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Research Paper

Why go green? Comparing rationales and planning criteria for green infrastructure in U.S. city plans

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HIGHLIGHTS

- There is a misalignment between rationale and criteria used to site GI practices.
- Rationale emphasize multifunctionality (stormwater, social cohesion, biodiversity).
- Criteria emphasize stormwater, available space, and technocratic elements.

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ABSTRACT

Green infrastructure is an increasingly popular urban sustainability strategy, widely promoted for its ability to provide multiple benefits. We examined 120 planning documents from 19 U.S. cities to identify if and how the stated benefits that cities use within their rationales for green infrastructure programs (rationale statements) align with the criteria used to site green infrastructure at the neighborhood scale (siting statements). Our findings suggest that many of the desired benefits stated in the rationales for green infrastructure lack corresponding and specific siting criteria. This was particularly evident for rationale statements concerning social and cultural ecosystem services, seemingly because certain benefits, especially those related to stormwater management, are prioritized over other green infrastructure services. While multiple benefits remain a dominant rationale for green infrastructure in the cities analyzed, including stormwater management, social cohesion, and biodiversity benefits, siting criteria were dominated by stormwater management, available locations, and other logistical considerations. These findings indicate a large-scale misalignment between the multifunctional ideal of urban green infrastructure and the procedures used to implement green infrastructure programs. We conclude with a discussion of how siting criteria and processes can be elaborated to deliver the desired benefits of green infrastructure.

Abbreviations: GI, Green Infrastructure.

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1. Introduction

Cities in the United States (U.S.) are increasingly promoting green infrastructure (GI) and integrating it into plans to provide a variety of future sustainability and resilience benefits. Definitions of GI differ. GI is simultaneously conceptualized as facilities like rain gardens and bioswales that are designed to manage stormwater (U.S. Environmental Protection Agency, 2021), as connected ecological elements providing multiple functions and benefits (Benedict and McMahon, 2002), and as planning approaches to harmonize relationships between built and natural systems for social benefit (Grabowski et al., 2022a; Matsler et al., 2021).

For all three of these conceptualizations, urban GI must be planned and sited spatially like other land uses and elements of the built environment, and this inevitably requires negotiating conflicting priorities (Campbell, 1996). Yet, when it comes to planning GI, there seems to be a gap between theory and practice. GI is widely promoted in the academic and policy discourse on the basis of its multifunctionality, and planning guidance emphasizes the importance of factoring multiple benefits into siting decisions (Lovell and Taylor, 2013; Hansen and, Pauleit 2014; Firehock, 2015). But research suggests that in practice, decisions about where to site GI are often opportunistic or based on one or a few benefits, and GI is therefore not strategically sited to maximize the full range of desired functions (Jordan et al., 2021; Hoover et al., 2021; Meerow and Newell, 2017; Dagenais, Thomas, and Paquette, 2017; Mell et al., 2013; Roe and Mell, 2013). This is especially problematic because many of these benefits – or undesired consequences like green gentrification and associated displacement – are very localized (Hansen and Pauleit, 2014). Residents in the neighborhoods where GI is developed are the ones who will receive most of the benefits or services, but also bear the brunt of any disservices. Planning decisions are further complicated by the fact that there may be trade-offs between different GI planning priorities (Wright, 2011). For example, planning GI based on a single (expected) benefit might overlook areas of high need for others (Hoover and Hopton, 2019). Different GI types (e.g., bioswale vs. park) may also provide a limited subset of benefits.

This study analyzes 120 formal plans in 19 U.S. cities that address GI to examine how benefits stated within the guiding rationales for GI align with the criteria used to site GI projects. To guide this empirical analysis, we provide an overview of literature examining GI definitions, benefits, disamenities, and their integration into planning approaches thus far, including concerns of environmental racism and equity, emphasizing the importance of spatially explicit analyses and implementation approaches.

2. Green infrastructure planning

Definitions of GI vary by location, discipline, and have evolved over time (Grabowski et al., 2022; Matsler et al., 2021). A review of both academic and non-academic 'gray' literature suggests three concurrent understandings (Matsler et al., 2021). The earliest conceptualizations position GI as a greenspace planning concept and define it as the full network of vegetation and open space providing multiple functions and benefits to society (Benedict and McMahon, 2002). Defined this way, GI can include parks, greenways, or green belts, and is often traced back to Howard's Garden Cities vision (Matsler et al., 2021). A second GI conceptualization similarly classifies any vegetation, open space, and natural areas as GI, but focuses more on their ecological functions, or the ecosystem services they provide. This is more commonly how GI is conceptualized by European researchers and practitioners. The third category views GI primarily as an approach to manage stormwater that seeks to mimic natural drainage through engineered or natural systems. Here GI includes both vegetated and non-vegetated engineered systems like permeable pavement, and it can be used synonymously with terms like Low Impact Development (LID) or Best Management Practices (BMPs). In the United States, GI is increasingly employed in this third way (Matsler et al., 2021). For example, the U.S. EPA's website references the definition from the 2019 Water Infrastructure Improvement Act: "The range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters" (U. S. Environmental Protection Agency, 2021). Drawing upon the same body of plans examined in this analysis, a review of definitions in city plans found that in addition to the three conceptualizations of GI above, cities are increasingly using the GI concept to integrate diverse technological infrastructures with natural systems (Grabowski et al., 2022a).

How GI is defined, and by what types of plans, influences the benefits GI can provide (Matsler et al., 2021; Grabowski et al., 2022). For example, a large forested park may infiltrate and evapotranspirate stormwater, but it also provides spaces for people to recreate, can facilitate active transportation, cool the surrounding environment, and serve as habitat for different wildlife species (Miller, 2020). A parking lot made out of permeable pavement might mitigate stormwater, but it would not serve these other functions. Research suggests that GI can mitigate flooding (Eger, Chandler, and Driscoll, 2017), improve water quality (Golden and Hoghooghi, 2018), reduce air pollution (Pugh et al., 2012), and more. While GI services are well-documented, it can also have negative consequences, or disservices, such as increased incidence of pests and allergens, green gentrification, and maintenance requirements (von Döhren and Haase, 2015; Brown et al., 2022). For example, one study on the High Line in New York City, a railway that was transformed into a miles-long, linear park, found that the surrounding neighborhoods faced rapid redevelopment and climbing rent prices (Haase et al., 2017). This may have been an unintended consequence of this GI siting and investment or it may have been a concerted effort to increase the surrounding land value that now generates significantly increased tax revenue to the city. While GI benefits and functions ultimately depend on how GI is configured with urban ecological and infrastructural systems, many of the effects of GI, whether positive or negative, are localized, so where GI is sited determines who is primarily affected (Zhang and Chui, 2019). The heat mitigation benefits of GI, for example, diminish with distance. Research across a variety of cities and park sizes shows that any cooling effect of parks, usually referred to as the "park cooling distance," only extends a couple hundred meters into the surrounding neighborhoods (Gao, Zhao, and Han, 2022; Feyisa, Dons, and Meilby, 2014). This highlights why it is important to strategically plan GI and the importance of decision-making processes around the siting and design of GI, what has been termed the "politics of green infrastructure planning" (Meerow, 2020).

