morawska, L.; Watts, J.F. Green Infrastructure for Air Quality Improvement in Street Canyons. In *Environment International*; Elsevier Ltd.: Amsterdam, The Netherlands, 2021. https://doi.org/10.1016/j.envint.2020.106288.
25. Liu, O.Y.; Russo, A. Assessing the contribution of urban green spaces in green infrastructure strategy planning for urban ecosystem conditions and services. *Sustain. Cities Soc.* **2021**, *68*, 102772. https://doi.org/10.1016/j.scs.2021.102772.
26. Chen, H.S.; Lin, Y.C.; Chiueh, P.T. High-resolution spatial analysis for the air quality regulation service from urban vegetation: A case study of Taipei City. *Sustain. Cities Soc.* **2022**, *83*, 103976. https://doi.org/10.1016/j.scs.2022.103976.
27. Weerakkody, U.; Dover, J.W.; Mitchell, P.; Reiling, K. Quantification of the Traffic-Generated Particulate Matter Capture by Plant Species in a Living Wall and Evaluation of the Important Leaf Characteristics. *Sci. Total Environ.* **2018**, *635*, 1012–1024. https://doi.org/10.1016/j.scitotenv.2018.04.106.
28. Alves, A.; Gersonius, B.; Kapelan, Z.; Vojinovic, Z.; Sanchez, A. Assessing the Co-Benefits of Green-Blue-Grey Infrastructure for Sustainable Urban Flood Risk Management. *J. Environ. Manag.* **2019**, *239*, 244–254. https://doi.org/10.1016/j.jenvman.2019.03.036.
29. Barwise, Y.; Kumar, P.; Tiwari, A.; Rafi-Butt, F.; McNabola, A.; Cole, S.; Field, B.C.T.; Fuller, J.; Mendis, J.; Wyles, K.J. The Co-Development of HedgeDATE, a Public Engagement and Decision Support Tool for Air Pollution Exposure Mitigation by Green Infrastructure. *Sustain. Cities Soc.* **2021**, *75*. https://doi.org/10.1016/j.scs.2021.103299.
30. Tiwari, A.; Kumar, P. Integrated Dispersion-Deposition Modelling for Air Pollutant Reduction via Green Infrastructure at an Urban Scale. *Sci. Total Environ.* **2020**, *723*, 138078. https://doi.org/10.1016/j.scitotenv.2020.138078.
31. Tiwari, A.; Kumar, P. Quantification of Green Infrastructure Effects on Airborne Nanoparticles Dispersion at an Urban Scale. *Sci. Total Environ.* **2022**, *838*, 155778. https://doi.org/10.1016/j.scitotenv.2022.155778.
32. Ramyar, R.; Saeedi, S.; Bryant, M.; Davatgar, A.; Mortaz Hedjri, G. Ecosystem Services Mapping for Green Infrastructure Planning–The Case of Tehran. *Sci. Total Environ.* **2020**, *703*, 135466. https://doi.org/10.1016/j.scitotenv.2019.135466.
33. Schmidt, J.P.; Moore, R.; Alber, M. Integrating Ecosystem Services and Local Government Finances into Land Use Planning: A Case Study from Coastal Georgia. *Landsc. Urban Plan* **2014**, *122*, 56–67. https://doi.org/10.1016/j.landurbplan.2013.11.008.
34. Chen, Y.; Ge, Y.; Yang, G.; Wu, Z.; Du, Y.; Mao, F.; Liu, S.; Xu, R.; Qu, Z.; Xu, B.; et al. Inequalities of Urban Green Space Area and Ecosystem Services along Urban Center-Edge Gradients. *Landsc. Urban Plan* **2022**, *217*. https://doi.org/10.1016/j.landurbplan.2021.104266.

35. Doick, K.J.; Peace, A.; Hutchings, T.R. The Role of One Large Greenspace in Mitigating London's Nocturnal Urban Heat Island. *Sci. Total Environ.* **2014**, *493*, 662–671. https://doi.org/10.1016/j.scitotenv.2014.06.048.
36. Du, C.; Jia, W.; Chen, M.; Yan, L.; Wang, K. How Can Urban Parks Be Planned to Maximize Cooling Effect in Hot Extremes? Linking Maximum and Accumulative Perspectives. *J. Environ. Manag.* **2022**, *317*. https://doi.org/10.1016/j.jenvman.2022.115346.
