Landscape and Urban Planning 241 (2024) 104923

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Urban resilience through green infrastructure: A framework for policy analysis applied to Madrid, Spain

Marta Suárez [a,b,*], Amaya M. Rieiro-Díaz [c], David Alba [d], Johannes Langemeyer [e,f], Erik Gómez-Baggethun [g,h], Ibone Ametzaga-Arregi [a]

[a] UNESCO Chair on Sustainable Development and Environmental Education, University of the Basque Country UPV/EHU, Leioa, Spain
[b] Social-Ecological Systems Laboratory, Department of Ecology, Universidad Autónoma de Madrid, Madrid, Spain
[c] Universidad Internacional de la Rioja, Logroño, Spain
[d] Asociación Ecología y Educación para una Ciudad Sostenible – Transitando, Madrid, Spain
[e] Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, Spain
[f] Department of Geography, Humboldt Universität zu Berlin, Germany
[g] Department of International Environment and Development Studies, Norwegian University of Life Sciences, Ås, Norway
[h] Norwegian Institute for Nature Research, Oslo, Norway

HIGHLIGHTS

- Impact of green infrastructure policies on resilience measured through an index.
- Planning instruments foster resilience more than other types of policies.
- Policies that focus on vulnerable neighbourhoods have better resilience results.
- Citizen engagement is key for urban resilience.
- Financing and political will are main challenges for implementation.

ARTICLE INFO

Keywords:
Policy analysis
Social-ecological justice
Urban green infrastructure
Urban resilience index

ABSTRACT

Urban resilience and how to assess it have become main policy objectives in the face of accelerated climate and other global environmental change. We develop a conceptual framework and an assessment tool to analyse how green infrastructure policies contribute to urban resilience and discuss barriers and opportunities for implementation. The conceptual framework is designed to analyse how resilience is fostered through six resilience factors: diversity, self-sufficiency and autonomy, polycentric governance, social cohesion, learning and innovation, and social-ecological justice. The assessment tool consists of a resilience index composed of 30 indicators. We use the capital city of Madrid, Spain, as a case study. Our results suggest that planning policies that focus on vulnerable neighbourhoods and include mechanisms for citizen engagement are the policies that most effectively foster urban resilience. We also identified that financing and political will are major barriers for the implementation of resilience policies. We assume that the proposed framework is suitable to assess to what extent local policies foster urban resilience and suggest further testing in other cities.

1. Introduction

Projected increases in hazards from climate and other global environmental changes have sparked policy interest in urban resilience (Moser et al., 2019; Andersson et al., 2021). Urban resilience is defined as the ability of an urban area to maintain or rapidly recover desired functions in the face of disturbance; it is characterised by the capacity to adapt to change and to transform those aspects that hinder adaptive capacity (Meerow et al., 2016). Resilience is often seen as a system property that can be intentionally fostered through adequate practices

* Corresponding author at: UNESCO Chair on Sustainable Development and Environmental Education, University of the Basque Country UPV/EHU, Barrio Sarriena s/n, 48940 Leioa, Spain.
E-mail address: msuarez023@ikasle.ehu.eus (M. Suárez).

https://doi.org/10.1016/j.landurbplan.2023.104923
Received 13 December 2022; Received in revised form 27 September 2023; Accepted 7 October 2023
Available online 17 October 2023

and policies (Elmqvist et al., 2019; Andersson et al., 2021).

Over the last decade, growing interest has been paid to the role of urban green infrastructure in enhancing adaptive capacities (Andersson et al., 2015; Green et al., 2016; De Luca et al., 2021). Green infrastructure (GI) is defined as a 'strategically planned network of natural and semi-natural areas with other environmental features designed to deliver a wide range of ecosystem services' (European Commission, 2013). These ecosystem services contribute to urban resilience in a variety of ways (McPhearson et al., 2015). For example, urban agriculture increases social cohesion and learning (Camps-Calvet et al., 2016), and represents a local source of food, reducing dependence on external supply sources and increasing the resilience of the city in the face of possible economic or energy crises (Langemeyer et al., 2021). Urban vegetation provides multiple regulating ecosystem services, such as water flow, runoff, or urban temperature regulation (Gómez-Baggethun & Barton, 2013), these, in turn, increase resilience to climate change. Green space, if well-designed and fairly distributed (Kabisch & Haase, 2014), can enhance social cohesion (Konijnendijk et al., 2013) and sense of place (Łaszkiewicz et al., 2018), which are attributes that foster resilience (Townshend et al., 2015; Winstanley et al., 2015). Green infrastructure, therefore, can enhance urban resilience to a wide variety of disturbances: extreme weather events (Voskamp & Van de Ven, 2015), economic crises (Langemeyer et al., 2021) or even health emergencies such as the recent COVID-19 pandemic (Labib et al., 2022). Specific policies to foster resilience through green infrastructure can be locally developed. They can be directed to specific kinds of disturbances or can promote general resilience, that is, the capacity to adapt and transform in response to a wide variety of unfamiliar and unexpected shocks (Carpenter et al., 2012; Bouska et al., 2019; Yumagulova & Vertinsky, 2021). In this paper we focus on general resilience, considering a wide variety of disturbances such as those mentioned above.

Local governments can enhance GI to foster resilience through policy instruments (Conway et al., 2020). Mendonça et al. (2021) differentiate three types of policy approaches: planning/legislative, economic or market-based, and citizen engagement and information policies. The first category of policies may consist of formally sanctioned rules, (e.g., laws or regulations), or of guidelines, (e.g., local GI strategies). Economic policies aim to encourage behaviour shifts, discouraging particular practices by charging fees or taxes, or incentivising GI through subsidies and similar instruments. Citizen engagement and information policies include training and education, communication processes and stakeholder engagement (Zuniga-Teran, Gerlak et al., 2020; Mendonça et al., 2021).

How can we measure the degree to which GI policies increase urban resilience? Which kind of GI policies are more effective on fostering resilience? To our knowledge, there are no studies that directly analyse how GI policies can increase urban resilience, but several frameworks and methodologies to analyse the degree to which GI fosters resilience to a wide variety of disturbances have been developed in the last decades. For instance, Biggs et al. (2012) approached the theme developing a framework that enumerates and explains principles to enhance the resilience of ecosystem services. These, included diversity, learning and experimentation, and polycentric governance systems (see also De Luca et al., 2021). Calderón-Contreras & Quiroz-Rosas (2017) analysed urban resilience through ecosystem services, using as proxies the scale, quality and diversity of green infrastructure. Rayan et al. (2021) developed a model composed of a set of GI planning indicators to build climate-resilient urban regions in Pakistan. Karabakan & Mert (2021) assessed the role of green infrastructure in resilience, in terms of changes that could potentially take place, using Geographic Information Systems. Bănică et al. (2020) assessed the statistical relationship between indicators of green infrastructure and different proxies for urban resilience.

Building on the above-cited work, we propose a complementary methodology to measure to what extent GI policies promote urban resilience to a wide variety of disturbances. To this aim, we develop an urban resilience index composed of 30 indicators based on the framework by Suárez et al. (2016) and Suárez, Gómez-Baggethun et al. (2020) to assess social-ecological resilience in cities. This framework assumes that resilience can be fostered through six factors (i.e., diversity, modularity, feedbacks length, social cohesion, learning and innovation and equity) in five urban dimensions (i.e., social, economic, ecological infrastructure, grey infrastructure and governance). The framework rests on the idea that a comprehensive set of resilience indicators should measure all these factors and dimensions. We use this assessment tool to evaluate the degree to which GI policies foster resilience in Madrid, Spain.

The paper is organised in five main sections. Following this introduction, we first explain the methodology used to assess to what extent GI policies increase urban resilience. Second, we describe the results of applying this methodology to Madrid, Spain. Third, we discuss which type of GI policies foster urban resilience the most, the main barriers and opportunities for GI implementation, how justice issues are addressed and the methodological limitations of the proposed framework. Based on our results, we propose policy recommendations to foster urban resilience through green infrastructure policies.

2. Methodology

2.1. Study area

Our case study area comprises the municipality of Madrid. Madrid is Spain's capital and largest city. With more than 3 million people and 5512 inhabitants per km^2 (INE, 2021; ALMUDENA, 2020), Madrid is also a very densely populated urban area.

Madrid has a relatively high ratio of green space (18.3 m^2 per inhabitant) and trees (1.4 trees per 3 inhabitants) per inhabitant as compared to the 15 m^2 per inhabitant and 1 tree per 3 inhabitants recommended as a minimum by the World Health Organization (Madrid City Council, 2018b). Moreover, these numbers only include green space and trees managed by the City Council, therefore the actual ratio is higher. Green space in Madrid is comprised of urban parks (more than 90 %), but also includes botanical and zoological gardens, sports and leisure facilities, building plots, community gardens and landscaped areas in streets. Peri-urban green space covers more than 25 % of the municipality and is mainly composed by herbaceous vegetation associations, arable land, pastures, and forests (Fig. 1). This space consists mostly of natural protected areas located at the north and south-east of the municipality. However, they are not managed by the City Council and therefore not analysed in this paper.

The municipality is divided into 21 districts. As in most other cities (see e.g., Suárez, Barton et al., 2020), GI is unevenly distributed. Following the common pattern, the central districts are, in general, densely urbanised with a scarcity in green space and trees, whereas more peripheral districts have higher ratios of green space per inhabitant (Madrid City Council, 2018b).

