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Envisioning carbon-smart and just urban green infrastructure

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ABSTRACT

To address the inter-connected climate and biodiversity crises, it is crucial to understand how multifunctional urban green infrastructure (UGI) is perceived to contribute to carbon neutrality, biodiversity, human well-being, and justice outcomes in cities. We explore how urban residents, including youth, associate carbon-related meanings with multifunctional UGI and how these meanings relate to co-benefits to biodiversity, well-being, and broader sustainability outcomes. Our findings are based on a survey distributed among urban residents of Helsinki, Finland (n = 487) and reveal how carbon-related meanings of UGI manifest at different levels of abstraction, agency, and scale, and incorporate community values and concerns attributed to the planning, features, functions, and transformational dimensions of UGI. Core carbon-related meanings of UGI emphasize either actions towards sustainability, carbon neutrality, biodiversity, or unfamiliarity towards such meanings. Perceived justice concerns and the socio-demographic contexts of the respondents covaried with carbon-related meanings associated with UGI. The results illustrate community perceptions of how it is not only possible, but rather expected, that multifunctional UGI is harnessed to tackle climate change, human well-being, and biodiversity loss in cities. Challenges for implementing the carbon-related benefits of UGI include navigating the different expectations placed on UGI and including residents with diverse socio-economic backgrounds during the process. Our findings contribute to a holistic understanding of how multifunctional UGI can help bridge policy agendas related to carbon neutrality, biodiversity protection, and human well-being that cities can implement when aiming for sustainable, just, and socially acceptable transitions towards a good Anthropocene.

1. Introduction

Policy makers across the globe are urgently searching for rapid solutions to tackle the ongoing and interconnected climate and biodiversity crises (Ripple et al., 2020; Turney et al., 2020). While forests, arable land, and many other land-cover types surpass urban areas in extent, the need for such solutions concerns also cities and urban green infrastructure (UGI) within them, i.e., the system of interconnected urban ecosystems and built infrastructures (IPCC, 2019; De la Sota et al., 2019; Grabowski et al., 2022).

The nature-based solutions (NBS) framework provides a way to address biodiversity and climate challenges by connecting multiple sustainable development goals and planning strategies (Frantzeskaki et al., 2019, Seddon et al., 2021). The framework also helps identify the co-benefits and costs that managing UGI for increased carbon sequestration or storage, or for increased biodiversity, has the potential to deliver (Raymond et al., 2017; IUCN, 2020). By considering the needs of people and nature, the NBS framework highlights how UGI can help cities "*conserve* nature, *restore* nature, and *thrive with* nature" (Xie and Bulkeley, 2020).

While UGI indeed contributes to climate change mitigation and adaptation by sequestering and, to an extent, storing carbon dioxide from the atmosphere (Sun et al., 2019), and while this potential can be enhanced through specific management initiatives (Ariluoma et al., 2021), several other expectations are also placed on UGI (Madureira and Andersen, 2014). This is especially the case in rapidly consolidating

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cities, where increasingly diverse expectations by a growing number of urban residents are placed on increasingly small green areas (Haaland & van Den Bosch 2015; Hansen et al., 2019). For example, UGI has been shown to, or is expected to, provide well-being and recreation for urban residents (Casado-Arzuaga et al., 2014, van den Bosch and Sang 2017, Gulsrud et al., 2018), mitigate the urban heat island effect (Gill et al., 2007; Depietri et al., 2013), and, increasingly, provide habitat for diverse species communities (Borysiak et al., 2017; Korhonen et al., 2021). However, it remains unclear how, and to what extent, managing UGI for increased carbon sequestration or storage is perceived possible, and whether this would in fact provide ecological, social, and economic co-benefits or balance trade-offs between them (Wickenberg et al., 2021).

Efforts to manage UGI for tackling climate change or biodiversity loss are further complicated by concerns over environmental justice and social acceptability of NBS in cities. Narratives describing the dire consequences of climate change may be used to justify initiatives for carbon sequestration that would otherwise be perceived as unacceptable or unjust and would thus lack social sustainability (Harper, 2020). Similarly, overly technocratic decision-making focusing solely on addressing specific environmental problems can hinder the delivery of co-benefits and even result in costs for urban residents (Savasta-Kennedy, 2014).

While the inclusion and recognition of different stakeholders in decision-making around UGI, and the distribution of environmental goods and bad among them (Nesbitt et al., 2018), are increasingly being addressed in the NBS literature, little attention has been given to justice concerns of younger residents. The youth of today will face the future consequences of current decision-making (O'Brien et al., 2018), and yet remain widely underrepresented in traditional decision-making processes (Heinrich and Million, 2016). Youth may also value UGI in different ways than adult residents (Gearin and Kahle, 2006), highlighting the need to include their opinions in UGI planning. NBS that are planned in exclusion of the very stakeholders who are most closely associated with the consequences of said solutions, or that are implemented in a fashion that leads to the unequal or unjust distribution of co-benefits and costs, may under-deliver in terms of social sustainability and are unlikely to enjoy stakeholder support in the long term (Seddon et al., 2021, Cousins et al., 2021).