37. Shi, D.; Song, J.; Huang, J.; Zhuang, C.; Guo, R.; Gao, Y. Synergistic Cooling Effects (SCEs) of Urban Green-Blue Spaces on Local Thermal Environment: A Case Study in Chongqing, China. *Sustain. Cities Soc.* **2020**, *55*. https://doi.org/10.1016/j.scs.2020.102065.
38. Razzaghmanesh, M.; Borst, M.; Liu, J.; Ahmed, F.; O'Connor, T.; Selvakumar, A. Air Temperature Reductions at the Base of Tree Canopies. *.J Sustain. Water Built. Environ.* **2021**, *7*. https://doi.org/10.1061/jswbay.0000950.
39. Alim, M.A.; Rahman, A.; Tao, Z.; Garner, B.; Griffith, R.; Liebman, M. Green Roof as an Effective Tool for Sustainable Urban Development: An Australian Perspective in Relation to Stormwater and Building Energy Management. *J. Clean. Prod.* **2022**. https://doi.org/10.1016/j.jclepro.2022.132561.
40. Marando, F.; Heris, M.P.; Zulian, G.; Udías, A.; Mentaschi, L.; Chrysoulakis, N.; Parastatidis, D.; Maes, J. Urban Heat Island Mitigation by Green Infrastructure in European Functional Urban Areas. *Sustain. Cities Soc.* **2022**, *77*. https://doi.org/10.1016/j.scs.2021.103564.
41. Zhuang, Q.; Lu, Z. Optimization of Roof Greening Spatial Planning to Cool Down the Summer of the City. *Sustain. Cities Soc.* **2021**, *74*. https://doi.org/10.1016/j.scs.2021.103221.
42. Dong, J.; Peng, J.; He, X.; Corcoran, J.; Qiu, S.; Wang, X. Heatwave-Induced Human Health Risk Assessment in Megacities Based on Heat Stress-Social Vulnerability-Human Exposure Framework. *Landsc. Urban Plan* **2020**, *203*. https://doi.org/10.1016/j.landurbplan.2020.103907.
43. Rocha, A.D.; Vulova, S.; Meier, F.; Förster, M.; Kleinschmit, B. Mapping Evapotranspirative and Radiative Cooling Services in an Urban Environment. *Sustain. Cities Soc.* **2022**, *85*. https://doi.org/10.1016/j.scs.2022.104051.
44. Feyisa, G.L.; Dons, K.; Meilby, H. Efficiency of Parks in Mitigating Urban Heat Island Effect: An Example from Addis Ababa. *Landsc. Urban Plan* **2014**, *123*, 87–95. https://doi.org/10.1016/j.landurbplan.2013.12.008.
45. Cheng, X.; Wei, B.; Chen, G.; Li, J.; Song, C. Influence of Park Size and Its Surrounding Urban Landscape Patterns on the Park Cooling Effect. *.J Urban Plan Dev.* **2015**, *141*. https://doi.org/10.1061/(asce)up.1943-5444.0000256.
46. Venter, Z.S.; Krog, N.H.; Barton, D.N. Linking Green Infrastructure to Urban Heat and Human Health Risk Mitigation in Oslo, Norway. *Sci. Total Environ.* **2020**, *709*. https://doi.org/10.1016/j.scitotenv.2019.136193.
47. Liu, Y.; Engel, B.A.; Flanagan, D.C.; Gitau, M.W.; McMillan, S.K.; Chaubey, I. A Review on Effectiveness of Best Management Practices in Improving Hydrology and Water Quality: Needs and Opportunities. *Sci. Total Environ.* **2017**, *601*, 580–593. https://doi.org/10.1016/j.scitotenv.2017.05.212.
48. Li, S.; Kazemi, H.; Rockaway, T.D. Performance Assessment of Stormwater GI Practices Using Artificial Neural Networks. *Sci. Total Environ.* **2019**, *651*, 2811–2819. https://doi.org/10.1016/j.scitotenv.2018.10.155.
49. Mason, E.; Montalto, F.A. The Overlooked Role of New York City Urban Yards in Mitigating and Adapting to Climate Change. *Local Environ.* **2015**, *20*, 1412–1427. https://doi.org/10.1080/13549839.2014.907249.