The main watercourse of the municipality is the Manzanares river. The Manzanares is 92 km long and drains a water basin of 52,796 ha. It crosses the western and southern districts of the municipality and three of the most important green spaces in Madrid (El Pardo, Casa de Campo, and Madrid Río), hence acting as an important ecological corridor.

Previous studies (Suárez & Alba, 2017) suggest that policies between 2003 and 2015 have been dominated by a focus on urban development, at the expense of GI. In 2015, a citizen platform gathering diverse social movements won the local elections, replacing the political party governing the City Council for the previous 24 years. During this office term (2015–2019), the Madrid City Council promoted GI and biodiversity in the municipality through several policy initiatives. For example, the Green Infrastructure and Biodiversity Plan and the Madrid + Natural Program (whose aim is to improve climate change adaptation through so-called nature-based solutions).

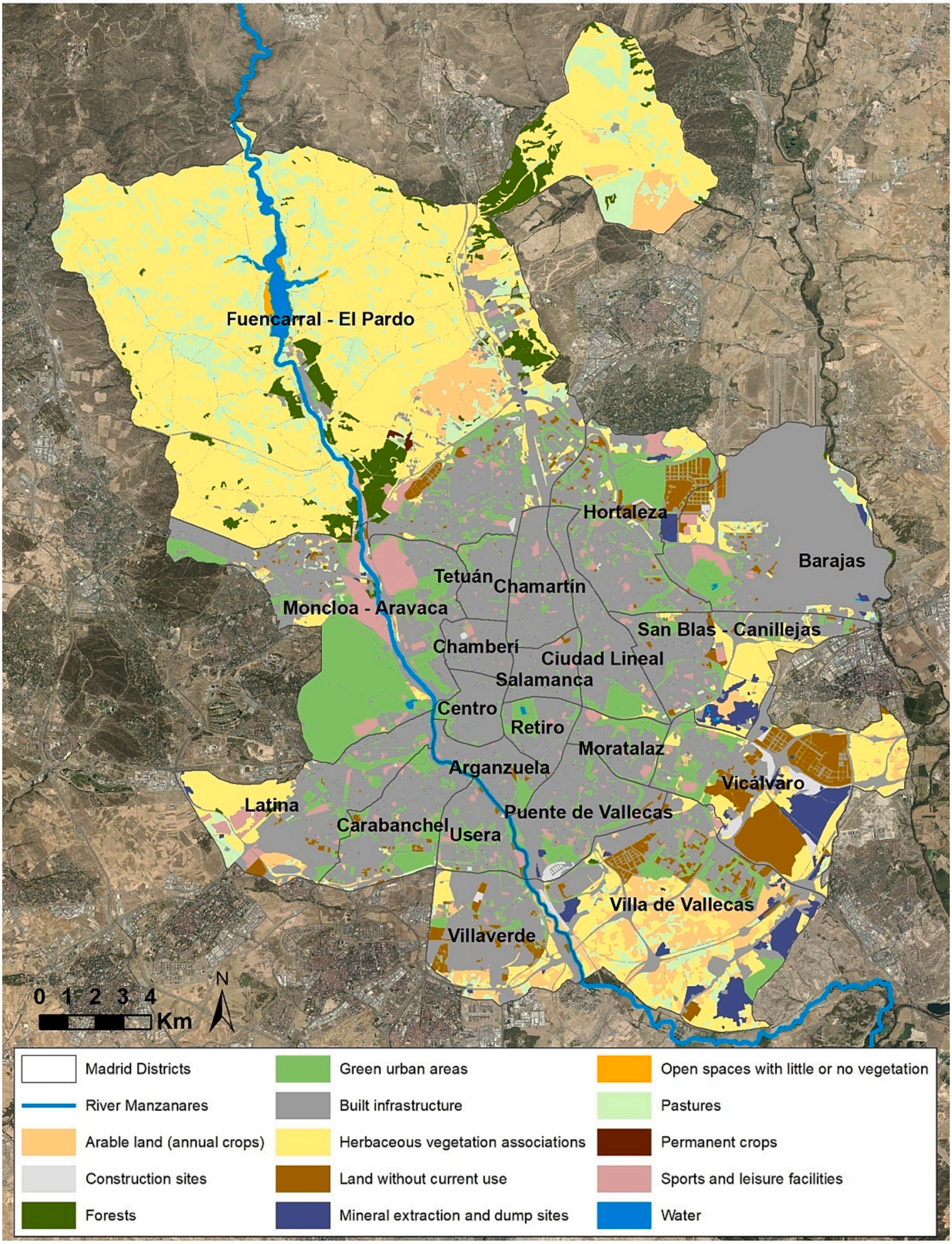

Fig. 1. Green infrastructure in the municipality of Madrid. Source: Own design based on Urban Atlas (EU Copernicus Programme, 2012). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Green infrastructure policies review

We conducted a search in the official website of Madrid City Council to identify ongoing and planned GI policies. We selected all plans, programs, and budgets that included objectives or actions to improve the GI through direct interventions (e.g., developing green spaces, planting trees, and creating green roofs) and carried out by the Madrid City Council, either totally or partially, during the term of office extending from 2015 to 2019. We excluded those policies that affect GI but do not explicitly include objectives or actions to improve it (e.g., urbanization plans that reduce green space area). We also excluded budgets and some plans that are part of strategic plans. Overall, we identified 27 GI policies that match these criteria (Table A.1 in Appendix A).

We carried out a double evaluation. First, we assessed the degree to which GI policies foster resilience. Second, we assessed to what extent specific actions included in GI policies increase resilience. Six of the selected policies consisted of a compilation of specific actions, therefore, they only were included in the second assessment (see column "Type of assessment" in Table A.1 in Appendix A).

To assess to which degree GI policies foster resilience, we reviewed all the related documents and summarise each plan or program in a pre-designed template. This template included relevant information to evaluate how given policies were expected to affect urban resilience, and descriptors such as policy name, type of policy, brief description, spatial location, date of approval, date of execution, local government department, main objectives, GI elements affected by the policy, main actions, participatory process, monitoring plan and related policies. Policies were reviewed only when all their objectives were specifically directed to improve GI. When only specific parts of the policy included objectives or actions to improve GI, only those parts were assessed.

To analyse to what extent GI actions foster resilience, we identified specific actions included in the selected GI policies. The following actions were excluded because of the difficulty to assess them: i) actions with a vague description; ii) actions that are preliminary studies to analyse the viability to develop specific actions; iii) education or community actions; and iv) actions without a specified location. All actions were geolocated using ArcGIS 10.7. When an action was carried out in more than one district, we split it into the same number of sections as districts were affected. Each section is counted as one action. Overall, we identified 620 actions.

To complete missing information on the reviewed documents, we interviewed seven officials and policymakers of the Madrid City Council involved in the development of GI policies between May and June 2019. The Madrid City Council is structured in government departments (*Áreas de gobierno*) and subdepartments. We interviewed one policymaker from the government department of *Territorial Coordination and Public-Social Cooperation*; two officials from the government department of *Sustainable Urban Development* and the subdepartment of *Strategic Planning*; and four officials from the government department of *Environment and Transport* and the subdepartments of *Water and Green Spaces*, *Energy and Climate Change* and *Environmental Education*.

Policies were finally classified following Mendonça et al.'s (2021) categories: i) planning/legislative; ii) economic or market-based, iii) and citizen engagement and information (see Table A.1 in Appendix A). Although each policy falls into a single category some policies can include instruments of the two other categories.

2.3. Assessment of urban resilience

The methodology developed in this paper to assess to what extent GI policies foster urban resilience to a wide variety of disturbances, such as climate change, extreme weather events, and economic or energy crises, follows four steps: i) revision of the conceptual framework; ii) selecting resilience indicators; iii) building the urban resilience index; and iv) evaluating the degree to which GI policies and actions foster urban resilience. The whole process was developed through an expert consultation. In the following subsections we explain how the expert consultation was conducted, the revision of the conceptual framework, the resilience indicators, the urban resilience index and the evaluation of the degree to which GI policies and actions foster urban resilience.

2.3.1. Expert consultation

We carried out an expert consultation applying a Delphi approach (Hasson et al., 2000) consisting in two rounds of on-line surveys, as Delphi technique is commonly used to reach a consensus. The first round included questions about the consistency of the conceptual framework, the suitability of the pre-selected indicators and the templates to assess to what extent GI policies and actions promote urban resilience (see details in sections 2.3.2, 2.3.3 and 2.3.5). It also included questions about the experts' profile (academic background, current occupation, and fields of knowledge). It was sent to 63 experts on resilience, green infrastructure, ecosystem services, public policy, environmental justice, or sustainability indicators. 25 % (12 academics and 4 private consultants with different backgrounds, see Appendix B for further details) completed the online survey in October 2019. The second round of surveys was specifically focused on the relevance of indicators to measure each resilience factor (see details in section 2.3.4). The survey was sent to the same 16 experts who participated in the first round. By February 2020, we obtained 7 responses. The conceptual and methodological framework, the set of resilience indicators and the urban resilience index were constructed following experts' responses. The process is explained in the following subsections and summarised in Fig. C.1 in Appendix C.

2.3.2. Revision of the conceptual framework

Before expert consultation, Suárez, Gómez-Baggethun et al.'s (2020) framework to assess urban resilience was revised by the research team. The proposed assessment tool is designed to help urban planners and policymakers to foster urban resilience through GI policies directed at specific or multiple shocks and stresses. Therefore, some terms were replaced by more understandable concepts. Thus, we replaced the factors *feedbacks length* and *modularity* with *self-sufficiency* and *decentralisation*, that are intrinsically related (see Suárez et al., 2016), and the dimension *ecological infrastructure* with *green infrastructure.* Although some authors argue that *ecological infrastructure* is more comprehensive (Childers et al., 2019), urban planners in our study area are more familiarised with *green infrastructure*. Finally, we replaced *equity* with *environmental justice*. Equity, in the context of GI, usually refers to equal distribution, whereas the concept of *environmental justice* also includes recognition of the diversity of participants and potential users, and fair integration of all affected groups into the planning and decision process (Schlosberg, 2004; Kabisch & Haase, 2014).