Urgent research is thus needed on the perceived potential and limits of UGI to simultaneously help tackle climate change, biodiversity loss and other expectations placed on the urban green in a just and socially acceptable manner across different age groups. Currently, we do not adequately understand what meanings or co-benefits concerning carbon sequestration or storage are perceived in connection with UGI, or how perceived environmental or intergenerational justice concerns and residential socio-demographic backgrounds covary with such perceptions. Yet perceptions of co-benefits expected from UGI managed to sequester or store carbon, and how such perceptions vary across residential groups, are key to understanding the social acceptability implications of implementing such UGI management. Namely *who* accepts, *what* is being accepted, and *why*.

Our aim in this paper is to explore and identify carbon-related meanings that urban residents, including youth, associate with UGI and, through this, contribute to a holistic understanding of how multi-functional UGI could help bridge key policy concerns of climate change mitigation, biodiversity conservation, and human well-being in cities. Our aim is also to critically reflect on how residential justice concerns and socio-demographic backgrounds may influence the expectations placed on, and the carbon-related meanings associated with, UGI and to contribute to the discussion on for whom and for what reasons UGI is planned and implemented. We reach these aims by responding to the following research questions:

1. *What are the carbon-related meanings or co-benefits associated with urban green infrastructure among urban residents?*
2. *How do perceived environmental justice and socio-demographic context covary with the meanings associated with urban green infrastructure?*

2. Materials and methods

2.1. Study area, sample, and data collection

The data for this study were collected between March 26th and May 26th, 2021, in Kumpula, Helsinki (Finland) in survey format through the online participatory mapping platform Maptionnaire. With a population of 5312 inhabitants, Kumpula is a relatively green neighborhood located in central Helsinki and characterized by long streets of detached single-family wooden houses. Kumpula also hosts one of the campuses from the University of Helsinki, residential apartment buildings, and student housing. This grants Kumpula a strong mix of residents by age and length of residence, enabling a detailed assessment of a diversity of views towards UGI. Further, the area surrounding the district has a high proportion of schools of different levels of education, facilitating engagement with students and data collection.

The survey, which was developed and refined in collaboration with city planners connected to the study area, was distributed following a mixed-mode approach (Dillman et al., 2014). First, the survey was distributed via postal invitations to a random sample of 1500 households in Kumpula. We then publicized the survey in local social media groups, online sites advertising local community events, and the local newspaper. Finally, to engage with younger residents, the survey was distributed to high school students between 16 and 19 years of age. This was achieved with seven workshops in two local upper secondary schools close to Kumpula in May 2021, where students were presented with the project and could complete the survey during class. Permission to distribute the survey among students was granted by the City of Helsinki in March 2021 (permit number HEL 2021-002634).

2.2. Survey content

The survey gathered a wide range of spatial, quantitative, and qualitative variables related to public understandings of the benefits of multi-functional UGI as well as aspects of perceived environmental justice. To elicit community perceptions of the carbon storage and sequestration benefits of multi-functional UGI, we elected to draw upon the conceptual metaphor of 'carbon-smart UGI' in the survey. Through this, we encouraged survey participants to directly consider the different ways of understanding the carbon sequestration and storage benefits of UGI, which would have likely been overlooked if we drew solely upon the UGI or NBS concepts. Basic socio-demographic variables such as age, gender, level of education, income, employment status, access to different types of UGI, and domicile were also collected. Perceived environmental justice was measured with 5-point Likert scale statements concerning urban green space management and decision-making in Kumpula. The statements were based on the procedural, recognitional, and distributional dimensions of justice, inspired by Fraser (2012) and Schlosberg (2007), as well as on aspects of carbon equity inspired by carbon and low-carbon gentrification literature (Bouzarovski et al., 2018; Rice et al., 2019) (Table 1).

A shortened version of the survey was provided to students (hereafter the "youth version") to allow for complete responses within a time frame suitable for teaching requirements in the two schools. For example, income and education levels were omitted from the youth version (visit Appendix 1 for the complete outline of both survey versions). At the beginning of the survey, participants were provided with information about the research project and data treatment. To continue, participants had to give informed consent; participants could withdraw from the survey at any point.

Table 1
Survey elements and questions used in this study. For a full overview of the content of the survey, see Appendix 1.

Survey element	Question / Statement	Question type, response options
Meanings associated with carbon-smart UGI	*Could you please describe with a few sentences what 'carbon-smart' suggests to you in the context of urban green spaces?*	Open-ended
Socio-demographic context	*"What is your age?"*	Categorical ordered: *15–24, 25–44, 45–64 or 65 years or older*
	"What is your gender?"	Categorical non-ordered: *female, male, other, prefer not to say*
	"How much do you earn yearly?"	Categorical ordered: *Less than €9,999, €10,000–19,999, €20,000–29,999, €30,000–39,999, €40,000–49,999, €50,000–59,999, €60,000–69,999, €70,000–79,999 and Over €80,000.*
	"Are you employed?"	Categorical non-ordered: *Employed, Unemployed, Student, Laid-off, Retired, Parental leave*
	"What is your education?"	Categorical ordered: *Primary school, Upper secondary level school, Bachelor's degree, Master's degree, Doctoral degree*
Environmental justice: Procedural	*I have taken part in or organized voluntary work concerning the green spaces in Kumpula.* *I have participated in public opinion surveys of the city of Helsinki concerning urban development in Kumpula.*	5-point Likert scale: *Strongly disagree, Disagree, Neither agree or disagree, Agree, Strongly agree*
Environmental justice: Recognition	*Green spaces managers and planners listen to and respect my opinions on the matter.* *My cultural or language background has prevented me from participating in the management or decision-making of green spaces in Kumpula.**	
Environmental justice: Distribution	*There are enough green spaces close to my home in Kumpula for me to enjoy them easily.* *The green spaces close to my home in Kumpula are managed as well as those in the rest of Helsinki.* *Green spaces in Kumpula are not as accessible to me because of my physical condition or disabilities.**	
Environmental justice: Carbon equity	*Everyone in Kumpula will have an equal opportunity to take advantage of government incentives for carbon-smart development such as tax subsidies and education programs.* *Carbon-smart urban development, such as expanded urban green spaces and improved public transportation, is targeted equally across Kumpula.* ** = scores reversed before calculating the compound measure of justice used in the analyses.*	