50. Ebrahimian, A.; Wadzuk, B.; Traver, R. Evapotranspiration in Green Stormwater Infrastructure Systems. *Sci. Total Environ.* **2019**, *688*, 797–810. https://doi.org/10.1016/j.scitotenv.2019.06.256.
51. Shojaeizadeh, A.; Geza, M.; Hogue, T.S. GIP-SWMM: A New Green Infrastructure Placement Tool Coupled with SWMM. *J. Environ. Manag.* **2021**, *277*. https://doi.org/10.1016/j.jenvman.2020.111409.
52. Dai, X.; Wang, L.; Tao, M.; Huang, C.; Sun, J.; Wang, S. Assessing the Ecological Balance between Supply and Demand of Blue-Green Infrastructure. *J. Environ. Manag.* **2021**, *288*. https://doi.org/10.1016/j.jenvman.2021.112454.
53. van Oorschot, J.; Sprecher, B.; van 't Zelfde, M.; van Bodegom, P.M.; van Oudenhoven, A.P.E. Assessing Urban Ecosystem Services in Support of Spatial Planning in the Hague, the Netherlands. *Landsc. Urban Plan* **2021**, *214*. https://doi.org/10.1016/j.landurbplan.2021.104195.
54. Li, C.; Liu, M.; Hu, Y.; Zhou, R.; Wu, W.; Huang, N. Evaluating the Runoff Storage Supply-Demand Structure of Green Infrastructure for Urban Flood Management. *J. Clean Prod.* **2021**, *280*. https://doi.org/10.1016/j.jclepro.2020.124420.
55. Wong, G.K.L.; Jim, C.Y. Identifying Keystone Meteorological Factors of Green-Roof Stormwater Retention to Inform Design and Planning. *Landsc. Urban Plan* **2015**, *143*, 173–182. https://doi.org/10.1016/j.landurbplan.2015.07.001.
56. Fan, G.; Lin, R.; Wei, Z.; Xiao, Y.; Shangguan, H.; Song, Y. Effects of Low Impact Development on the Stormwater Runoff and Pollution Control. *Sci. Total Environ.* **2022**, *805*. https://doi.org/10.1016/j.scitotenv.2021.150404.
57. Gong, Y.; Zhang, X.; Li, H.; Zhang, X.; He, S.; Miao, Y. A Comparison of the Growth Status, Rainfall Retention and Purification Effects of Four Green Roof Plant Species. *J. Environ. Manag.* **2021**, *278*. https://doi.org/10.1016/j.jenvman.2020.111451.
58. Fu, X.; Hopton, M.E.; Wang, X.; Goddard, H.; Liu, H. A Runoff Trading System to Meet Watershed-Level Stormwater Reduction Goals with Parcel-Level Green Infrastructure Installation. *Sci. Total Environ.* **2019**, *689*, 1149–1159. https://doi.org/10.1016/j.scitotenv.2019.06.439.
59. Martin-Mikle, C.J.; de Beurs, K.M.; Julian, J.P.; Mayer, P.M. Identifying Priority Sites for Low Impact Development (LID) in a Mixed-Use Watershed. *Landsc. Urban Plan* **2015**, *140*, 29–41. https://doi.org/10.1016/j.landurbplan.2015.04.002.
60. Gavrić, S.; Leonhardt, G.; Marsalek, J.; Viklander, M. Processes Improving Urban Stormwater Quality in Grass Swales and Filter Strips: A Review of Research Findings. *Sci. Total Environ.* **2019**, *669*, 431–447. https://doi.org/10.1016/j.scitotenv.2019.03.072.

61. Hoyle, H.; Hitchmough, J.; Jorgensen, A. All about the 'Wow Factor'? The Relationships between Aesthetics, Restorative Effect and Perceived Biodiversity in Designed Urban Planting. *Landsc. Urban Plan* **2017**, *164*, 109–123. https://doi.org/10.1016/j.landurbplan.2017.03.011.
62. Matos, P.; Vieira, J.; Rocha, B.; Branquinho, C.; Pinho, P. Modeling the Provision of Air-Quality Regulation Ecosystem Service Provided by Urban Green Spaces Using Lichens as Ecological Indicators. *Sci. Total Environ.* **2019**, *665*, 521–530. https://doi.org/10.1016/j.scitotenv.2019.02.023.