The framework to assess urban resilience was modified following experts' opinion in the first round of the survey. Experts were asked about the relevance of urban dimensions and resilience factors. Answers covered a wide range of suggestions to adapt the conceptual framework. We modified the conceptual framework following experts' comments backed up by the literature. The final urban dimensions and the resilience factors are described in Table 1 and Table 2, respectively.

Regarding urban dimensions, several experts suggested including the cultural dimension as the society's form of expression. Therefore, we changed the *social* dimension by *socio-cultural*. The term *green infrastructure* was widely criticised. Some consulted experts, who were not familiar with the concept, highlighted the difficulty to understand its meaning. Furthermore, they also pointed out that *green infrastructure* is a reductionist term, and it does not include all environmental aspects, such as city's metabolism. Hence, we substituted *green infrastructure* for the *ecological* dimension, to refer to green space, the services it provides and city's material, water, and energy flows (McPhearson et al., 2015; Meerow et al., 2016). Following experts' comments, the dimensions *grey infrastructure* and *governance* were also replaced with more

Table 1
Urban dimensions following the opinion of consulted experts.

Urban dimension	Description	References
Socio-cultural	The social dimension refers to the way human beings interact with each other. It includes all aspects that affect social justice, equity, and social cohesion. It is closely linked to community resilience. The cultural dimension refers to the form of expression and representation of human relationships. Social and cultural aspects are strongly connected; therefore, we consider them jointly as the *socio-cultural* dimension.	Adger, 2003; Walker & Salt, 2006; Carpenter et al., 2012; Meerow et al., 2016
Economic	It refers to the economic system, which has a strong influence on the resilience of the whole urban system.	Hopkins, 2008; Cato, 2013
Ecological	It includes all GI elements (e.g., trees and plants, parks, green roofs…), but it also refers to the city metabolism, such as material, water and energy flows and the ecosystem services supplied by GI.	McPhearson et al., 2015; Meerow et al., 2016
Physical and technological	It refers to the built environment and human-made infrastructure, such as buildings and transport, energy, and water networks.	Meerow et al., 2016
Governance system	It is defined by 'the exercise of deliberation and decision making among groups of people who have various sources of authority to act and may be practiced through a variety of organizational forms' such as local governments, NGOs or organized citizen groups.	Biggs et al., 2012, p. 437

understandable terms namely, *physical and technological* dimension and *governance system*.

Regarding resilience factors, *self-sufficiency* was renamed *self-sufficiency and autonomy*. Self-sufficiency refers to the consumption rates of materials and energy (i.e., minimising their consumption to reduce dependency from other ecosystems) (Walker et al., 2004; Hopkins, 2008). The concept of autonomy is complementary to self-sufficiency. As one expert explained, it refers to the city's capacity to provide all the necessary services, throughout the whole city, to guarantee citizen well-being.

One expert argued that the diversity of independent stakeholders is beneficial for urban resilience but also a coordinating entity with a comprehensive vision. Therefore, it is not clear which is the optimum degree of decentralisation. Instead, some experts suggested including a resilience factor related to the adaptation capacity of the governance system. Therefore, we replaced *decentralisation* with *polycentric governance* in which different and independent institutions participate at different scales, collaborating among them horizontally and nested within broader governance units vertically (Biggs et al., 2012).

Finally, some experts pointed out that temporal and spatial trade-offs were not explicitly included in the framework (i.e., increasing resilience in one spatial or temporal scale can diminish resilience in other scales, for example, in other ecosystems or human communities) (Chelleri et al., 2015). We replaced *environmental justice* with *social-ecological justice* to include these aspects. Social-ecological justice is the right of coexistence of human societies and non-human ecologies within a common planetary social-ecological system (Yaka, 2019). It encompasses social, environmental, and ecological justice (Aguado Caso, 2016) and

Table 2
Resilience factors following the opinion of consulted experts.

Resilience factor	Factor's description and how it fosters resilience	References
Diversity	Diversity includes three properties: variety, balance, and disparity. The former refers to the number of different elements and it provides different kinds of functions. Balance answers the question how many of each element we have, that is, components with similar functions but different responses to disturbance. Disparity refers to how different elements are from one another.	Rosenfeld, 2002; Stirling, 2007; Biggs et al., 2012; Carpenter et al., 2012
Self-sufficiency and autonomy	Self-sufficiency refers to the consumption rates of materials and energy. Although a city cannot be self-sufficient, minimising consumption reduces the system's dependency from other ecosystems and increases its resilience. The concept of autonomy refers to city's capacity to provide all the necessary services (i.e., public services, water and energy networks…), throughout the whole city, to guarantee citizens' well-being.	Rees & Wackernagel, 1996; Folke et al., 1997; Walker et al., 2004; Hopkins, 2008
Polycentric governance	In a polycentric governance system, different institutions participate at different scales. Each governance unit is independent from each other within a geographic area or domain of authority, but they collaborate among them horizontally and are nested within broader governance units vertically.	Ostrom, 2005; Folke et al., 2007; Biggs et al., 2012
Social cohesion	Trust, social networks, sense of belonging and leadership are components of social cohesion, and they increase the capacity of community response to disturbances.	Adger, 2003; Berkes et al., 2003; Walker & Salt, 2006 Goldstein, 2009; Cutter et al., 2010; Carpenter et al., 2012
Learning and innovation	Learning is 'the process of modifying existing or acquiring new knowledge, behaviours, skills, values, or preferences' (Biggs et al., 2012, p. 434). Learning and innovation allow creating new ways to respond to changes.	Walker & Salt, 2006; Goldstein, 2009; Ernstson et al., 2010; Biggs et al., 2012
Social-ecological justice	Social-ecological justice is the right of coexistence of human societies and non-human ecologies within a common planetary social-ecological system. It encompasses social, environmental, and ecological justice and recognizes intra-generational, inter-generational, and multi-species rights.	Aguado Caso, 2016; Washington et al., 2018; Yaka, 2019; Pineda-Pinto et al., 2021; Pope et al., 2021

recognises intra-generational, inter-generational, and multi-species rights. Therefore, it presents a spatial and temporal amplification in relation to the concept of environmental justice (Pope et al., 2021).

2.3.3. Selection of resilience indicators

We followed Suárez, Gómez-Baggethun et al.'s (2020) framework to select resilience indicators. A literature review was conducted searching for indicators to assess how policies can foster each resilience factor in each dimension. We pre-selected 23 indicators.

Experts were asked, in the first round of the consultation, to value to what extent the 23 pre-selected indicators explain urban resilience using a 5-point scale, 1 being very little and 5 a lot. We considered that an indicator explains urban resilience in a significant way when it obtained a weighted average higher than 3. The weighted averages for the 23 indicators were higher than 3, therefore, we did not remove any of them (indicators 1–23 in Table 3). We also asked experts to propose new indicators if they thought the 23 indicators were not enough to explain how GI policies might foster urban resilience. They suggested 7 more indicators that were valued by the experts in the second round using the same 5-point scale. The 7 indicators obtained weighted averages higher than 3, therefore, they were also included in the indicators system (indicators 24–30 in Table 3).

Experts were also asked to indicate which urban dimensions and resilience factors each indicator explains. We considered that an indicator explains a particular dimension or factor when more than 50 % of the consulted experts referred to their link.

Fig. 2 represents the framework to assess to what extent GI policies promote urban resilience, based on the opinion of the consulted experts. Local governments can enhance urban resilience through policies that improve green infrastructure. These policies can modify the five urban dimensions and the six resilience factors to foster resilience. The degree to which they foster the resilience factors in the different dimensions can be measured by the 30 resilience indicators.

2.3.4. Urban resilience index

Following Nardo et al. (2005) and advice from consulted experts (see Appendix C), the 30 indicators were weighted and aggregated into an urban resilience index.

To decide the weighting coefficients of the factors, we used a budget allocation approach (Nardo et al., 2005). Experts were given a 'budget' of 10 points and were asked to distribute them over the 6 resilience factors, 'paying' more for those indicators whose importance they wanted to stress. The coefficient is the average of the points given to each factor. The urban resilience index equation with the resulting weighing coefficients is:

$$URI = 2D + 1.7SA + 1.6PG + 2.1SC + 1.7LI + 1.7SJ$$

where *URI* is the urban resilience index, *D* is diversity, *SA* self-sufficiency and autonomy, *PG* polycentric governance, *SC* social cohesion, *LI* learning and innovation and *SJ* social-ecological justice.