2.3. Qualitative analyses

We used both qualitative (content analysis) and quantitative (logistic and multinomial regression, Chi-square tests, Student's t-tests) analyzes to explore residential understandings of carbon-smart UGI (the carbon sequestration and storage benefits and meanings linked with UGI) and their relationship to perceived environmental justice and socio-demographic context. First, to understand in detail how residents associated carbon-related meanings and benefits with UGI, two of the authors (JL and OG-A) conducted qualitative content analysis of the responses to the open question assessing people's understanding of carbon-smart UGI (Table 1). The open-ended responses were inductively coded following a three-level classification that was iterated and refined as the content analysis advanced (see Results). Each response could be coded into several, mutually exclusive tertiary level codes. The inter-rater reliability test showed a Cohen's kappa coefficient (k) of 0.84, revealing a strong level of agreement between the two coders (McHugh, 2012).

2.4. Quantitative analyses

To identify underlying divisions between the respondents in the way they associated meanings with carbon-smart UGI, the results of the qualitative content analysis were subjected to K-means clustering (PAST software). The initial number of clusters was determined via an exploratory principal component analysis (PCA) (Appendix 2). Later, we used Pearson correlations (IBM SPSS Statistics version 28) to identify which of the individual meanings associated with carbon-smart UGI characterized each of these clusters (Appendix 4).

To assess the relationship between meanings associated with carbon-smart UGI and perceived environmental justice, we first calculated a compound measure of perceived environmental justice for each respondent by averaging all Likert scale environmental justice statements. The higher a given respondent scored with this compound measure, the more included and represented the person perceived themselves to be regarding urban green spaces and their management in their city district. The greatest lower bound for the reliability of the scale (Ten Berge and Socan, 2004) was 0.68. We then built binary logistic regression models explaining the odds of associating carbon-smart UGI with each meaning by this compound measure of justice. Only meanings mentioned by a minimum of ten respondents were included in the models. We also built multinomial logistic regression models to explain the odds of respondents belonging to any of the four major clusters of understanding carbon-smart UGI with the compound justice measure.

To explore the relationship between socio-demographic variables and meanings associated with carbon-smart UGI, we performed Chi-square tests (IBM SPSS Statistics version 28). We first transformed the socio-demographic variables into binary variables to reach the minimum expected count for Chi-square performance. For age, respondents were classified as youth (< 25 years) or adult (>= 25 years) following the UN definition of youth (UN General Assembly resolution A/36/215, 1981). For income, we classified the variables as above (A) and below (B) €40,000/year (the category most comparable with the approximate median income in Finland), and for education above (A) and below (B) undergraduate studies. The relationship between socio-demographic groups and the odds of belonging to any of the clusters of understanding carbon-smart UGI was also examined with multinomial logistic regression. We concluded the analyses by assessing the links between perceived environmental justice and the socio-demographic context of the respondent with Student's t-tests (IBM SPSS Statistics version 28).

3. Results

3.1. Survey response rate, respondent characteristics and representativity

A total of 487 people responded to the survey, with 38.4 % taking the youth and 61.5 % the adult version of the survey. The responses to the youth version were obtained entirely through the student workshops, while responses to the adult version were obtained through invitation letters, media engagement and social media outreach. More females (62.7 %) than males (34.2 %) participated in the survey, with female representation in the survey being slightly higher than that in the population of Kumpula (53 %) (CityFacts, 2021).

The most common age group among survey participants was that of 15–24 years (44.6 %), followed by 25–44 (29.2 %), 45–65 (17.5 %) and > 65 years (8.8 %) (n = 487). As a result of specifically engaging with youth, respondents were on average younger than the median age in Kumpula (39 years) (CityFacts, 2021). Most of the adult respondents were either employed (59.7 %), studying (18.9 %), or retired (15.9 %) (n = 201), and a high proportion (87.7 %) had completed higher education programs such as a bachelor's degree (26.4 %), master's degree (50.8%), or Ph.D.-level programs (10.5 %) (n = 191). In comparison, 52 % of all residents in Helsinki between 25 and 64 years of age have completed higher education programs (City of Helsinki, 2020). The most common income class among adult participants was €30,000–39,999 (17.8 %) (n = 214), while the most common income class in Helsinki was €40,000–50,000 (City of Helsinki, 2021).

3.2. Benefits and meanings associated with carbon-smart UGI

On average, the respondents expressed their understanding of carbon-smart UGI within 22 words. Five primary, fourteen secondary, and forty tertiary groups emerged from the qualitative content analysis regarding these understandings (Fig. 1). The primary five groups related to (1) the planning and management of UGI (with 31 % of respondents associating carbon-smart UGI with meanings of this group), (2) the features and properties of UGI (46.3 %), (3) functions of UGI (68.8 %), (4) more abstract notions about sustainability transitions concerning UGI (22.6 %), and (5) meanings and reflections about the concept itself (21.3 %). On average, each definition contained 2.3 tertiary level meanings.