63. Wong, G.K.L.; Jim, C.Y. Do Vegetated Rooftops Attract More Mosquitoes? Monitoring Disease Vector Abundance on Urban Green Roofs. *Sci. Total Environ.* **2016**, *573*, 222–232. https://doi.org/10.1016/j.scitotenv.2016.08.102.
64. Mitsova, D.; Shuster, W.; Wang, X. A Cellular Automata Model of Land Cover Change to Integrate Urban Growth with Open Space Conservation. *Landsc. Urban Plan 2011*, *99*, 141–153. https://doi.org/10.1016/j.landurbplan.2010.10.001.
65. Wang, J.; Rienow, A.; David, M.; Albert, C. Green Infrastructure Connectivity Analysis across Spatiotemporal Scales: A Transferable Approach in the Ruhr Metropolitan Area, Germany. *Sci. Total Environ.* **2022**, *813*. https://doi.org/10.1016/j.scitotenv.2021.152463.
66. Chen, D.; Zhang, F.; Zhang, M.; Meng, Q.; Jim, C.Y.; Shi, J.; Tan, M.L.; Ma, X. Landscape and Vegetation Traits of Urban Green Space Can Predict Local Surface Temperature. *Sci. Total Environ.* **2022**, *825*. https://doi.org/10.1016/j.scitotenv.2022.154006.
67. Deutscher, J.; Kupec, P.; Kučera, A.; Urban, J.; Ledesma, J.L.J.; Futter, M. Ecohydrological Consequences of Tree Removal in an Urban Park Evaluated Using Open Data, Free Software and a Minimalist Measuring Campaign. *Sci. Total Environ.* **2019**, *655*, 1495–1504. https://doi.org/10.1016/j.scitotenv.2018.11.277.
68. Scheidl, C.; Heiser, M.; Kamper, S.; Thaler, T.; Klebinder, K.; Nagl, F.; Lechner, V.; Markart, G.; Rammer, W.; Seidl, R. The Influence of Climate Change and Canopy Disturbances on Landslide Susceptibility in Headwater Catchments. *Sci. Total Environ.* **2020**, *742*. https://doi.org/10.1016/j.scitotenv.2020.140588.
69. Koroxenidis, E.; Theodosiou, T. Comparative Environmental and Economic Evaluation of Green Roofs under Mediterranean Climate Conditions – Extensive Green Roofs a Potentially Preferable Solution. *J. Clean. Prod.* **2021**, *311*. https://doi.org/10.1016/j.jclepro.2021.127563.
70. Shih, W.Y. Socio-Ecological Inequality in Heat: The Role of Green Infrastructure in a Subtropical City Context. *Landsc. Urban Plan* **2022**, *226*. https://doi.org/10.1016/j.landurbplan.2022.104506.
71. Neumann, V.A.; Hack, J. Revealing and Assessing the Costs and Benefits of Nature-Based Solutions within a Real-World Laboratory in Costa Rica. *Environ. Impact Assess Rev.* **2022**, *93*, 106737. https://doi.org/10.1016/j.eiar.2022.106737.
72. Tiwary, A.; Kumar, P. Impact Evaluation of Green-Grey Infrastructure Interaction on Built-Space Integrity: An Emerging Perspective to Urban Ecosystem Service. *Sci. Total Environ.* **2014**, *487*, 350–360. https://doi.org/10.1016/j.scitotenv.2014.03.032.
73. Maas, J.; Verheij, R.A.; Groenewegen, P.P.; de Vries, S.; Spreeuwenberg, P. Green Space, Urbanity, and Health: How Strong Is the Relation? *J. Epidemiol. Community Health* **2006**, *60*, 587–592. https://doi.org/10.1136/jech.2005.043125.
74. Derkzen, M.L.; van Teeffelen, A.J.A.; Verburg, P.H. REVIEW: Quantifying Urban Ecosystem Services Based on High-Resolution Data of Urban Green Space: An Assessment for Rotterdam, the Netherlands. *J. Appl. Ecol.* **2015**, *52*, 1020–1032. https://doi.org/10.1111/1365-2664.12469.