Each factor is calculated through the weighted addition of all the indicators that explain that factor. To decide the weighting coefficients of the indicators we also used the budget allocation technique. In this case, given the high number of indicators that explain some resilience factors, we asked the experts to distribute 20 points over the indicators that explain each factor in the second round of the consultation. The weighting coefficients are the average score (see details in Fig. C.1 in Appendix C). Finally, the urban resilience index equation is:

$$URI = 2(2.2I_1 + 3.1I_2 + 1.6I_3 + 3.7I_4 + 1.9I_5 + 2I_6 + 1.6I_7 + 1.6I_8 + 1.2I_9 + 1.2I_{10}) + 1.7(2,9I_{16} + 3.3I_{17} + 3.3I_{18} + 2.6I_{19} + 7.9I_{30}) + 1.6(4.3I_{11} + 4.2I_{12} + 7I_{14} + 4.5I_{25}) + 2.1(5.47I_{13} + 10.3I_{24} + 4.3I_{29}) + 1.7(7.6I_{20} + 6.9I_{21} + 5.5I_{26}) + 1.7(2I_{15} + 5.6I_{22} + 4.3I_{23} + 4.7I_{27} + 3.3I_{28})$$

where I_n are the indicators.

2.3.5. Assessment of the degree to which green infrastructure policies foster urban resilience

We assessed the degree to which GI policies and actions enhance urban resilience in the scenario that all policies would have been fully implemented. First, we designed a template based on experts' suggestions to guide the process of evaluating the degree to which GI policies foster resilience indicators (Appendix D). Although GI policies are expected to increase resilience, they may have a negative effect on specific indicators. Therefore, each indicator was scored using a scale between −2 and +2, where −2 means a strong negative effect on urban resilience and +2 means a strong positive effect. Second, we followed the template to assess to what extent GI policies foster urban resilience, assigning values to the indicators. Third, we calculated the average values and rounded them to whole numbers if the difference between the assigned values by each member of the research team were no higher than 1. When the difference was higher than 1, they were reviewed and discussed until consensus was reached by the research team. Fourth, we calculated the resilience index for each policy. Following Nardo et al.'s (2005) methodology, the results were re-scaled between 0 and 10, where higher values mean that the policy increases urban resilience in high degree.

We followed the same procedure to assess the degree to which specific GI actions enhance urban resilience. However, in this case, instead of assessing action by action, we classified the actions into different categories, and assigned values to each category (see Appendix E for more details). Unlike in the policy assessment, each indicator was valued using a scale between −1 and +1 following a similar template (Appendix F). This template was also designed following experts' opinion. Therefore, we only evaluated if each category of actions has a negative, neutral, or positive effect on each indicator, but we did not distinguish between different degrees of negative or positive effect. The urban resilience index was calculated for each category and the obtained resilience values were assigned to the respective actions. To assess to what extent GI actions foster resilience in each district we added the resilience values of all the actions proposed in each district.

Finally, we analysed if some social groups (defined by age, gender, origin, level of education, and income) benefited more than others from green infrastructure policies. To this end, we carried out bivariate Pearson correlations between resilience values for the actions that were planned in the 21 districts and the following socio-economic variables: percentage of i) children younger than 14 years old; ii) elderly over 65; iii) women; iv) people with not Spanish nationality; v) people over 25 years of age who are illiterate, have no primary education or only have compulsory education (population with low educational level or without education); and vi) average household income. These variables were selected because several studies have found that GI is commonly unevenly distributed depending on ethnicity, age, education level or gender (see e.g., Suárez, Barton et al., 2020). Research has found that low-income people is the main excluded group in most cases, but also, migrants, less educated, elderly, youth or females have recently been identified as less benefited groups from GI (Zuniga-Teran et al., 2021). Statistical analyses were carried out with SPSS v27. We previously checked that the data were normally distributed.

Table 3
Indicators used to assess the degree to which GI policies foster urban resilience based on literature and the opinion of consulted experts.

N°	Indicator	Definition	Resilience factors explained by the indicator	Urban dimensions explained by the indicator	References
1	Diversity of people	Degree to which the policy affects or may affect the diversity of users or beneficiary people by green infrastructure, considering all the social groups living in the intervention area.	Diversity, social cohesion	Socio-cultural, governance system	Adger, 2003; Hopkins, 2008; Agencia de Ecología Urbana de Barcelona, 2012; Buijs et al., 2016; Cutter et al., 2016; Rieiro Díaz, 2018
2	Diversity of organised citizen groups	Degree to which the policy affects or may affect the diversity of users or beneficiary organised citizen groups	Diversity, social cohesion, learning and innovation	Socio-cultural, governance system	Adger, 2003; Hopkins, 2008; Agencia de Ecología Urbana de Barcelona, 2012; Buijs et al., 2016; Suárez et al., 2016; Rieiro Díaz, 2018
3	Diversity of businesses	Degree to which the policy affects or may affect the diversity of local businesses with socio-environmentally sustainable principles.	Diversity, self-sufficiency and autonomy	Economic, governance system	Adger, 2003; Agencia de Ecología Urbana de Barcelona, 2012; Hopkins, 2008; Suárez et al., 2016; Rieiro Díaz, 2018
4	Biodiversity	Degree to which the policy affects or may affect biodiversity.	Diversity	Ecological	Elmqvist et al., 2003; Agencia de Ecología Urbana de Barcelona, 2012; Leslie & McCabe, 2013; Suárez et al., 2016; Rieiro Díaz, 2018;
5	Diversity of green infrastructure	Degree to which the policy affects or may affect the diversity of GI components.	Diversity, social-ecological justice	Ecological	McPhearson et al., 2015; Calderón-Contreras & Quiroz-Rosas, 2017
6	Diversity of ecosystem services	Degree to which the policy affects or may affect the diversity of provisioning, regulating and cultural ecosystem services supplied by GI.	Diversity, self-sufficiency and autonomy, social-ecological justice	Ecological	McPhearson et al., 2015; Calderón-Contreras & Quiroz-Rosas, 2017
7	Diversity of human-made facilities	Degree to which the policy affects or may affect the diversity of human-made facilities that improve the capacity to supply ecosystem services.	Diversity, polycentric governance, social cohesion	Socio-cultural, physical and technological, governance system	McPhearson et al., 2015
8	Diversity of participating people	Degree to which the policy affects or may affect the diversity of people participating in the different execution stages of GI (diagnosis, design, implementation, use, maintenance, monitoring and assessment).	Diversity, social cohesion	Socio-cultural, governance system	Adger, 2003; Buijs et al., 2016
9	Diversity of participating organised citizen groups	Degree to which the policy affects or may affect the diversity of organised citizen groups participating in the different execution stages of GI (diagnosis, design, implementation, use, maintenance, monitoring and assessment).	Diversity, social cohesion	Socio-cultural, governance system	Adger, 2003; Agencia de Ecología Urbana de Barcelona, 2012; Buijs et al., 2016; Rieiro Díaz, 2018
10	Diversity of participating economic sectors	Degree to which the policy affects or may affect the diversity of economic sectors participating in the different execution stages of GI (diagnosis, design, implementation, use, maintenance, monitoring and assessment).	Diversity, self-sufficiency and autonomy	Socio-cultural, economic, governance system	Agencia de Ecología Urbana de Barcelona, 2012; Buijs et al., 2016; Suárez et al., 2016
11	Diversity of participating public administrations	Degree to which the policy affects or may affect the diversity of public administrations participating in the different execution stages of GI (diagnosis, design, implementation, use, maintenance, monitoring and assessment).	Diversity, polycentric governance	Governance system	Suárez et al., 2016
12	Diversity of participating government departments	Degree to which the policy affects or may affect the diversity of government departments participating in the different execution stages of GI (diagnosis, design, implementation, use, maintenance, monitoring and assessment).	Diversity, polycentric governance	Governance system	Suárez et al., 2016
13	Social networks	Degree to which the policy affects or may affect the creation or maintenance of social networks.	Social cohesion	Socio-cultural, governance system	Villatoro & Ribera, 2007; Rieiro Díaz, 2018
14	Multilevel and decentralised governance	Degree to which the policy affects or may affect the creation or maintenance of mechanisms that allow multilevel and decentralised governance.	Polycentric governance	Governance system	Buijs et al., 2016; Rieiro Díaz, 2018
15	Demand of provisioning ecosystem services	Degree to which the policy affects or may affect the demand of provisioning ecosystem services.	Social-ecological justice	Socio-cultural, ecological	McPhearson et al., 2015; Suárez et al., 2016
16	Demand of regulating ecosystem services	Degree to which the policy affects or may affect the demand of regulating ecosystem services.	Self-sufficiency and autonomy, social-ecological justice	Socio-cultural, ecological	McPhearson et al., 2015; Suárez et al., 2016; Fernández de Manuel et al., 2021
17	Supply of provisioning ecosystem services	Degree to which the policy affects or may affect GI capacity to supply provisioning ecosystem services.	Self-sufficiency and autonomy, social-ecological justice	Ecological	McPhearson et al., 2015; Suárez et al., 2016; Rieiro Díaz, 2018
18	Supply of regulating ecosystem services	Degree to which the policy affects or may affect GI capacity to supply regulating ecosystem services.	Self-sufficiency and autonomy, social-ecological justice	Ecological	McPhearson et al., 2015; Suárez et al., 2016, Rieiro Díaz, 2018; Fernández de Manuel et al. 2021
19	Supply of cultural ecosystem services	Degree to which the policy affects or may affect GI capacity to supply cultural ecosystem services.	Self-sufficiency and autonomy	Socio-cultural, ecological, governance system	McPhearson et al., 2015; Suárez et al., 2016; Rieiro Díaz, 2018
20	Social innovation	Degree to which the policy affects or may affect social innovation.	Social cohesion, learning and innovation	Socio-cultural, governance system	Suárez et al., 2016; Rieiro Díaz, 2018

(*continued on next page*)

Table 3 (*continued*)