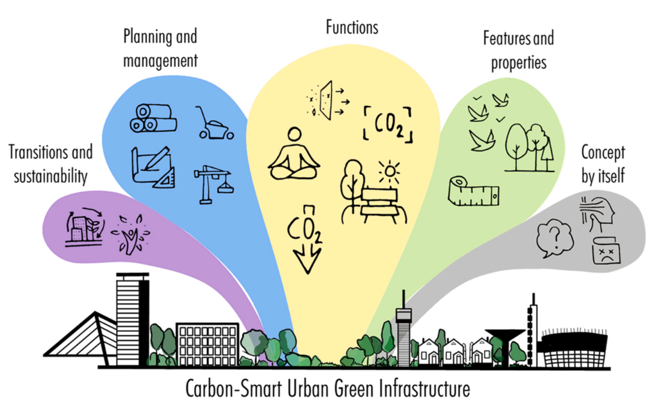

Fig. 1. Graphical representation of meanings associated with carbon-smart urban green infrastructure, as reported by the survey respondents ($n = 416$). The colored fields correspond to the primary groups of meanings, with the size of the field proportionally related to the number of mentions. For a description of each meaning, see Table 1. Figure drawn by OG-A.Icons depicting individual meanings adapted from Flaticon.com (Freepik Company, 2021).

Meanings in the first primary group involved notions about the way UGI is planned, constructed, or managed, but also those highlighting the protection of urban green spaces as a part of carbon-smartness. For example, a female respondent 25–44 years of age described carbon-smartness with "*I assume it means that green spaces should be designed to act as carbon-sinks or at the least to be carbon neutral*", and another of the same age and gender with "*It is carbon-smart to spare as much green spaces as possible. Whatever they are, but especially forests. Even the small ones.*"

Meanings in the second primary group highlighted carbon-smartness of UGI as something related to the properties and features of urban green infrastructure, such as specific types of vegetation, but also those dependent on personal perceptions, such as notions about aesthetic appearance or cues to care (Li and Nassauer, 2020). For example, a respondent 45–64 years of age (sex unknown) described the concept as "*For me, carbon-smartness stands for nature, forests, trees and meadows and wild animals*" and a male respondent in the same age group as "*Carbon-smartness signifies a lush streetscape…*".

The third, and largest, group compiled meanings associated with how UGI functions or how urban residents can utilize green spaces. For example, responses included in this group were related to carbon sequestration and/or storage, cooling effects, and recreation and relaxation. A female respondent 25–44 years of age expressed this concisely with "*A carbon-smart green space sequesters carbon dioxide efficiently,*" while another female respondent of 45–64 years of age understood the concept more through well-being: "*One of the most important factors affecting the pleasantness of living. A source of strength and joy.*"

The fourth group of meanings related carbon-smartness of UGI to more abstract notions of sustainable actions, choices, lifestyles, and life in the surrounding city. For example, a female respondent 45–64 years of age described carbon-smartness as "*Actions to restrain climate change*" and a female student respondent with "*The environment and infrastructure is built in a way that ensures the citizens are able to live as carbon neutral life as possible.*"

Finally, the fifth group of meanings consisted of responses indicating unfamiliarity with and, at times, doubt towards the concept. For example, a male respondent of 17 years of age mentioned that "*I am not aware of the concept*" and another male respondent of 45–64 years of age expressed their doubt towards the term as "*Carbon + smart, not a very good pair of concepts.*" More precise descriptions supported with quotations of each of the primary, secondary, and tertiary groups of benefits and meanings associated with carbon-smart UGI are presented in Appendix 3.

3.3. K-means clustering of meanings associated with carbon-smart UGI

As the PCA ordination representing the two first principal components suggested four distinct groups of tertiary level meanings associated with carbon-smart UGI, K-means clustering divided the respondents into four clusters. Pearson correlations between tertiary-level meanings associated with carbon-smart UGI and cluster identity revealed that cluster 1 (43.6 % of respondents) represented respondents with a diverse, action-oriented understanding of UGI carbon-smartness. For example, a senior male respondent in this cluster described carbon-smartness as "*To be carbon-smart is to favor cycling instead of driving by car. To not warm up your summer cabin with the stove and to choose vegetarian foods in your diet.*" On the other hand, cluster 2 (20.8 %) represented respondents who were, to varying extents, unfamiliar with carbon-smart UGI, as illustrated by a male respondent in the age group 25–44: "*It means nothing, I have not heard of the term before.*" cluster 3 (21.8 %) represented those who linked the concept primarily with the function of carbon sequestration. For example, a female student 17 years of age described carbon-smart UGI with "*To me, carbon-smart green spaces suggest areas that don't produce more carbon emissions, but instead do carbon sequestration, such as trees in parks or small forest areas between* *buildings''*. Finally, cluster 4 (13.8 %) represented respondents who linked the concept primarily with biodiversity-related features, such as vegetation diversity, as illustrated by a female respondent 25–44 of age: "*A green space that is sufficiently 'unmanaged'. Overgrown with bushes, diverse in terms of flora and thus also of fauna. Soil that suits the vegetation naturally without human intervention. Retains water sufficiently, is lush from spring to autumn, with plants growing on their 'own', there being lots of them*." From now on we will refer to clusters 1, 2, 3 and 4 as "Sustainability actions", "Unfamiliarity", "Carbon sequestration and storage" and "Biodiversity" clusters, respectively. For a more detailed description of the correlations between each cluster and tertiary-level understandings of carbon-smart UGI, see Appendix 4.