75. Xiao, Y.; Wang, D.; Fang, J. Exploring the Disparities in Park Access through Mobile Phone Data: Evidence from Shanghai, China. *Landsc. Urban Plan* **2019**, *181*, 80–91. https://doi.org/10.1016/j.landurbplan.2018.09.013.
76. Navarrete-Hernandez, P.; Laffan, K. A Greener Urban Environment: Designing Green Infrastructure Interventions to Promote Citizens' Subjective Wellbeing. *Landsc. Urban Plan* **2019**, *191*. https://doi.org/10.1016/j.landurbplan.2019.103618.
77. Song, S.; Lim, M.S.; Richards, D.R.; Tan, H.T.W. Utilization of the Food Provisioning Service of Urban Community Gardens: Current Status, Contributors and Their Social Acceptance in Singapore. *Sustain. Cities Soc.* **2022**, *76*, 103368. https://doi.org/10.1016/j.scs.2021.103368.
78. Langemeyer, J.; Camps-Calvet, M.; Calvet-Mir, L.; Barthel, S.; Gómez-Baggethun, E. Stewardship of Urban Ecosystem Services: Understanding the Value(s) of Urban Gardens in Barcelona. *Landsc. Urban Plan* **2018**, *170*, 79–89. https://doi.org/10.1016/j.landurbplan.2017.09.013.
79. Hurley, P.T.; Emery, M.R. Locating Provisioning Ecosystem Services in Urban Forests: Forageable Woody Species in New York City, USA. *Landsc. Urban Plan* **2018**, *170*, 266–275. https://doi.org/10.1016/j.landurbplan.2017.09.025.
80. Fitzky, A.C.; Sandén, H.; Karl, T.; Fares, S.; Calfapietra, C.; Grote, R.; Saunier, A.; Rewald, B. The Interplay Between Ozone and Urban Vegetation—BVOC Emissions, Ozone Deposition, and Tree Ecophysiology. *Front. For. Glob. Chang.* **2019**, *2*. https://doi.org/10.3389/ffgc.2019.00050.
81. Reyes-Paecke, S.; Gironás, J.; Melo, O.; Vicuña, S.; Herrera, J. Irrigation of Green Spaces and Residential Gardens in a Mediterranean Metropolis: Gaps and Opportunities for Climate Change Adaptation. *Landsc. Urban Plan* **2019**, *182*, 34–43. https://doi.org/10.1016/j.landurbplan.2018.10.006.
82. Houdeshel, C.D.; Hultine, K.R.; Johnson, N.C.; Pomeroy, C.A. Evaluation of Three Vegetation Treatments in Bioretention Gardens in a Semi-Arid Climate. *Landsc. Urban Plan* **2015**, *135*, 62–72. https://doi.org/10.1016/j.landurbplan.2014.11.008.
83. Razzaghmanesh, M.; Beecham, S.; Brien, C.J. Developing Resilient Green Roofs in a Dry Climate. *Sci. Total Environ.* **2014**, *490*, 579–589. https://doi.org/10.1016/j.scitotenv.2014.05.040.
84. Rabbani, M.; Kazemi, F. Water Need and Water Use Efficiency of Two Plant Species in Soil-Containing and Soilless Substrates under Green Roof Conditions. *J. Environ. Manag.* **2022**, *302*. https://doi.org/10.1016/j.jenvman.2021.113950.

85. Wolch, J.R.; Byrne, J.; Newell, J.P. Urban Green Space, Public Health, and Environmental Justice: The Challenge of Making Cities 'Just Green Enough.' *Landsc. Urban Plan* **2014**, *125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017.
86. Pearsall, H. From Brown to Green? Assessing Social Vulnerability to Environmental Gentrification in New York City. *Environ. Plan. C Gov. Policy* **2010**, *28*, 872–886. https://doi.org/10.1068/c08126.
87. Rigolon, A.; Németh, J. Green Gentrification or 'Just Green Enough': Do Park Location, Size and Function Affect Whether a Place Gentrifies or Not? *Urban Stud.* **2020**, *57*, 402–420. https://doi.org/10.1177/0042098019849380.