N°	Indicator	Definition	Resilience factors explained by the indicator	Urban dimensions explained by the indicator	References
21	Education	Degree to which the policy affects or may affect the number of education projects and specific tools to promote collective learning.	Social cohesion, learning and innovation	Socio-cultural, governance system	Biggs et al., 2012; Rieiro Díaz, 2018
22	Equal distribution of green infrastructure	Degree to which the policy affects or may affect the equal distribution of GI, with special focus on the most vulnerable groups.	Social-ecological justice	Socio-cultural, ecological, governance system	Chelleri et al. 2015; Romero-Lankao et al. 2016; Baró et al. 2019
23	Equal access to the benefits of green infrastructure	Degree to which the policy affects or may affect the fair access to the benefits provided by GI, with special focus on the most vulnerable groups.	Social-ecological justice	Socio-cultural, ecological, governance system	Chelleri et al. 2015; Romero-Lankao et al. 2016; Venter et al. 2020
24	Sense of belonging	Degree to which the policy affects or may affect citizens' sense of belonging.	Self-sufficiency and autonomy, social cohesion	Socio-cultural	Berkes et al., 2003; Goldstein, 2009
25	Political innovation	Degree to which the policy affects or may affect political innovation.	Self-sufficiency and autonomy, polycentric governance, learning and innovation	Governance system	Walker & Salt, 2006; Goldstein, 2009; Ernstson et al., 2010; Biggs et al., 2012
26	Technical innovation	Degree to which the policy affects or may affect technical innovation.	Self-sufficiency and autonomy, learning and innovation	Physical and technological	Ernstson et al., 2010; Walker & Salt, 2006
27	Temporary impact	Degree to which the policy affects or may affect resilience on the short- and long-term.	Social-ecological justice	Socio-cultural, economic, ecological	Gunderson & Holling, 2002; Chelleri et al., 2015
28	Universal accessibility to green infrastructure	Degree to which the policy affects or may affect universal accessibility to GI.	Social cohesion, social-ecological justice	Socio-cultural, ecological	Chelleri et al., 2015; Romero-Lankao et al., 2016
29	Social conflicts	Degree to which the policy affects or may affect social conflicts.	Social cohesion	Socio-cultural, governance system	Adger, 2003; Walker & Salt, 2006
30	Economic autonomy of the policy	Degree to which the policy has economic resources to be implemented.	Self-sufficiency and autonomy, polycentric governance	Economic, governance system	Sharifi & Yamagata, 2014

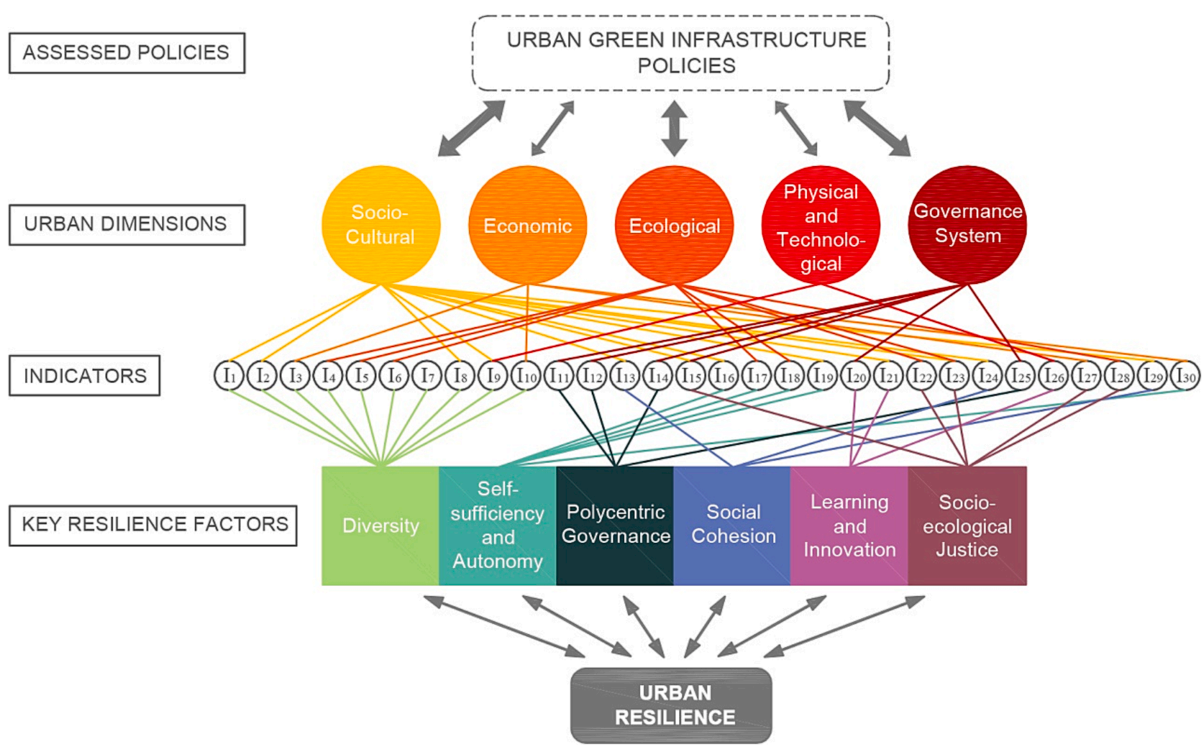

Fig. 2. Conceptual and methodological framework to assess to what extent GI policies foster urban resilience following the opinion of consulted experts. Arrows show the relationship between factors, urban dimensions, indicators, and urban resilience. Arrows' thickness shows the degree to which GI policies promote resilience on urban dimensions.

3. Results

Our results indicate that all analysed policies increase urban resilience to different degrees (Fig. 3) and that some resilience factors are fostered more than others (Fig. 4). Social-ecological justice (average resilience value of 0.98, re-scaled between 0 and 2), learning and innovation (0.98) and diversity (0.95) were found to be the most strongly favoured by GI policies, whereas weaker effects were obtained for social cohesion (0.81), self-sufficiency and autonomy (0.76) and polycentric governance (0.69).

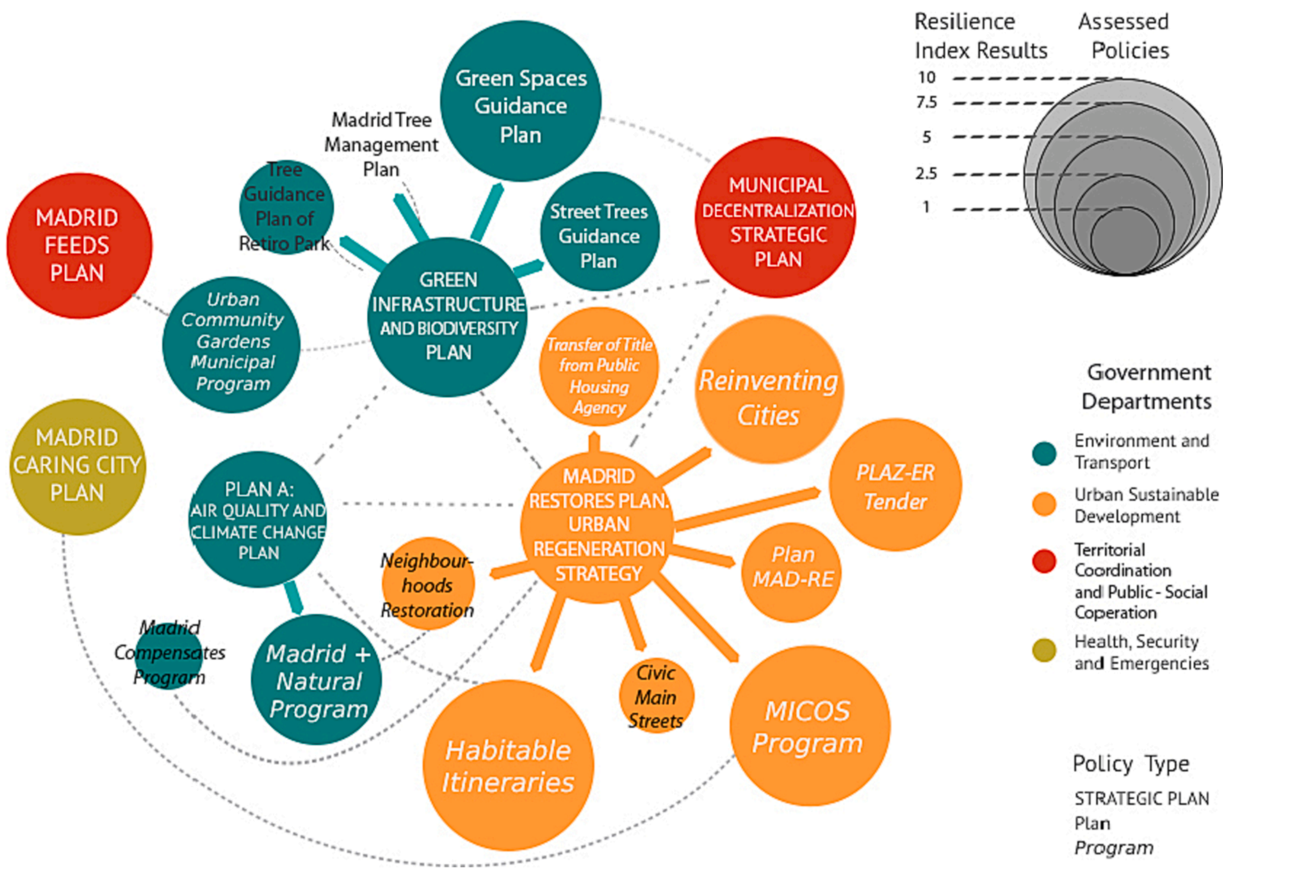

Fig. 3. Urban resilience index results for Madrid City Council's GI policies. Colour arrows join the strategic plans and the plans or programs that specify actions of the strategic plans. Dashed lines join policies that shared specific actions.