3.4. Relationships between meanings associated with carbon-smart UGI, perceived environmental justice, and socio-demographic context

Binary logistic regression models revealed that perceived environmental justice had a significant negative relationship with the odds of associating carbon-smart UGI with the meaning of *Carbon sequestration and storage*. On the other hand, perceived justice had a significant positive relationship with the odds of associating carbon-smart UGI with meanings of *Recreation and access* and *Environmentally friendly urban lifestyles and practices* (Table 2**.**).

Similarly, multinomial logistic regressions showed that the odds of a given respondent belonging to a particular cluster of meanings covaried to some extent with perceived environmental justice. Namely, respondents who scored high on perceived environmental justice were more likely to fall in the Sustainability Actions cluster, Unfamiliarity cluster, or Biodiversity cluster than in the Carbon Sequestration and Storage cluster (Table 3).

Multinomial regressions suggested that the odds of belonging to a particular K-means cluster were only weakly linked with a respondent's socio-demographic context. The only exception emerged between respondent's gender and the odds of belonging to cluster 4: female respondents were more likely than male respondents to fall in the Biodiversity cluster than the Sustainability Actions cluster (B 0.90, standard error 0.38, p-value 0.02, Exp(B) 2.46). However, when looking at the individual meanings associated with carbon-smart UGI, Chi-squared tests of independence tests showed a co-variance with the socio-demographic context of the respondents (Table 4). Respondents below 25 years of age understood carbon-smart UGI as relating specifically to the way green spaces are constructed and to their low carbon emissions. In comparison, respondents older than 25 years of age had a more pluralistic view of the concept, highlighting, for example, biodiversity and the coexistence of nature and humans. Respondents older than 25 years were also more critical towards the concept than younger respondents, mentioning more often that carbon-smart UGI has no meaning and appears either artificial or unfamiliar.

As for sex, female respondents were more likely to relate carbon-smart UGI with the coexistence of nature and humans in cities and with specific types of green space vegetation than males. Males, on the other hand, were more likely to state that the whole concept has no meaning. Medium to high income respondents focused more on carbon sequestration and low carbon emissions of a green space when describing carbon-smartness, whereas medium to low-income respondents related the concept to vegetation. Finally, while employment did not relate to differences in understanding of carbon-smart UGI, respondents with higher levels of education were more likely to question the concept or suggest that it appears artificial or unfamiliar more often than those with lower education levels.

Finally, Student's t-tests revealed statistically significant links between perceived environmental justice and respondent socio-demographic context. Namely, adult respondents, those with higher incomes, and those with higher levels of education, reported a higher level of perceived environmental justice than youth, those with lower incomes, and those with lower levels of education. Although only nearly significant, female respondents and those employed also reported higher levels of perceived environmental justice relative to males and unemployed participants. Detailed descriptions of these results are included in Appendix 5.

4. Discussion

Mitigating and adapting to climate change (IPCC, 2019) and protecting and restoring biodiversity (European Commission, 2020) are central agendas for adapting to global environmental change. This paper has sought to provide an understanding of carbon-related benefits urban residents associate with UGI, thus contributing to a more holistic understanding of the benefits multifunctional UGI provides and how such benefits can advance carbon neutrality, biodiversity conservation, and human well-being in cities. Based on our results, carbon-related benefits of UGI manifest at different levels of abstraction, agency, and scale, and incorporate values and concerns attributed to the planning, features, functions, and transformational dimensions of urban green infrastructure. These benefits may be advanced by both public and private stakeholders, in public and private UGI, and at scales ranging from individual green spaces to the entire city. Importantly, the carbon-related benefits and meanings that urban residents associate with UGI vary according to personal socio-demographic background and perceived environmental justice concerns. We consider these results among the first exploratory steps in building understanding on how, by whom, and why UGI are perceived to contribute to carbon neutrality. This perceptual information will eventually help make more informed decisions on how to advance carbon neutrality in the context of UGI, while at the same time elicit the social acceptability outcomes of such policies.

4.1. Key carbon-related benefits and meanings associated with urban green infrastructure

Four primary conceptualizations of carbon-related benefits of UGI emerge from the diversity of meanings described above, with each of these highlighting different perceptions of how multifunctional UGI

Table 2
Summary of statistically significant (p-value $<$ 0.05) or near-significant (p-value $<$ 0.05–0.09) binary logistic relationships between the odds of associating carbon-smartness with specific meanings and perceived environmental justice. Positive values of B imply a positive relationship between perceived environmental justice and each meaning associated with carbon-smart UGI, negative values of B a negative relationship. Only meanings with a minimum of ten occurrences across the respondents in the initial dataset (n = 339) are included *in* the models. Statistically significant (p-value $<$ 0.05) relationships appear in bold.