While the performance of GI has been widely researched, few studies examine planning and siting processes (Finewood, Marissa Matsler, and Zivkovich, 2019; Heckert and Rosan, 2016). Studies that do exist are primarily case studies of individual cities (Jordan, Hoover, and Hopton, 2021; Finewood et al., 2019; Meerow and Newell, 2019). For example, case studies of Philadelphia (Finewood et al., 2019) and Pittsburgh (Heckert and Rosan, 2016) show that the cities' GI programs are very focused on technical stormwater management, as opposed to other potential goals, which the authors point out could result in inequitable distribution of GI. Meerow and Newell (2019) and Meerow (2020) make similar arguments, drawing on studies of Detroit and New York City, respectively. They find that while both cities use the multiple benefits of GI to justify its use over traditional gray infrastructure, decisions about where to implement GI are almost exclusively based on stormwater management goals. They also show that there are spatial trade-offs related to which neighborhoods show the greatest need for GI benefits, highlighting the importance of a transparent and strategic spatial planning process. In other words, if GI is just implemented opportunistically, as opposed to being located strategically to achieve desired benefits, there is no guarantee that it will deliver on those benefits.

Hoover et al. (2021) examine the GI siting process in 19 U.S. cities as described in the cities' planning documents, which were also studied through an equity lens (Grabowski et al., 2022a; Grabowski et al., 2023). Hoover and colleagues (2021) cross-sectional study suggests that what these earlier case studies found holds more broadly, namely that water-related and other technical considerations dominate other social or ecological considerations. However, Hoover et al. (2021) did not focus on whether such siting criteria were aligned with the rationale cities provided for GI. Thus, it is still unclear whether cities' desired outcomes from GI are primarily technical and hydrological, or if there is a mismatch between their stated aims and the practical plans for the implementation of GI. This study explicitly addresses this question.

2.1. Methodological approach for comparing rationale and siting statements in city plans

We analyze the content of plans from diverse cities across the United States, examining the guiding rationales for GI (hereafter referred to as rationale statements) and the statements on the criteria for siting GI (hereafter referred to as siting statements). Cities were first identified based on their leadership and prevalence of GI development using Hopkins et al. (2018) as a guide. Adding in cities to represent geographical, social, and biophysical diversity resulted in the 19 cities examined in this study (Fig. 1). From this, a set of 303 planning documents from 19 of the cities were screened and filtered to only include 120 plans that were officially endorsed by city government, were written in English, and contained language on 'green infrastructure'. Note that this sample includes both strategic plans (e.g., sustainability plans and comprehensive plans) and more technical documents (e.g., watershed improvement plans and Clean Water Act compliance plans), which address GI with a varying degree of detail. A more detailed description with a list of plans by city is available in supplementary material. We defined siting statements as text explaining or describing criteria, metrics, or rankings used to identify locations for GI at the parcel level. Rationale statements were defined as text describing the motivations and justifications for GI, which included descriptions of the benefits (perceived or measured) that implementing GI would yield.

Coding and analysis of statements was completed first with a combination of open and axial coding and a small list of initial code categories in Atlas.TI software. Three researchers read the documents, coding for statements using thematic and open coding techniques. The rationale statement coding structure was previously established (see Grabowski et al., 2022a; Grabowski et al., 2023), and in parallel with the siting statement codes developed in Hoover et al. (2021), and we therefore took a recursive approach to align siting and rationale statement codes. We aligned the rationale and siting statement codes by adding new siting or rationale statement codes or combining similar rationale statement codes to match existing siting statement codes, resulting in our final codebook (In supplementary material) (Table 1). Where statements contained multiple rationales or criteria, statements were coded with all relevant categories and thus were double-counted.

Consistent with previous works from this database and to aid in descriptive analysis and discussion, initial coding results were further organized using a 'group: category: subcategory' structure. A total of seven thematic parent 'groups' were identified based on themes within the codes: *Hydrology*, Ecology, *Social*, *Economic*, *Logistics*, *Transportation*, and *Other*. In line with content analysis methods (Friese et al., 2018), statements refer to the blocks of text containing rationale or siting content, groups refer to the themes present in those blocks of text, categories refer to specific benefits or siting criteria that are associated with the identified themes, and subcategories refer to even more specific explications of rationale or siting categories (see supplementary data for detailed group, category, and subcategory definitions). The seven thematic groups were as follows:

Fig. 1. Map of the continental United States showing the cities examined in the study.

Table 1
Aggregated rationale categories (and subcategories following colons) that were aggregated or renamed to align with siting statement categories when a one-to-one nomenclature was not present. The Logistics, Transportation, and Other thematic groups lacked corresponding rationale statements, and only contained siting statements. They are thus excluded from this table.

Categories: subcategories of codes for rationale statements	Categories: subcategories of codes for siting statements	Thematic groups
Water quality: Water quality, pollutant removal and, loads	Water quality	**Hydrology**
Water availability	Water quantity	
Sewer infrastructure: Stormwater performance, combined sewer performance	Sewer infrastructure	
Flooding: Flooding, Flood regulation	Flooding	
Sediment remediation	Soils	**Ecology**
Species conservation	Ecology	
Resilience: climate change	Resiliency or climate change	
Ecosystem services, co-benefits	Multifunctionality	
Habitat: Habitat, species conservation, ecological protection	Habitat	
Air quality	Air quality	
Economic development	Economic development	**Economic**
Property value	Property value	
Jobs	Jobs	
Business opportunities	Funding availability	
Cost savings, cost of services	Cost of services/cost-savings	
Thermal regulation	Heat	**Social**
Recreation, Outdoor experience	Recreation	
Health and well-being: heath, psychological well being	Community: Health	
Aesthetic	Visibility	
Physical safety: Safety, crime reduction	Community: safety	
Livability	Community: quality of life	
Education	Community: education	
Community belonging: Community building, Sense of place		
Multifunctionality: multifunctionality, co-benefits	Multifunctionality	
Equity	Environmental justice	
Green or open space	Green or open space	

- *Hydrology* refers to text related to either stormwater management or other water-related infrastructure.
- *Ecology* refers to text that had to do with ecology or the environment, but did not concern water-related infrastructure.
- *Social* encompassed community-related concerns, including environmental injustices.
- *Economic* codes involved property rights, value, project budgeting, and other cost-related factors.
- *Logistics* refers to the practicality or feasibility of a project.
- *Transportation* coded text referring to parking lots, streets or sidewalks, and other similar topics.
- *Other* consisted of four code categories with text that did not fit into any of the aforementioned groups.

3. Results: Comparing green infrastructure rationale and siting statements

Across the 19 cities and 120 planning documents, we coded a total of 3,266 text segments related to siting and rationale, composed of 1,518 rationale statements and 1,748 siting statement quotations. Fig. 2 shows a breakdown of the seven thematic groups of coded rationale and siting statements. Out of the seven broad groups, rationale and siting statements were most closely aligned within the *Economy* and *Hydrology* groups (Fig. 3). Notably, we found that cities discussed cultural and social benefits of GI in rationale statements with greater frequency than they did in siting statements, with a few exceptions. GI rationale statement codes were concentrated in the *Hydrology*, *Social*, and *Ecology* groups, while siting statements were most often associated with *Hydrology*, *Logistics*, and *Social* groups. Rationale statement codes were notably absent from *Logistics*, *Transportation*, and *Economy* groups. Most plans (regardless of plan type) did not match siting statements to rationale statements, except for a few specific GI plans (Fig. 4). This suggests that cities are claiming a number of benefits of GI projects in their plans, but not ensuring the actualization of those benefits by translating them into specific siting and design criteria.