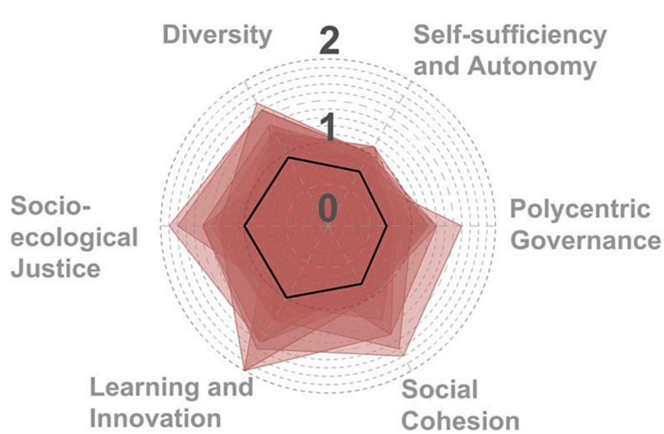

Fig. 4. Combined resilience scores of Madrid City Council's GI policies in the resilience factors. Factors' scores were re-scaled between 0 and 2. The black line is the average score.

The three policies with the highest resilience values (7.5, 6.8 and 6.6, re-scaled between 0 and 10) are mainly focused on vulnerable neighbourhoods and emphasise citizen participation. They better integrate the social aspects of GI, such as citizen participation, diversity of users, and universal accessibility to green space, and have a strong positive influence on social-ecological justice, learning and innovation, social cohesion, and polycentric governance (Fig. 5, policies HI_plan, MD_info, MI_plan).

The two policies with a resilience value of 6.4 are the main strategic planning instruments to manage GI in Madrid. One of their main objectives is to rebalance GI throughout the city but they do not promote citizen engagement in a great extent. Therefore, they mainly promote diversity, learning and innovation, and social-ecological justice (Fig. 5, policies GIB_plan and GS_plan).

Other policies with resilience values higher than 5 include other planning instruments and one economic policy. The main objectives of these policies are not specifically designed to enhance GI, but they include some actions that directly improve GI to pursue some of their objectives and, therefore, foster most resilience factors in low degree (Fig. 5, policies MR_plan, MF_plan, RC_econ, MCC_plan and AQC_plan).

All policies with resilience values lower than 5 were plans or programs that specify actions of the strategic plans. In general, their impact in the resilience factors is low (equal or lower than + 1), and some factors are more favoured than others. For example, *Urban Community Gardens Municipal Program* (resilience value of 4.9) was found to have a strong influence on social cohesion (see also Camps-Calvet et al., 2016) but weak on diversity (Fig. 5, policies UCG_info and PT_econ), whereas *Madrid + Natural program* (resilience value of 4.4) was found to have a strong influence on diversity and weak on social cohesion and polycentric governance (Fig. 5, policy MN_plan).

Madrid Tree Management Plans is the only policy that does not increase urban resilience, according to our framework (resilience value of 0, Fig. 5, policy MTM_plan). It focuses on pruning and planting of trees and has a neutral effect on most indicators. There are two reasons for this. First, there are resilience factors that are not considered by this policy (e.g., social cohesion, learning and innovation, or social-ecological justice). Second, the positive effect on some indicators is compensated by a negative effect on the same or other indicators (e.g., planting trees increases the supply of ecosystem services or biodiversity but pruning decreases them).

Outlying districts seem to be more favoured by GI policies than central districts (Fig. 6). Bivariate Pearson correlations show that, in

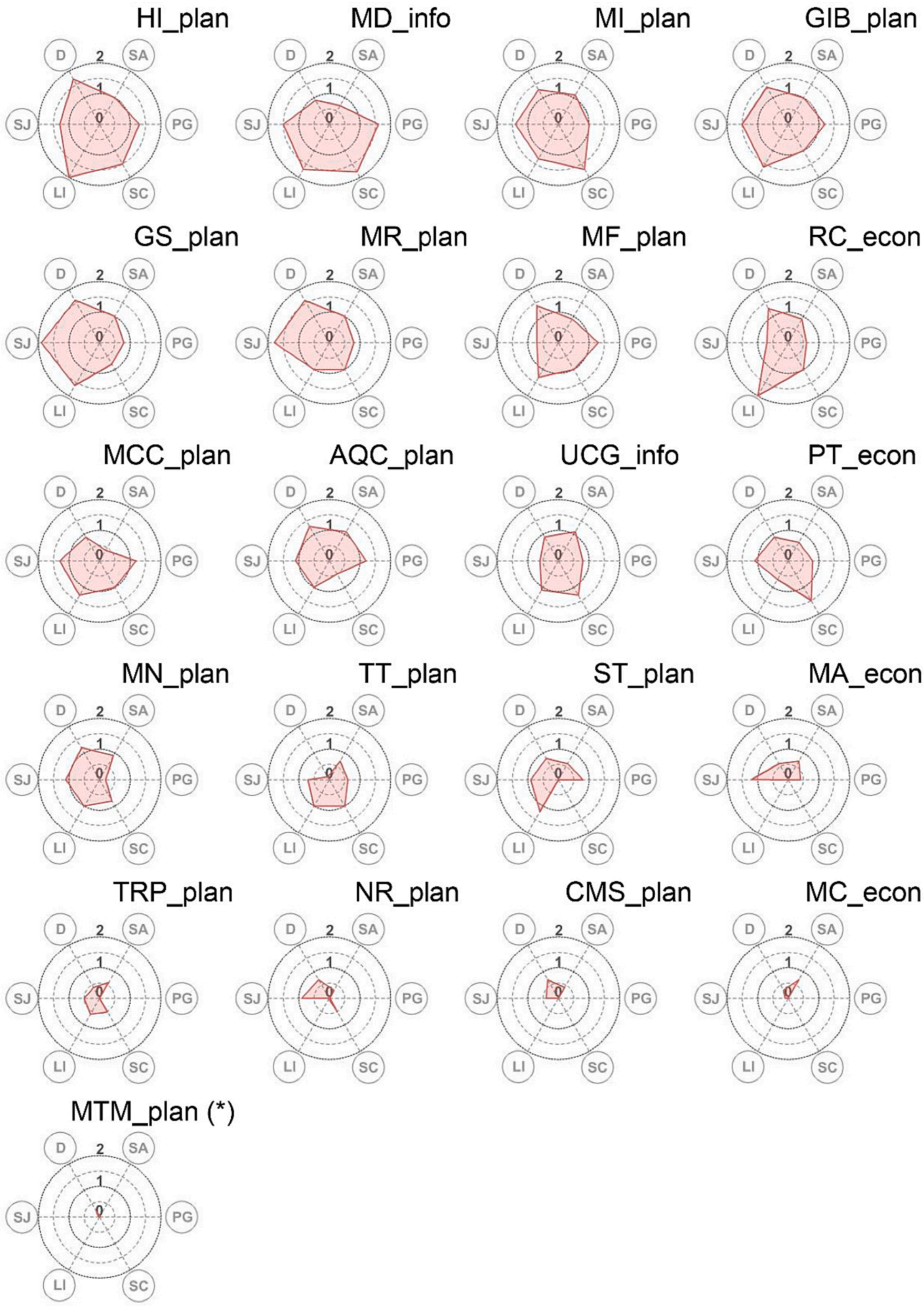

Fig. 5. Individual resilience scores of Madrid City Council's GI policies in the resilience factors. Graphs are ordered by resilience results. Factors' scores were re-scaled between 0 and 2. D is diversity, SA self-sufficiency and autonomy, PG polycentric governance, SC social cohesion, LI learning and innovation and SJ social-ecological justice. The policy with (*) obtained negative values (-0.1) for self-sufficiency and autonomy and social-ecological justice.