88. Fernández-Alvarado, J.F.; Coloma-Miró, J.F.; Cortés-Pérez, J.P.; García-García, M.; Fernández-Rodríguez, S. Proposing a Sustainable Urban 3D Model to Minimize the Potential Risk Associated with Green Infrastructure by Applying Engineering Tools. *Sci. Total Environ.* **2022**, *812*, 152312. https://doi.org/10.1016/j.scitotenv.2021.152312.
89. Rodríguez-Amigo, A.; Fernández-Alvarado, J.F.; Fernández-Rodríguez, S. Case of Study on a Sustainability Building: Environmental Risk Assessment Related with Allergenicity from Air Quality Considering Meteorological and Urban Green Infrastructure Data on BIM. *Sci. Total Environ.* **2022**, *838*. https://doi.org/10.1016/j.scitotenv.2022.155910.
90. Malaviya, P.; Sharma, R.; Sharma, P.K. Rain Gardens as Stormwater Management Tool. In *Sustainable Green Technologies for Environmental Management*; Springer Singapore: Singapore, 2019; pp. 141–166. https://doi.org/10.1007/978-981-13-2772-8_7.
91. Scholz, M.; Lee, B. Constructed Wetlands: A Review. *Int. J. Environ. Stud.* **2005**, *62*, 421–447. https://doi.org/10.1080/00207230500119783.
92. Abass, F.; Ismail, L.H.; Wahab, I.A.; Elgadi, A.A. A Review of Green Roof: Definition, History, Evolution and Functions. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *713*, 012048. https://doi.org/10.1088/1757-899X/713/1/012048.
93. Manso, M.; Castro-Gomes, J. Green Wall Systems: A Review of Their Characteristics. *Renew. Sustain. Energy Rev.* **2015**, *41*, 863–871. https://doi.org/10.1016/j.rser.2014.07.203.
94. Imran, H.M.; Akib, S.; Karim, M.R. Permeable Pavement and Stormwater Management Systems: A Review. *Environ. Technol.* **2013**, *34*, 2649–2656. https://doi.org/10.1080/09593330.2013.782573.
95. Carsell, K.M.; Pingel, N.D.; Ford, D.T. Quantifying the Benefit of a Flood Warning System. *Nat. Hazards Rev.* **2004**, *5*, 131–140. https://doi.org/10.1061/(ASCE)1527-6988(2004)5:3(131).
96. Mihăilescu, N.; Daescu, V.; Holban, E.; Badea, M.N.; Paceagiu, J. Energy Conservation and CO2 Emissions Reduction for Clinker Portland Cement Manufacturing Process. In *Environmental Engineering and Management Journal*; Gheorghe Asachi Technical University of Iasi: Iasi, Romania, 2009; Volume 8, pp. 947–952. https://doi.org/10.30638/eemj.2009.137.
97. Nieuwenhuijsen, M.J. Green Infrastructure and Health. *Annu. Rev. Public Health* **2021**, *42*, 317–328. https://doi.org/10.1146/annurev-publhealth-090419-102511.
98. Krauze, K.; Wagner, I. From Classical Water-Ecosystem Theories to Nature-Based Solutions — Contextualizing Nature-Based Solutions for Sustainable City. *Sci. Total Environ.* **2019**, *655*, 697–706. https://doi.org/10.1016/j.scitotenv.2018.11.187.
99. Easton, S.; Lees, L.; Hubbard, P.; Tate, N. Measuring and Mapping Displacement: The Problem of Quantification in the Battle against Gentrification. *Urban Stud.* **2020**, *57*, 286–306. https://doi.org/10.1177/0042098019851953.
100. Zölch, T.; Rahman, M.A.; Pfleiderer, E.; Wagner, G.; Pauleit, S. Designing Public Squares with Green Infrastructure to Optimize Human Thermal Comfort. *Build Environ.* **2019**, *149*, 640–654. https://doi.org/10.1016/j.buildenv.2018.12.051.
101. Matsunaga, S.N.; Shimada, K.; Masuda, T.; Hoshi, J.; Sato, S.; Nagashima, H.; Ueno, H. Emission of Biogenic Volatile Organic Compounds from Trees along Streets and in Urban Parks in Tokyo, Japan. *Asian J. Atmos. Environ.* **2017**, *11*, 29–32. https://doi.org/10.5572/ajae.2017.11.1.029.