The groups, categories, and subcategories varied considerably between rationale statements and siting statements. Representative quotations of these statements taken from plans are cited in the format of: city abbreviation-document #, page # (see supplementary material for document key).

3.1. Hydrology

Hydrology group codes were associated with the largest portion of rationale statements and siting statements (n = 660, 415 respectively; Fig. 5). The categories of *water quality*, *runoff*, *flooding*, and *infiltration* were prevalent in both rationale and siting statements. Using excerpts from the same plan, we illustrate typical coded content under the *flooding* and *water quality* categories:

Excerpts from the *flooding* category

Rationale statement: *address flooding caused by excess runoff and subsidence caused by pumping of stormwater (MSY-02, 7)*
Siting statement: *locate projects in areas subject to subsidence or urban flooding (MSY-02, 11)*

Excerpts from the *water quality* category

Rationale statement: *These projects could treat and provide water quality improvements (ATL-05,* xviii)
Siting statement: *The following water quality parameters were modeled: TSS, Fecal coliform (ATL-05,* xiv)

While many siting statements reference sewer type (e.g., prioritizing combined sewer systems over separated systems), we did not identify any statements discussing sewer type as a rationale for GI. Instead, the rationale statements focused on the desired outcomes of GI being placed in areas to reduce flooding or improve water quality, or other water balance components like *water quantity,* or *storage and retention.* For example, GI aiming "to absorb and store rainfall that falls on a building and prevent or decrease stormwater runoff from a site" (MWK-01, 63). While we found a few references to storage and retention (n = 13), most siting statements focused on managing runoff or flooding and sewer outfall locations; endpoints along the sewer system where untreated

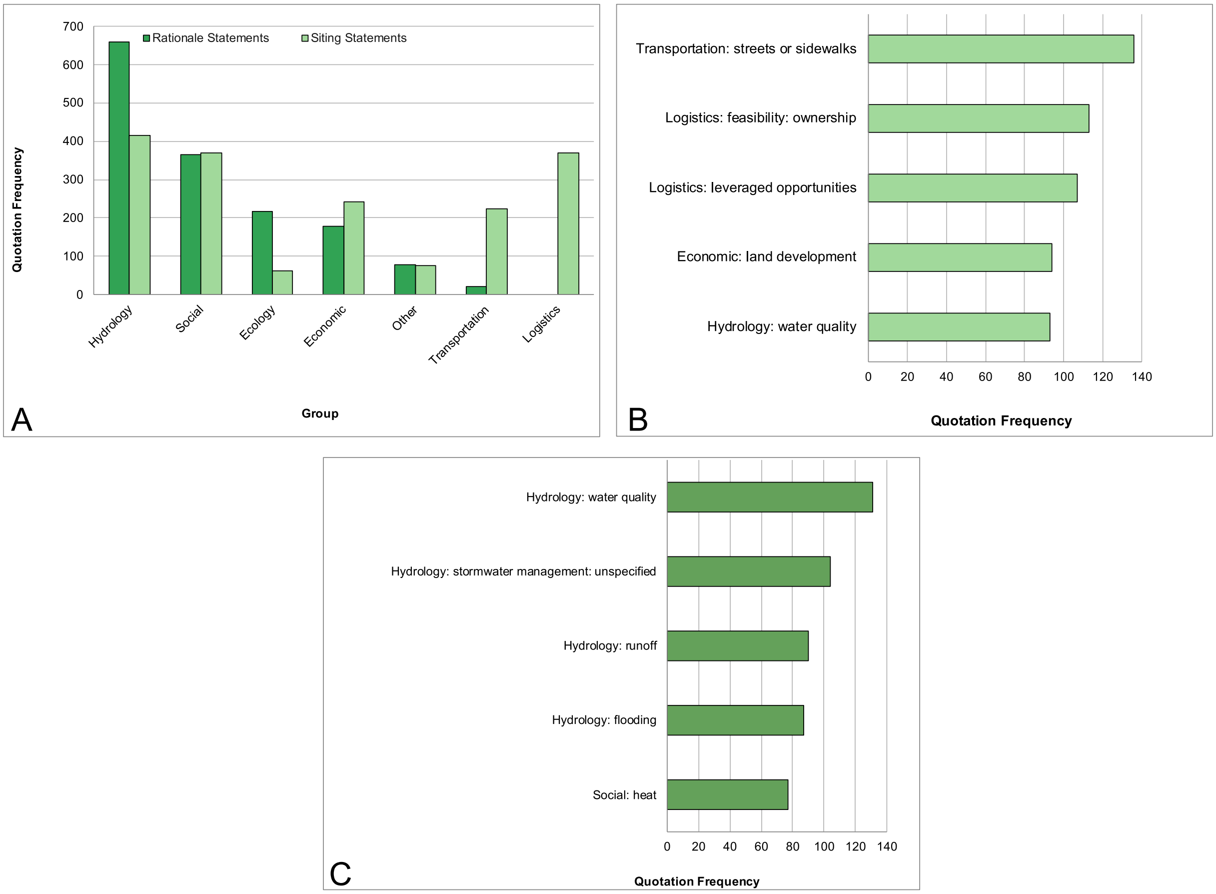

Fig. 2. Top five rationale statement codes (C-bottom right), top five siting statement codes (B-top right), and distribution of quotations for rationale and siting statements illustrated across all seven groups (A-left). In Fig. 2-A, the seven thematic groups display the frequency of rationale statements (dark green) and siting statements (light green), while 2-B and 2-C display the frequency of quotations (x-axis) for the top five code categories (y-axis). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

water empties into a waterbody. Examples include ordinances and sites that prioritize capturing/retaining stormwater runoff (ATL-02, 64; NYC-02, 173; DTW-01,19; MWK-01, 63), often "the first one inch" (PHI-03, 3-31; ATL-02, 64), and often through infiltration-based practices.

3.2. Social

Social was the second largest group for both rationale statements (n = 364) and siting statements (n = 369) but here too, the most common rationale statement categories did not align with the siting statements (Fig. 6). Under *Social,* the *multifunctionality* category contained statements with unspecified GI benefits to residents and people. For example, under a heading labeled 'Community' the following criteria statement was coded under *multifunctionality* in reference to GI: "focus on areas of greatest need and will target areas where co-benefits can be realized" (LVE-01, 36). References to *green or open space* were often stated without specifying the type, purpose or function, though GI seemed to function both as a way to increase green or open space, or conversely, green or open space served as a place to locate GI. In a table of variables to assess and rank GI programs, one criterion under public parcels was "green stormwater infrastructure located within a public parcel, such as a park or open space." (PHI-05, A-6). In reference to GI development, another siting statement said "developing multi-use spaces such as parks and basketball courts that can capture rainwater" (WAS-01, 150). There were a few categories where the prevalence of rationale statements mirrored siting statements. For example, *recreation* rationale statements suggested GI be used for "[p]roviding areas for human recreation and respite" (PDX-02, 54), or "[p]roviding passive recreation areas" (ATL-06, 6–4). Siting statements then, largely discussed paths or trails that were intended to be accessible to the public. In reference to a program, one such quotation reads "Green City, Clean Waters will improve aquatic habitat and accessibility to the Tacony Creek and the Cobbs Creek to enhance their appeal as passive recreational locations as well" (PHI-02, 18). When discussing *heat,* both rationale and siting statements focused on alleviating impacts of the urban heat island effect, rationalizing GI as a tool that "cools buildings and pavement" (WAS-01, 113), and siting statements referencing "neighborhoods particularly affected by consistently high temperatures" (PDX-02, 104). However, specific neighborhoods were often not named or identified.