Meaning associated with carbon-smart UGI	B	Standard error	Wald	df	Sig	Exp (B)	95 % confidence intervals
Managing for carbon	0.64	0.38	2.82	1	0.09	1.90	0.90–4.01
Sense of wildness / untouched nature	0.93	0.52	3.16	1	0.08	2.53	0.91–7.05
Carbon sequestration	-0.53	0.23	5.26	1	**0.02**	**0.59**	0.37–0.93
Carbon offsetting	0.95	0.56	2.90	1	0.09	2.57	0.87–7.656
Recreation, access and reachability	1.33	0.48	7.66	1	**0.01**	**3.79**	1.48–9.72
General sustainability	0.74	0.42	3.14	1	0.08	2.09	0.93–4.72
Environmentally friendly urban lifestyles and practices	0.98	0.45	4.67	1	**0.03**	**2.67**	1.10–6.50
The concept is artificial	1.27	0.69	3.46	1	0.06	3.57	0.93–13.66

Table 3
Multinomial logistic regression models explaining the likelihood of a respondent ($n = 339$) belonging to each cluster produced by K-means clustering with the compound measure of perceived environmental justice. Positive values of B imply a positive relationship between perceived environmental justice and the likelihood of the respondent to belong in the comparison cluster rather than in the reference cluster. Statistically significant relationships (p-value < 0.05) between the reference and comparison cluster appear in bold.

Reference cluster	Comparison clusters	B	Std. error	Wald	df	Sig.	Exp (B)	95 % confidence intervals
Sust. Actions	*Unfamiliarity*	0.08	0.28	0.08	1	0.78	1.08	0.62–1.89
	CSS	**−0.53**	0.26	4.07	1	**0.04**	**0.59**	0.35–0.99
	Biodiversity	0.17	0.34	0.25	1	0.62	1.18	0.61–2.28
Unfamiliarity	*Sust. Actions*	−0.08	0.28	0.08	1	0.78	0.92	0.53–1.60
	CSS	**−0.61**	0.31	3.78	1	**0.05**	**0.55**	0.30–1.01
	Biodiversity	0.09	0.37	0.06	1	0.81	1.09	0.53–2.28
CSS	*Sust. Actions*	**0.53**	0.26	4.07	1	**0.04**	**1.70**	1.02–2.82
	Unfamiliarity	**0.61**	0.31	3.78	1	**0.05**	**1.84**	1.0–3.39
	Biodiversity	**0.70**	0.36	3.70	1	**0.05**	**2.01**	0.99–4.08
Biodiversity	*Sust. Actions*	−0.17	0.34	0.25	1	0.62	0.85	0.44–1.63
	Unfamiliarity	−0.09	0.37	0.06	1	0.81	0.92	0.44–1.90
	CSS	**−0.70**	0.36	3.70	1	**0.05**	**0.50**	0.24–1.01

Table 4
Chi-square tests of independence ($\alpha = 0.05$) between the tertiary-level meanings of carbon-smartness and socio-demographic variables. Only statistically significant (p-value < 0.05) (in bold) or near significant (p-value < 0.05–0.09) differences (*) in the relationships are included. Employment is not included in the table due to lack of significant relationships. For income, two classes were designated: below (B) and above (A) €40,000/year. Education was segmented below (B) and above (A) undergraduate studies.

Tertiary-level meanings of carbon-smart UGI	Age ($n = 416$)		Gender ($n = 404$)		Income ($n = 202$)		Education ($n = 357$)	
	<24	>24	Female	Male	B	A	B	A
Considering carbon during green space construction	**7.45 %**	1.75 %					**7.41 %**	1.79 %
Managing for carbon	5.3 %	**11.4 %**					6.35 %*	11.31 %*
UGS protection			7.70 %*	3.5%*				
Extent of the GS					8.70 %*	3.10 %*		
Green space types					9.57 %*	3.10 %*		
Vegetation	16.48 %*	23.24 %*	**23.46 %**	13.99 %	**28.70 %**	13.40 %	15.34 %*	23.21 %*
Habitat provision								
Biodiversity	3.72 %	**9.65 %**					3.17 %	**10.71 %**
Sense of wilderness / untouched nature	3.19 %	**7.89 %**					2.65 %	**8.33 %**
C sequestration							22.75 %	**32.74 %**
C sinks and carbon neutrality					14.78 %	**27.84 %**	14.29 %*	22.02 %*
C offsetting	1.6 %	**6.14 %**					1.59 %	**7.74 %**
Low C emissions	**15.96 %**	6.58 %			2.61 %	**13.37 %**	**15.87 %**	7.74 %
Relaxation and restoration	3.19 %*	7.02 %*					1.59 %	**8.93 %**
Coexistence of nature and humans	1.60 %	**5.70 %**	**5.77 %**	0.70 %				
CC mitigation and adaptation	3.72 %*	8.33 %*						
The concept has no meaning	2.13 %	**7.46 %**	3.46 %	**8.40 %**			2.65 %*	6.55 %*
The concept is artificial	1.06 %	**7.02 %**					1.06 %	**7.74 %**
The concept sound unfamiliar	11.70 %	**20.18 %**					11.64 %	**22.62 %**

contributes to the carbon sequestration and storage dynamics in cities. Residents in the Carbon Sequestration and Storage cluster understood carbon-related benefits of UGI mainly through biophysical, carbon-related functions of UGI. This, and the fact that over 50 % of the respondent residents associated these benefits directly with the flows and stocks of carbon, highlights how residents readily link them with climate change mitigation and adaptation. On the other hand, residents in the other three clusters supported a more holistic view of carbon-related benefits, particularly the importance of nature's contributions to people (NCP) derived from UGI (Díaz et al., 2018). For example, residents in the Sustainability Actions cluster linked carbon-related benefits and meanings to urban form and densification trends, green space construction, and sustainable urban lifestyles, whereas those in the Biodiversity cluster emphasized the importance of UGI features and functions contributing to biodiversity conservation, as well as human well-being.