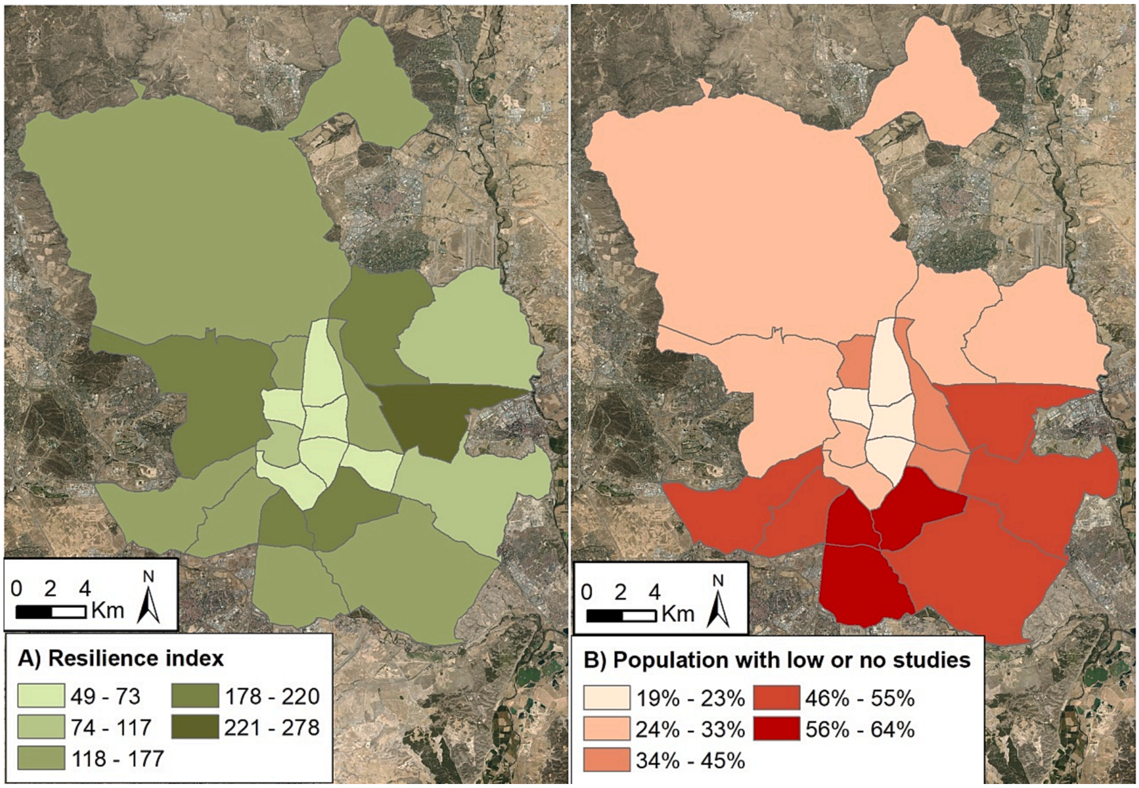

Fig. 6. Resilience index (A) and percentage of population with low educational level or without education by districts (B). Variables are classified following the Natural Breaks (Jenks) method.

relation to the social groups analysed, there is only significant moderate positive correlation between the urban resilience index and percentage of population with low educational level or without education ($p < 0.05$, $r = 0.569$).

4. Discussion

4.1. Green infrastructure policies to foster urban resilience

Planning instruments are the most numerous and have in general the highest resilience scores in Madrid. Planning and legislative policies comprise the first step in integrating the concept of GI in decision-making and are fundamental in supporting its implementation (Mendonça et al., 2021). In line with this, the strategic plans are in general the planning instruments with the highest resilience scores. These strategic plans lay the foundations of GI management, comprise multiple objectives and encompass the whole city. Therefore, they foster a wider range of resilience indicators and factors. However, some authors (Slovic & Ribeiro, 2018; Mendonça et al., 2021) argue that, although this type of policies constitute a first step for GI implementation, they need to be complemented by other approaches. Our findings support this statement because the planning policies with the highest resilience scores are those that also incorporate citizen engagement and information instruments.

The analysed policies belong to the government departments of *Environment and Transport* (9 policies), *Sustainable Urban Development* (9), *Territorial Coordination and Public-Social Cooperation* (2), and *Health, Security and Emergencies* (1) (see Table A.1 in Appendix A). Although the department of *Environment and Transport* is the only one that has explicitly incorporated the concept of GI in its policies, they have obtained lower average resilience scores than, for example, the policies of the department of *Sustainable Urban Development*. There are a few possible reasons for this. First, *Environment and Transport*'s policies mainly focus on green space and natural or semi-natural elements as part of an infrastructure that requires care and maintenance (Garmendia et al., 2016; Seiwert & Rößler, 2020). Second, the supply of ecosystem services is only considered a main objective in one of its policies. Although the absence of explicit references to the term ecosystem services does not necessarily mean that it is not recognised (Nordin et al., 2017), in this case it results in actions that poorly increase ecosystem service supply. Third, multifunctionality, a common principle in GI planning (Lafortezza et al., 2013; Monteiro et al., 2020; Seiwert & Rößler, 2020), is not one of the policies' main objectives, as it happens in other urban areas (e.g., Pozoukidou, 2020), and only regulating ecosystem services that increase resilience to climate change and some cultural ecosystem services are implicitly recognised. Fourth, participation of other government departments and civic organizations was only considered in the framework and guidance plans that obtained higher resilience values. The lack of appropriate mechanisms to allow and integrate the participation of civil society in GI policies, as well as different experts' opinion, has also been noted in other urban areas (Yao et al., 2019; Vaňo et al., 2021). In contrast, multifunctionality of GI and citizen engagement and participation processes have been better incorporated in *Sustainable Urban Development's* policies.

We detected some barriers for the implementation of GI in Madrid when we interviewed the officials and policymakers involved in the development of GI policies. Most policies are interrelated and have been developed in collaboration with other government departments, *Environment and Transport* and *Sustainable Urban Development* being the most actively involved (Fig. 3). However, in line with the findings from Davies and Lafortezza (2017) and Di Marino et al. (2019), most of the interviewed Madrid City Council's officials agree that they usually work in their own silos because the departmental Council's structure makes collaboration across administrative entities difficult. Collaboration across government departments, although necessary (Davies & Lafortezza, 2017; Zuniga-Teran, Staddon et al., 2020), mainly occurs because Madrid City Council's officials have the interest to collaborate with other departments. A common objective of both departments' framework policies and the programs that develop them, is climate change adaptation through nature-based solutions, especially to heat waves. Both, GI and nature-based solutions are closely related boundary concepts (Potschin et al., 2016) that allow understanding and cooperation among different disciplines (Garmendia et al., 2016; Feria Toribio & Santiago Ramos, 2017; Dorst et al., 2019; Hanson et al., 2020; Smets et al., 2020). It seems that the term nature-based solutions gained more attention in Madrid City Council and allowed collaboration among government departments. However, it is a goal-oriented concept that tends to focus on single-service delivery (Childers et al., 2019). If our focus is to promote general resilience to any kind of disturbance or stress, we need a broader approach. Instead, although GI has been defined in multiple ways and sometimes is used in a similar way than the nature-based solutions concept (Mell, 2015; Grabowski et al., 2022), it usually implies multifunctionality and a broader focus on general resilience (Lafortezza et al., 2013; Garmendia et al., 2016; Feria Toribio & Santiago Ramos, 2017; Monteiro et al., 2020; Seiwert & Rößler, 2020; Zuniga-Teran, Gerlak et al., 2020). Therefore, we suggest using GI as a boundary concept in multi-stakeholder participatory processes (Smets et al., 2020) to enable collaboration among departments but also, to better integrate multifunctionality in GI policies, or even more inclusive terms, e.g., *urban ecological infrastructure* (Childers et al., 2019).

The interviewed City Council's officials also mentioned the high difficulty to carry out the proposed actions because they do not have an assigned budget and their implementation mostly depends on political will. Both financing and political will, are however common challenges for the effective implementation of GI (Zuniga-Teran, Staddon et al., 2020; Mendonça et al., 2021). Resilience measures through GI are usually cheaper than grey infrastructure, but to carry out an economic valuation of the multifunctionality of GI that allow their benefits to be weighted on equal terms with those from grey infrastructure is a challenging task (Zuniga-Teran, Staddon et al., 2020).

Equal distribution of GI is considered an environmental justice issue in many urban areas (e.g., Wolch et al., 2014; Jennings et al., 2016). Migrants (Kabisch & Haase, 2014) and low-income residents are usually the most disadvantaged in several cities (Dai, 2011; Davis et al., 2012; Ernstson, 2013). In Madrid, the social-ecological justice factor has obtained, in general, high resilience scores (Fig. 4) because a common objective found in many of the analysed policies is to re-balance GI, focusing in the most vulnerable neighbourhoods. *Madrid Restores Plan* considers vulnerable neighbourhoods those with a high percentage of low-income households, and with high percentages of elderly population and of population without education, among other indicators (Madrid City Council, 2018b). Vulnerable neighbourhoods are usually located at the surrounding districts, obtaining the highest resilience values (Fig. 6.A). In contrast, high-income central districts have fewer green spaces and street trees (Madrid City Council, 2018a; 2018b). Therefore, our results suggest that some vulnerable groups would be the most benefited by GI policies and actions, but the re-balancing objective would not be achieved. However, uneven distribution of GI does not necessarily mean unequal access (Suárez, Barton et al., 2020). On the one hand, central districts are well connected to green space in other districts by public transport. On the other hand, it is common for high-income residents living in Madrid to own a second home next to the countryside where they spend the weekends or holidays. Further research could explore why high-income neighbourhoods are less "green" and why Madrid City Council's GI policies do not focus on increasing GI and resilience in these neighbourhoods.

4.2. Methodological limitations

Further research using and building on our index should have several considerations in mind. The first concern is the applicability of the index in other geographical and socio-cultural contexts. We believe that our methodology can be safely applied in other urban areas but also that the level of accuracy in results will be higher if the framework is adapted in the light of the concrete local policies applied in different cities. Moreover, the proposed methodology could also be useful during the designing process of GI policies and not only in the execution phase.

The second consideration concerns how the term resilience can be understood very differently across consulted experts, potentially affecting the internal consistency of the obtained results. We used resilience as a boundary concept to bring knowledge from different disciplines (Brand & Jax, 2007; Davoudi, 2012; Moser et al., 2019). A panel of experts with different backgrounds reviewed the conceptual framework. The result was a wide range of suggestions and comments that enriched the resilience framework. However, we also noticed that resilience was interpreted differently by experts. Although Delphi technique is commonly used to reach a consensus (Hasson et al., 2000), the complexity of the framework, the method to carry out the consultation (an online survey) and the impossibility of conducting a third round due to limited time and resources, did not allow to reach consensus across consulted experts. Adding a deliberative element through workshops or focus groups with the participation of the experts to discuss the resilience concept would help to construct a common and more widely shared framework to assess urban resilience (Smets et al., 2020).