Siting statements were frequently vague regardless of whether they aligned with rationale statements or not. For example, siting statements in the *outreach* category mention reconciling "factors such as community support and overlapping city priorities" (SEA-04, 5–9) in the project prioritization, but excludes details on how this will happen, reflecting larger issues with a lack of inclusive mechanisms for design and implementation (Grabowski et al., 2023). The subcategory *community: education* siting statements mainly discussed prioritizing sites with educational purposes to provide high quality educational "institutions that meet the needs of residents" (ATL-02, 8). Subcategories like *safety,* and *health and well-being* within the *community* category, which are commonly referenced as valuable cultural ecosystem services (Tzoulas et al., 2007), were discussed as benefits of GI but seemingly not central to the siting process. Rationale statements mention that "implementing green stormwater infrastructure provides opportunities to increase the quality of neighborhoods and add community amenities" (CHI-02, 20), but this did not translate to siting statements, which instead tended to

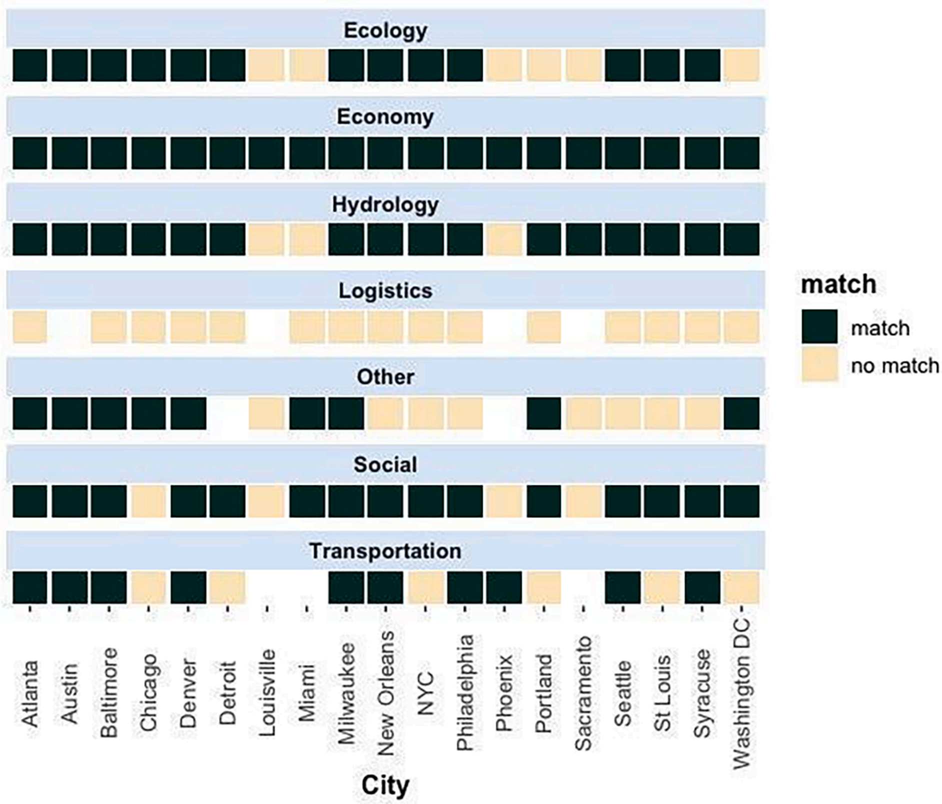

Fig. 3. City level matching between GI rationale and siting statements across all groups (listed alphabetically). Black or dark green squares indicate that the city had both siting statements and rationale statements within that group across all of the city's plans analyzed in the study. Light gold squares indicate a lack of matching siting statements and rationale statements within that group. Blanks indicate that the city did not have any rationale or siting statements for that group. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

include more technical concerns like "Service requests made regarding these complaints are tracked to identify "hotspots" – locations that are either repeat problems or where there are clusters of service requests" (BAL-03, 36, 1:332). Finally, equity-related rationale statements (n = 8) included more holistic or multi-dimensional considerations when referencing GI, while siting statements typically focused on identifying and targeting GI in communities of color, low-income communities, or areas where amenities were absent:

Equity category rationale statement examples

The city will work to develop and implement resilience initiatives aimed at making housing more affordable (ATL-11, 74)
fosters a sense of place and social equity, improves residents' quality of life, encourages resident participation in building a healthier and more sustainable community MWK-03, 39)

Equity category siting statement example

Grant funding to promote GI implementation on private property, focusing on low-income communities of color (ATL-01, 9)

3.3. Ecology

The *Ecology* group contained more rationale statements (n = 217) than siting statements (n = 22). This group comprised ecological siting statements that referenced terrestrial and atmospheric systems and species, whereas codes were assigned to the *Hydrology* group if they were water-related. Similar to some of the *Social* group categories, rationale statements emphasizing the ecological benefits or multi-functionality of GI did not translate to siting statements. For example, rationale statements promoted GI for its ability to, "Enhance wildlife habitats and biodiversity, including support for vital pollinators" (BAL-02, I-8), or "alleviate pollution from vehicles and industry" (PDX-02, 103). There was also a focus on using GI as a tool for climate change resilience, statements such as "Adapt parks and expand green infrastructure to shield adjacent communities from the impacts of extreme weather events" (NYC-01, 332). Ecological siting statements, however, did not specify how these goals would be achieved, instead discussing soil conditions, type and related National Resources Conservation Service (NRCS) soil survey data as limitations or means for identifying GI locations, for example, "Site specific limitations (i.e., groundwater, bedrock, soil types, etc)." (NYC-06, 5-11), or "soil sampling to produce a city-wide soils survey that will inform the siting and design of green infrastructure." (MSY-01, Attachment A-28). Note that the *ecology multifunctionality* category contained criteria and rationale statements referencing unspecified benefits or criteria related to increasing the presence of nature, biodiversity or vegetated space, as illustrated in the following example, "co-benefits associated with increased green space" (MWK-03, 2).

3.4. Economy

The *Economy* group contained cost-related rationale statements (n = 179) and siting statements (n = 243). with more siting than rationale statements (Fig. 7). These results are distributed across categories that include *jobs*, *property value* (intentions to increase), *development* (land and/or economic), and more. Rationale statements in the *Economy* group were coded most frequently under the subcategory of *cost services, effectiveness, sharing, analysis* (n = 60). This was also a common code applied to siting statements (n = 50), but the most frequent siting category in this group was actually *land development* (n = 94).

While both rationale and siting statements were commonly coded under *cost services, effectiveness, sharing, and analysis*, we observed several discrepancies in how siting versus rationale statements were discussed within this category. Often, plans rationalized GI in broad economic development terms, such as "activities [that will] help support social justice and will provide economic vitality by supporting clean economy jobs and business development opportunities" (LVE-01, 5).