These different conceptualizations of how UGI can contribute to supporting carbon neutrality unveil, on the one hand, a diversity of benefits directly linked with the flows and stocks of carbon in cities; on the other hand, they corroborate previous evidence of the perceived importance of UGI for biodiversity and human well-being (Tyrväinen et al., 2007; Casado-Arzuaga et al., 2014; Madureira et al., 2015). In past research, the benefits and meanings associated with UGI have been primarily unrelated to carbon neutrality, emphasizing instead the biodiversity or well-being benefits of the urban green (e.g., O'Brien et al., 2017, Lampinen et al., 2021). Our results suggest that managing UGI for increased benefits to carbon sequestration and storage is perceived to be possible, but ought to avoid overly technocratic approaches that rely solely on biophysical aspects of UGI, such as forestation initiatives (Seddon et al., 2019), or so-called carbon-reduction tunnel vision (Savasta-Kennedy, 2014). Instead, efforts that aim to advance carbon neutrality with UGI would benefit from conceptualizations that transcend the ecosystem service approach and include perceived benefits related to biophysical, well-being and justice outcomes of UGI (Reyes-Riveros et al., 2021) while incorporating many different planning objectives for UGI (Nordh and Olafsson, 2021). The flexibility, inherent multifunctionality and diversity of carbon-related benefits associated with UGI, as illustrated in our results, may, however, also pose a challenge for operationalizing them into practice. For example, it is well recognized (Hansen and Pauleit, 2014) that city planners and managers may find it difficult to navigate the different core meanings of climate change mitigation, recreation and well-being, and biodiversity conservation associated with UGI.

This challenge emerges also in the responses, with certain respondents criticizing the holistic understanding of "carbon-smart UGI", our conceptual metaphor for eliciting carbon-related benefits of UGI. For example, residents in the Unfamiliarity cluster rejected the concept as something either vaguely understandable, artificial, or even unacceptable. We propose that due to dealing with "carbon" and its inherent relationship with "climate change," "carbon-smart UGI" may have appeared either overly abstract or ambiguous as a concept and was thus met with skepticism and low social acceptability by certain respondents. This resonates with the public's difficulty to make sense of the rather technical, but mainstreamed, terms associated with climate change, as demonstrated by research on carbon and climate change literacy (Whitmarsh et al., 2011).

In addition, the result that the youth and highly educated residents were more likely to assign such negative connotations to "carbon-smart UGI" mirrors current criticism of the NBS framework as lacking transparency, being vague, and even being a form of institutional greenwashing (FOEI, 2021). Building on what the IUCN (2020) suggests, we propose clear standards to be set for assessing the potential and limitations of UGI to support carbon-related benefits and their relationship with outcomes for biodiversity and human well-being. Such ambitions will need "carbon-smart UGI" and other efforts harnessing the carbon-related benefits of UGI to be further conceptualized and implemented with participatory and co-design processes (Basnou et al., 2020) and to be coupled with communication efforts to raise public awareness of the possibilities of UGI to advance carbon neutrality.

4.2. Perceived justice concerns and socio-demographic context covary with carbon-related meanings associated with urban green infrastructure

We also found that perceived justice concerns and residential socio-demographic context covary with carbon-related meanings associated with UGI. For example, residents reporting higher levels of perceived justice highlighted recreational opportunities, aspects of biodiversity, or other contributions that cities derive from the urban green more often than residents reporting lower levels of perceived justice. Likewise, the carbon-related meanings associated with UGI by respondents reporting lower levels of perceived justice related primarily to carbon sequestration and storage instead of other benefits. Several explanations for these results exist. First, residents who are less recognized and participate less in decision-making processes concerning the urban green may have less access either to UGI itself or to the benefits it provides (e.g., Nesbitt et al., 2018), leading to the under-reporting of a diversity of NCP. Conversely, residents reporting high levels of perceived justice likely enjoy a secured status founded on high income and education that renders them more capable of acknowledging and benefiting from the co-benefits, carbon-related or not, UGI could provide. This supports previous knowledge that marginalized and vulnerable groups, as opposed to the affluent and the educated, are less capable of identifying and benefiting from the co-benefits of UGI (Rutt and Gulsrud, 2016). Residents in vulnerable positions may also be less capable of attending to practices of care related to the urban green, which in itself reflects an injustice due to lack of time and resources these residents have at their disposal (Williams, 2016). It should be noted that these results are based on perceptual rather than indicator-based measures of justice. Perceptual measures may help elicit a more inclusive understanding of how justice concerns vary across residential contexts than by using indicator-based measures only, as the two are not always aligned (Paloniemi et al., 2018). This warrants future research linking carbon-related understandings of UGI to both indicator-based and perceptual measures of justice.