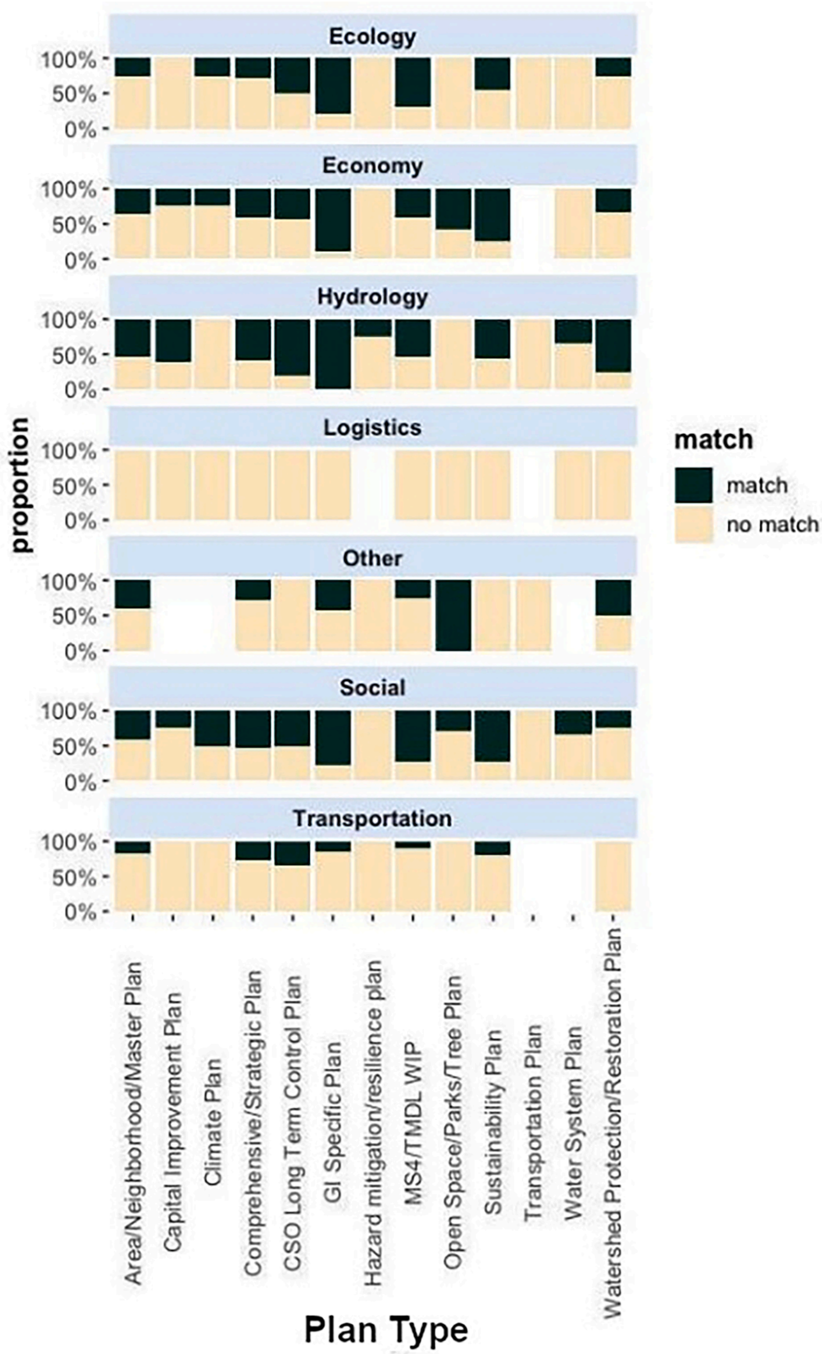

Fig. 4. Plan type matching between stated GI rationale and siting statements across all cities. Percentages represent the percentage of plans of that type with matching rationale and siting statements for that group (green/black), and the percentage of plans that did not have both rationale and siting statements within that group (light gold). Blanks indicate where the plan type did not have any rationale or siting statements for that group. Groups are shown in alphabetical order. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Meanwhile, siting statements focused on minimizing local engineering, construction, and other costs, rather than identifying which projects had the most economic development potential. The categories and subcategories of *available funding and budget* and *land development* were mentioned as integral parts of the siting process despite not being discussed in rationale statements, and cost in general was emphasized as a "major determining factor in the prioritization of projects" (ATL-04, Appendix F-2). This example (coded under the *jobs* category) is emblematic of how plans often discussed GI as a source for jobs and other economic benefits, without translating that rationale to corresponding siting statements. We were unable to identify any siting statements related to jobs such as measuring or stating the number of jobs desired, or communities to target for those job opportunities.

Jobs rationale statement examples

The installation of green infrastructure that is well-maintained can address economic, social, and environmental challenges by increasing both green space and job opportunities. (BAL-01, 115)
Creating and preserving jobs and enhancing our revenue (PHX-02, 11)

In general, we found GI was rationalized based on cursory relationships between property values and social concerns like, "Enhanced Property Values – Improved aesthetics, decreased crime and increased live-ability can improve property values in the areas where GI is installed" (WAS-06, 2–4). We did not find many corresponding siting statements discussing how those benefits would be actualized, instead they focused on costs associated with materials, contracting, or cost ranking.

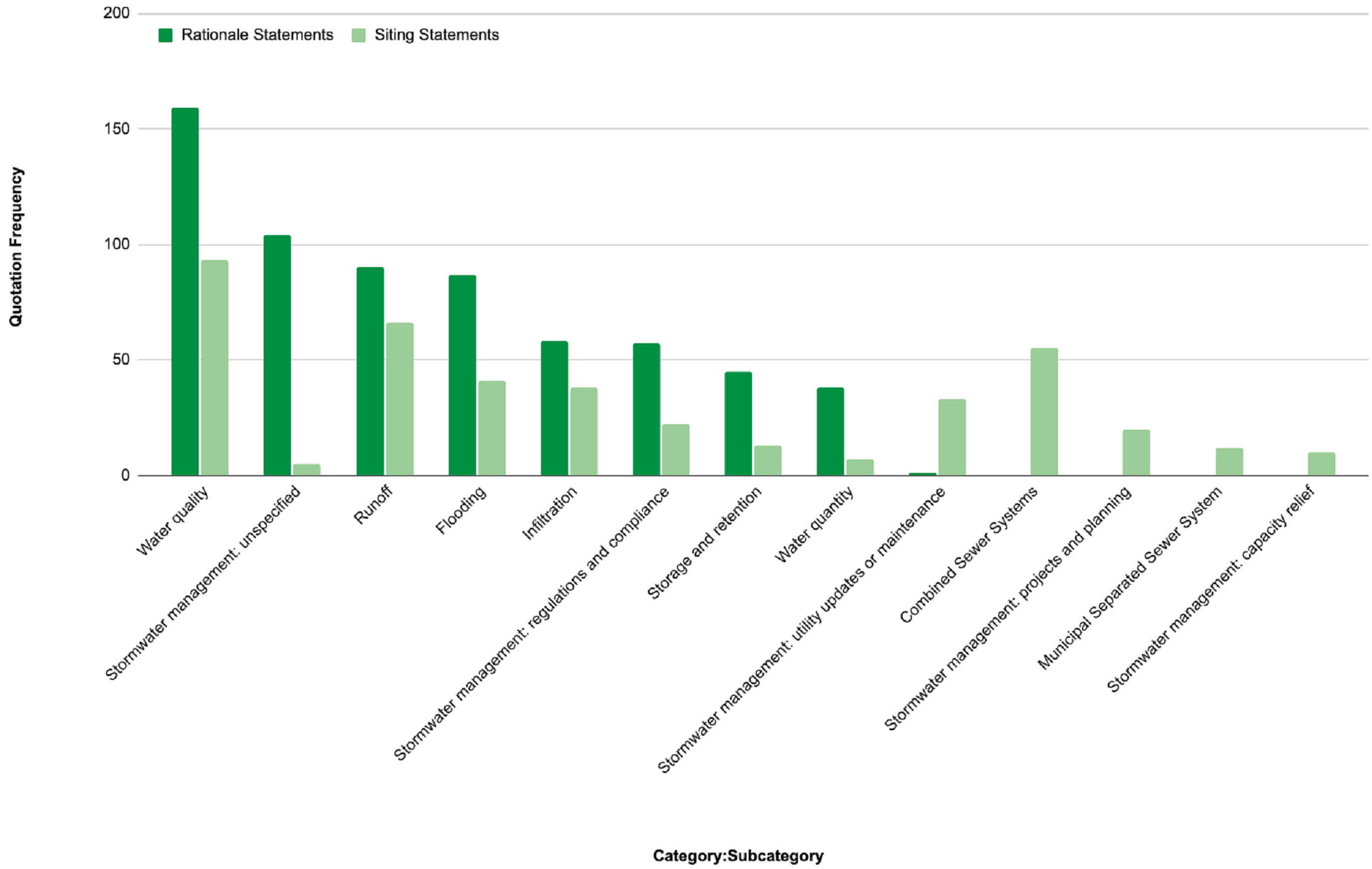

Fig. 5. A side-by-side comparison of the frequency of GI rationale (dark) and siting (light) statements for the *Hydrology* grouped codes by category and subcategory. *Water quality* was the most frequent category for rationale and siting statements. This was the group where the siting statements and rationale statements appeared most aligned. Categories refer to specific benefits or siting criteria that are associated with the identified themes, and subcategories refer to even more specific explications of rationale or siting.

3.5. Transportation

Transportation was emphasized much more in the siting statements (n = 223) than in rationale statements (n = 21). *Streets or sidewalks* (n = 21 rationale statements; n = 136 siting statements) was the only shared category. Siting statements included additional categories like right-of-way (*ROW)* (n = 48), *parking lots* (n = 22), *traffic* (n = 15), and *other* (n = 2). For *streets or sidewalks* and *traffic*, siting statements referenced partnerships with local transportation services and officials to restore sidewalks or alleviate traffic congestion. Rationale statements included “sidewalk improvements along connector streets” (SYR-02, 57), and “ensuring connectivity between pedestrian, bike, transit and road facilities” (PHX-02, 21). Meanwhile, siting statements tended to prioritize GI in “existing streets and underutilized space within rights-of-way (e.g. freeway ROW)” (PDX-08, 104), but in a few instances aligned with rationale statements, like in this example: “Prioritize tree plantings at bus stops to provide shade and shelter to public transportation users” (SYR-02, 59).

3.6. Logistics

The *Logistics* group contains two categories, *feasibility* (n = 209) and *leveraged opportunities* (n = 107), that only emerged as common themes among the siting statements and thus were not identified in rationale statements in any plan. That being said, we could imagine scenarios where cities would justify using GI instead of gray infrastructure by arguing that it is more feasible either based on available space, existing utilities, or other definitions of feasible, and this would then have been coded as a *Logistics* rationale statement. These two categories focused on the practicality, profitability, ease of development or implementation, or available physical space. The subcategories *feasibility: ownership (n = 113)* and *feasibility*: *leveraged opportunities (n = 107)* were the two dominant means of locating GI.

Leveraged opportunities refers to the implementation of GI based on its proximity to existing stormwater or sewer infrastructure, cost-sharing opportunities, or economic development. For example, under *feasibility: spatial constraints or availability,* siting statements suggested that GI should be implemented based on “…the project location and site constraints, street classification, parking needs, and the driving practices that will occur in the area” (MWK-02, 1). An example of a *feasibility: ownership* siting statements called for GI implementation based on “logistics [that] will be defined and public outreach project-specific efforts [that] will focus on intensively recruiting property owners to sign up for downspout evaluation and disconnection when feasible“ (WAS-07, 6–7). *Feasibility: field or site observations* referenced “addition of GI project sites based on opportunities observed in the field” (ATL-06, 15), without explanation or provision of a field assessment guide or rubric.

3.7. Other

Other captured the remaining siting and rationale statements that fit within the following categories: *exclude* (siting statements n = 32, rationale statements n = 0), *other (*siting statement n = 17, rationale statements n = 29), *multifunctionality* (siting statement n = 16, rationale statement n = 48), and *transitional (*siting statements n = 11, rationale statements n = 0). The category *other* contained siting statements such as “identifying and selecting projects that embody the principles of living with water” (MSY-01, 16). The categories *transitional* and *exclude*