As for socio-demographics, we found that highly educated residents with higher incomes were more likely to identify technical options through which UGI could advance carbon neutrality. In addition, females highlighted the coexistence between humans and nature as a part of carbon-related meanings associated with UGI more often than males did. We attribute these results to the gendered nature of environmental knowledge in both adults and youth (Miller et al., 2007; Goldman et al., 2017). Women are more emotionally engaged and show more concern over environmental destruction than men (Kollmuss and Agyeman, 2002), thus exhibiting more pro-environmental attitudes (Goldman et al., 2017). The results also mirror previous research suggesting that gender, income, and other socio-demographic characteristics influence the evaluation of ecosystem services delivered by the urban green (Sanyé-Mengual et al., 2018). These results must, however, be interpreted with awareness of the clear links observed between perceived justice and socio-demographic context, namely that, in our data, wealthy, educated adult respondents tended to report higher levels of perceived justice than the youth or those with less education and wealth. These findings resonate with previous studies asserting a systematic exclusion of youth in decision-making (Heinrich and Million, 2016), and their lower access to UGI (Sikorska et al., 2020). Similarly, low incomes (Łaszkiewicz et al., 2018) and low levels of education (Cole et al., 2019) have been associated with distributive (in)justice, which might help explain our findings. Following the capabilities framing of environmental justice, this illustrates how residential justice concerns are firmly embedded in the socio-demographic conditions and economic context of the residents in question (Sen, 2009, Rutt and Gulsrud, 2016).

Through envisioning carbon-related benefits of UGI as perceived by urban residents themselves we hope that co-benefits inherent to participatory planning itself, such as residential stewardship and agency, and political trust (Raymond et al., 2022), are more likely to be delivered in the implementation of these benefits than when residents of diverse contexts are excluded. Inclusivity and engagement likewise work towards understanding how UGI could advance carbon neutrality while enjoying social acceptance, as only by investigating the values and expectations residents place on the urban green may UGI be planned to respect those values and expectations (Madureira et al., 2015; Basnou et al., 2020). We believe that acknowledging and identifying the carbon-related benefits of UGI will help integrate the intertwined natures of urban socio-ecological-technological systems, contributing to the much-needed radical departures from unsustainable trajectories when moving toward a good–or better–Anthropocene (McPhearson et al., 2021). However, we also stress the need to acknowledge potential risks of advancing carbon-neutrality with UGI in exacerbating social injustices through green, or in this case, carbon gentrification, and the potential displacement of local communities that follows such risks (Rice et al., 2019). We propose UGI to be managed for increased benefits to carbon sequestration or storage in a manner "just green enough" (Wolch et al., 2014), i.e., that the socio-ecological benefits expected to be delivered from such efforts would be drafted in response to community concerns, desires and needs, rather than to those of city planners.

4.3. Future directions of research

This study presents an initial exploration of residential perceptions and understandings of carbon-related benefits of urban green infrastructure, and many open questions remain regarding how these perceptions form and interact with residential socio-ecological contexts. For example, previous research highlights how differences in valuation and perceptions of UGI relate to factors such as length of residency (e.g., Arnberger, 2012) and level of education (e.g., Fernandes et al., 2019), warranting future research regarding the links between place attachment, education, and perceived carbon-related benefits of UGI. Future research needs include pinpointing the exact UGI features or management interventions that are perceived to, and in reality do, provide benefits to carbon sequestration and storage, biodiversity, and human well-being. Equally important would be to assess the social acceptability and justice concerns of implementing such features or interventions in UGI. For example, investigating how personal context or spatial scale mediate the social acceptability and perceived carbon-related benefits of UGI, and identifying the segments of society whose values align with managing UGI for carbon, would help ensure that implementing such management does not perpetuate, but challenges, the potential injustices resulting from NBS. Thus, while providing a base for which to build new knowledge, we suggest similar studies on UGI are replicated in different contexts (e.g., city scale and in other cities) with more inclusive, co-productive, and diverse approaches for data collection, such as residential workshops or walking interviews in green spaces.

5. Conclusions

The diversity of carbon-related benefits and meanings associated with UGI as described in this study suggests that it is not only perceived as possible, but desirable, to bridge the policy agendas of carbon neutrality and biodiversity loss in cities (IPBES, 2022). Challenges remaining for such pursuits include navigating the different ways individuals associate meaning with UGI and tailoring the practical implementation of carbon-oriented UGI management to the needs of diverse residential groups, as certain co-benefits and meanings are identified by only a small section of society. Equally challenging, yet important, is to ensure continued reflection on the consequences that this entails for perceived environmental justice among residents. Issues of justice have remained less explored in the literature regarding NBS and the urban green (Rutt and Gulsrud, 2016, Cousins, 2021), and yet only by weaving justice into the heart of sustainability transitions may we expect for these transitions to be sustainable in the long term (Seddon et al., 2021). Thus, to ensure that a plurality of viewpoints and expectations are represented, it is crucial to include and meaningfully engage with residents of diverse socio-demographic contexts during the early stages of conceptualizing how UGI could be managed to advance carbon sequestration or storage (Basnou et al., 2020). Solving these challenges will increase the likelihood of achieving not only "carbon-smart", but also just and socially acceptable UGI in cities that face increasing pressures to respond to the challenges that climate change, biodiversity loss, and persistent inequality present.

CRediT authorship contribution statement

The contribution of the two first authors were equal. The precise contributions of each author were as follows: **Jussi Lampinen:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration. **Oriol García-Antúnez:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Anton Stahl Olafsson:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Kayleigh C. Kavanagh:** Conceptualization, Methodology, Validation, Investigation, Writing – review & editing. **Natalie M. Gulsrud:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Christopher M. Raymond:** Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2022.127682.

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