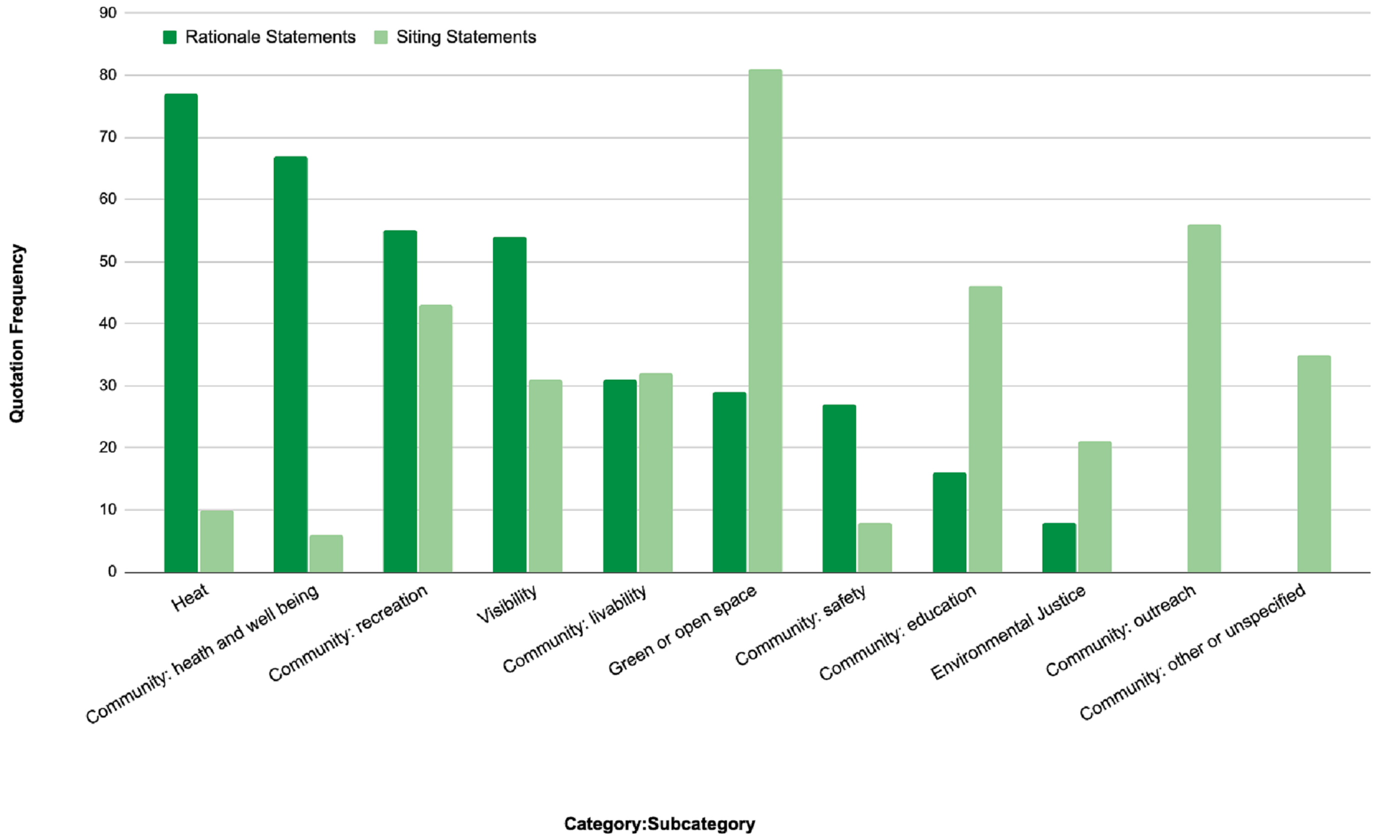

Fig. 6. A side-by-side comparison of the frequency of GI rationale (dark) and siting (light) statements for the *Social* grouped codes by category and subcategory. While *heat* was the most frequently mentioned rationale code, *green or open space* was the most common code among the siting statements. Categories refer to specific benefits or siting criteria that are associated with the identified themes, and subcategories refer to even more specific explications of rationale or siting. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

contained language identifying areas of possible opportunities or areas not to place GI respectively. For example, *transitional* siting statements discussed potential locations for temporary GI development until economic conditions become desirable for private investment or development. Similar to the rationale and siting statement language under the *jobs* codes, *multifunctionality* rationale statements focused on numerous ecosystem services that were not clearly translated into siting statements. When multifunctional rationale statements were included, a triple-bottom line approach was a focus. For example, "The city's GI including parks and multi-use recreational trails is a system that provides many benefits for Atlanta's citizens – social, educational and health – and encourages economic development" (ATL-02, 391) described the benefits possible from GI and was coded as a rationale statement. From the same city, a section coded as a siting statement mentioned a: "triple-bottom-line-based prioritization matrix […] to assign a score to each watershed improvement project" (ATL-06, 4.2). The key difference between these two quotes is that the rationale statement lists various benefits that are desired from GI, whereas the siting statement is specific to how the benefits ranked within a scoring system used to prioritize projects and their locations.

4. Discussion: Misalignment between statements on the rationales for GI versus siting statements

City plans suggest that communities justify GI based on its multifunctionality, and particularly different hydrologic and social benefits. Our findings confirm that stormwater-focused concepts (Grabowski et al., 2022a; 2023) and water-related benefits are a high priority for U. S. GI planning (Meerow, 2020; Matsler et al., 2021), and this is reflected in both the justification and siting processes across the cities. Yet many of the other commonly mentioned rationales do not appear to translate into the processes for locating particular GI projects, at least as described in formal city planning documents. When providing a rationale for GI in plans, cities commonly discuss a range of different benefits, including hydrologic benefits such as addressing flooding and water quality problems as well as social benefits like expanding outdoor recreation opportunities. Many of these same benefits are rarely incorporated into siting criteria. For example, there are many more quotations related to *community: recreation* and *community: health and well-being* within the rationale statements than in the siting statements we identified. The prevalence of siting statements coded under *Logistics* and *Feasibility* groups but not rationale statements suggests that space availability and external resources drive GI implementation, as opposed to its multifunctionality. Our analysis suggests that when it comes to siting GI, logistics and funding are key factors, but clear steps are rarely identified for prioritizing projects with the greatest opportunity to improve health and well-being – despite these being common rationales. This finding validates concerns voiced by other scholars (e.g., Newell et al., 2014; Meerow, 2020; Grabowski et al., 2022b) that while GI is widely heralded as multifunctional in policy discourse, in practice its implementation is much more narrowly focused. The fact that desired benefits do not appear to be factoring heavily into siting and design decisions raises questions about whether cities' GI plans are likely to deliver on their promises. For example, if a city claims that GI is going to expand recreation, but then motivated by an exclusive siting focus on stormwater management and reducing costs, the city invests the full GI budget into permeable pavement on existing parking lots, the GI program would not provide any promised recreation benefit. If communities overpromise and underdeliver, this could jeopardize residents' trust in city governments and their continued support for GI (Matsler et al., 2021).

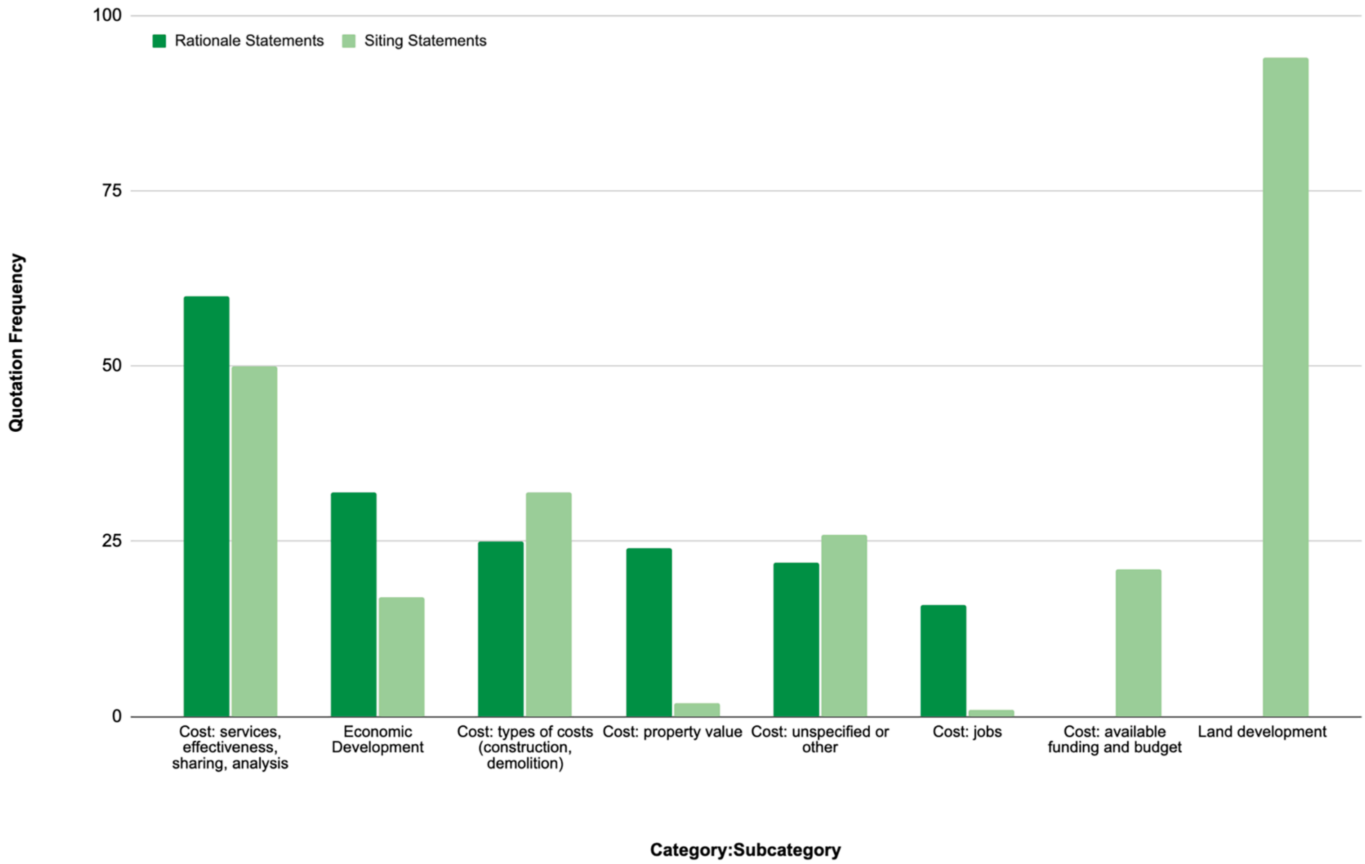

Fig. 7. A side-by-side comparison of the frequency of GI rationale (dark) and siting (light) statements for the *Economy* grouped codes by category and subcategory. The lower cost of investment under *cost: services, effectiveness, sharing, analysis* was the most common code in this group for the rationale statements. While this was also a common theme within the siting statements, the use of GI as a tool for *land development* was the most common code within this group. Categories refer to specific benefits or siting criteria that are associated with the identified themes, and subcategories refer to even more specific explications of rationale or siting.

One notable example of the differences between GI rationale and siting statements can be seen with heat. *Heat* was the fifth most frequently coded criteria for rationale statements, meaning that many city plans highlighted the potential for GI to mitigate heat. This benefit is widely supported by the literature, and vegetation is the strategy U.S. city planners most commonly report using to address heat risks (Meerow and Keith, 2022). It is therefore not surprising that many plans discuss this function of GI. Yet *heat* is not among the most commonly mentioned categories of siting statements. In fact, we only identified ten references to heat within siting statements. Some areas in U.S. cities are much hotter than others and certain populations are more vulnerable to heat, which it should be noted is the deadliest weather and climate-related hazard (Wilson, 2020). Formerly redlined neighborhoods, for example, are typically hotter and have less tree canopy cover (Hoffman, Shandas, and Pendleton, 2020), and additional tree canopy might have a greater cooling effect in these areas (Zhou et al., 2021). A strong equity and public health case could therefore be made for prioritizing GI in these communities, but we do not find much evidence for this. While this seems like a missed opportunity, the common practice of siting GI based on stormwater mitigation (e.g., prioritizing areas with extensive impervious surfaces) could potentially capture some of these hottest areas since they tend to be co-located (Meerow, 2020). It is also possible that there are other efforts to add vegetation for heat mitigation in the cities, but they are not discussed in plans as GI.

While the mismatch between the rationale and siting statements is itself potentially problematic, the type of siting statements that we commonly observed in plans raise further doubts about how equitable cities' GI efforts will be. Siting statements rarely mention environmental justice or equity explicitly (Hoover et al., 2021), and many of the technical and cost-related siting statements that are commonly discussed would potentially result in GI development mirroring long standing inequitable patterns of disinvestment in lower income or minority communities, or potentially contribute to green gentrification (Anguelovski, Connolly, Garcia-Lamarca, Cole, & Pearsall, 2018).

Drawing on data from diverse U.S. cities, this study broadly confirms what had previously only been identified in individual case studies: namely that green infrastructure is promoted for its multiple social and environmental benefits, but implemented based on a different, narrower set of more technical criteria and often to comply with specific stormwater focused regulations (Finewood et al., 2019, Meerow, 2020). While this is an important finding, with implications for the long-term success of GI, future research is needed to better understand why this mismatch is occurring. Our study analyzes plans, but plans may not be implemented as written. Interviews with stakeholders/decision makers would provide more detail on how siting decisions are made and plans implemented. Furthermore, we need careful evaluation of patterns of GI implementation, including the spatially explicit evaluation of where different types of GI related to different functions and benefits end up being located in relation to their stated rationales and guidelines for siting.

Our findings also point to a number of practical ways that cities can improve their GI planning. First, cities should clearly identify the benefits that they want to achieve with GI, rather than simply listing all potential co-benefits. These benefits should then be clearly linked to siting criteria, as well as explicit processes for communities to articulate their desired social and cultural GI benefits. In other words, if mitigating heat is a priority, there should be some siting statement that targets areas that are hotter or more vulnerable to heat and promotes GI designs that provide a cooling benefit. We recognize that there may be potential advantages of vagueness in planning documents as a resource for planners granting them flexibility in implementation (Buhler, 2021). However, since GI projects seek to provide specific and context-dependent services, they will ultimately require explicit and transparent criteria linking desired benefits with the social and physical characteristics of areas requiring intervention, even if the plan implementation process is ultimately socially negotiated. Balancing priorities and integrating residents' perspectives might mitigate possible negative impacts of GI, while ensuring benefits are reaped by residents where GI is placed, as well as providing a more coherent logic for the creation of GI systems such as alternative transit and greenspace networks, thus allowing for more equitable distribution and access to benefits of GI.

5. Conclusion: Navigating a way back to GI multifunctionality

Cities across the U.S. are expanding investments in GI as it becomes a common approach for promoting urban sustainability and resiliency. GI's growing prominence has sparked criticism that GI can mean different things, with variable performance, and if not carefully planned, actually lead to negative outcomes. This study compared the rationale cities provide for GI with criteria used for siting it across 120 municipal planning documents from 19 diverse U.S. cities. We found that the siting and rationale statements are often misaligned, where the rationales and benefits discussed as motivation for GI are not reflected in the criteria plans used for locating GI. Instead, siting statements prioritizing technical, logistical, and cost-related factors and stormwater concerns are prevalent, potentially missing out on opportunities to holistically improve a community's well-being. Unless communities better align their rationale and siting statements for GI, there is a real risk that GI programs will at best fail to maximize all promised benefits, and at worst reinforce existing inequities. We argue that cities should better match siting statements to rationale statements to ensure that GI is strategically planned to maximize intended benefits, minimize undesirable consequences like green gentrification, and to avoid overpromising. If multifunctional GI is the goal, cities should have a clear process for delivering multiple desired benefits.

CRediT authorship contribution statement

Fushcia-Ann Hoover: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Supervision. **Sara Meerow:** Formal analysis, Data curation, Visualization, Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Emma Coleman:** Methodology, Formal analysis, Visualization, Writing – original draft. **Zbigniew Grabowski:** Conceptualization, Methodology, Formal analysis, Data curation, Visualization, Writing – review & editing. **Timon McPhearson:** Funding acquisition, Project administration, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Supplementary data

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