Third, the system of indicators and the urban resilience index equation could also be improved. In this case, the authors had to take some decisions during the weighting and aggregation process when a consensus was not reached (see Fig. C.1 in Appendix C). Increasing the number of rounds of the expert consultation could be useful to decide: i) if the list of indicators is representative and comprehensive enough to assess to what extent GI policies foster urban resilience; ii) whether some indicators should be removed because they are redundant; and iii) the weighting coefficients in the resilience equation.

Fourth, although there are more robust weighting methods based on expert opinion, e.g., the Analytic Hierarchy Process (Saaty, 1980), we used a budget allocation approach to weight the resilience factors and indicators because of its simplicity. Our objective was to encourage experts to answer the survey and to build an index easily understandable by policymakers. To verify the stability of the model by changing the weights allocated to the resilience indicators and factors, we suggest carrying out sensitivity analysis in future research.

Fifth, we assessed the degree to which GI policies and actions enhance urban resilience in the scenario that all policies would have been fully implemented. Therefore, results should be interpreted considering the high degree of uncertainty concerning the implementation of the analysed policies. Applying the framework and the urban resilience index in the future and considering only the policies and actions that were implemented, may bring less optimistic results. Moreover, the proposed methodology is based on a qualitative approach where the research team valued the resilience indicators following a predesigned template. Therefore, results can be somewhat biased. Quantitative approaches can complement this study, for example, measuring to what extent GI fosters resilience through the provision of ecosystem services (Calderón-Contreras & Quiroz-Rosas, 2017).

Finally, results can be highly sensitive to the scale of analysis. To analyse how GI policies affect different social groups statistical analysis at the neighbourhood or census tract level could be carried out (Baró et al., 2019). We only found a significant moderate positive correlation between the resilience index and percentage of population with low educational level or without education (Fig. 6) at the district level, but different results could be obtained if we carry out the analysis using smaller administrative units.

5. Conclusions

Green infrastructure and the ecosystem services that it provides are increasingly seen as key elements to foster urban resilience. Because local governments manage green spaces, parks, street trees and other GI elements in public space, they have ample opportunities to enhance resilience through GI policies. The application of the framework and the resilience index used in this research project allows to measure the degree to which Madrid City Council's GI policies promote urban resilience if they were fully implemented.

Based in our results we highlight the following policy recommendations to foster urban resilience through green infrastructure. We believe these recommendations can be extrapolated to other urban areas:

- Comprehensive planning policies are the first step for GI implementation. However, they should incorporate citizen engagement and information instruments to foster resilience in higher degree, as participatory processes that involve all stakeholders during the design, implementation and monitoring of GI. Planning policies with citizen's engagement mechanisms and that focus on vulnerable neighbourhoods, have not only higher overall resilience scores, but also in the resilience factors *polycentric governance, social cohesion, learning and innovation* and *social-ecological justice.*
- *Self-sufficiency and autonomy* is the resilience factor less frequently addressed by GI policies. It mostly depends on the capacity of the urban area to provide the necessary ecosystem services for citizens' well-being. Policies should explicitly recognise the multi-functionality of GI to provide a wide range of ecosystem services.
- Collaboration among government departments, backing actions with appropriate budgets and political will are cross-cutting challenges for the implantation of all the proposed actions. To deal with these challenges, the concept of green infrastructure may allow understanding and cooperation among government departments.

We believe that the proposed framework is suitable to assess to what extent local policies foster resilience to a wide variety of disturbances in urban contexts and suggest further testing in other cities.

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.

Acknowledgements

This research is part of the project "Evaluación de la infraestructura verde de Madrid: Hacia una mejora de las políticas municipales para la resiliencia socio-ecológica" funded by Madrid City Council in 2018 with a budget of 35,088.17€ and carried out by Asociación Ecología y Educación para una Ciudad Sostenible – Transitando. We thank Ayar Rodríguez de Castro and Ana Paula García-Nieto for their support with GIS and Jorge Cerezal for his support with the policy review. We also thank the officials and policymakers of the City Council and the experts for their participation in the interviews and the consultation process. Open access funding provided by University of the Basque Country.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2023.104923.

References

Adger, W. N. (2003). Social capital, collective action and adaptation to climate change. *Economic Geography, 79*, 387–404. https://doi.org/10.1007/978-3-531-92258-4_19

Agencia de Ecología Urbana de Barcelona. (2012). Guía metodológica para los sistemas de auditoría, certificación o acreditación de la calidad y sostenibilidad en el medio urbano. (Methodological guide for auditing, certification or accreditation systems for quality and sustainability in urban areas.) Ministerio de Fomento, Gobierno de España.

Aguado Caso, M. (2016). *Vivir bien en un planeta finito. Una mirada socio-ecológica al concepto de bienestar humano (Living well on a finite planet. A social-ecological look at the concept of human well-being).* [Doctoral dissertation, Universidad Autónoma de Madrid]. UAM repository. Retrieved from - https://repositorio.uam.es/handle/10486/675536.

ALMUDENA (Municipal and zonal data bank). (2020). *Area.* Retrieved from - http://www.madrid.org/desvan/Inicio.icm?enlace=almudena.

Andersson, E., Borgström, S., Haase, D., Langemeyer, J., Wolff, M., & McPhearson, T. (2021). Urban resilience thinking in practice: Ensuring flows of benefit from green and blue infrastructure. *Ecology and Society, 26*(4), 39. https://doi.org/10.5751/ES-12691-260439

Andersson, E., McPhearson, T., Kremer, P., Gómez-Baggethun, E., Haase, D., Tuvendal, M., & Wurster, D. (2015). Scale and context dependence of ecosystem service providing units. *Ecosystem Services, 12*, 157–164. https://doi.org/10.1016/j.ecoser.2014.08.001

Bănică, A., Istrate, M., & Muntele, I. (2020). Towards green resilient cities in Eastern European Union countries. *Journal of Urban and Regional Analysis, 12*(1), 53–72. https://doi.org/10.37043/JURA.2020.12.1.4

Baró, F., Calderón-Argelich, A., Langemeyer, J., & Connolly, J. J. T. (2019). Under one canopy? Assessing the distributional environmental justice implications of street tree benefits in Barcelona. *Environmental Science & Policy, 102*, 54–64. https://doi.org/10.1016/j.envsci.2019.08.016

Berkes, F., Colding, J., & Folke, C. (Eds.) (2003). *Navigating Social-Ecological Systems. Building Resilience for Complexity and Change.* Cambridge University Press.

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., BurnSilver, S., Cundill, G., Dakos, V., Daw, T. M., Evans, L. S., Kotschy, K., Leitch, A. M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M. D., Schoon, M. L., Schultz, L., & West, P. C. (2012). Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources, 37*(1), 421–448. https://doi.org/10.1146/annurev-environ-051211-123836

Bouska, K. L., Houser, J. N., De Jager, N. R., Van Appledorn, M., & Rogala, J. T. (2019). Applying concepts of general resilience to large river ecosystems: A case study from the Upper Mississippi and Illinous rivers. *Ecological Indicators, 101*, 1094–1110. https://doi.org/10.1016/j.ecolind.2019.02.002

Brand, F., & Jax, K. (2007). Focusing the meaning(s) of resilience: Resilience as a descriptive concept and a boundary object. *Ecology and Society, 12*(1), 23. Retrieved from - http://www.ecologyandsociety.org/vol12/iss1/art23/main.html.

Buijs, A. E., Mattijssen, T. J., Van der Jagt, A. P., Ambrose-Oji, B., Andersson, E., Elands, B. H., & Steen Møller, M. (2016). Active citizenship for urban green infrastructure: Fostering the diversity and dynamics of citizen contributions through mosaic governance. *Current Opinion in Environmental Sustainability, 22*, 1–6. https://doi.org/10.1016/j.cosust.2017.01.002

Calderón-Contreras, R., & Quiroz-Rosas, L. E. (2017). Analysing scale, quality and diversity of green infrastructure and the provision of Urban Ecosystem services: A case from Mexico City. *Ecosystem Services, 23*, 127–137. https://doi.org/10.1016/j.ecoser.2016.12.004

Camps-Calvet, M., Langemeyer, J., Calvet-Mir, L., & Gómez-Baggethun, E. (2016). Ecosystem services provided by urban gardens in Barcelona, Spain: Insights for policy and planning. *Environmental Science & Policy, 62*, 14–23. https://doi.org/10.1016/j.envsci.2016.01.007

Carpenter, S., Arrow, K., Barrett, S., Biggs, R., Brock, W., Crépin, A.-S., … Zeeuw, A. (2012). General resilience to cope with extreme events. *Sustainability, 4*(12), 3248–3259. https://doi.org/10.3390/su4123248

Cato, M. S. (2013). *The bioregional economy: Land, liberty and the pursuit of happiness.* Routledge.

Chelleri, L., Waters, J. J., Olazabal, M., & Minucci, G. (2015). Resilience trade-offs: Addressing multiple scales and temporal aspects of urban resilience. *Environment and Urbanization, 27*(1), 181–198. https://doi.org/10.1177/0956247814550780

Childers, D. L., Bois, P., Hartnett, H. E., McPhearson, T., Metson, G. S., & Sanchez, C. A. (2019). Urban Ecological Infrastructure: An inclusive concept for the non-built urban environment. *Elementa, 7*, 46. https://doi.org/10.1525/elementa.385

Conway, T. M., Khan, A., & Esak, N. (2020). An analysis of green infrastructure in municipal policy: Divergent meaning and terminology in the Greater Toronto Area. *Land Use Policy, 99*, Article 104864. https://doi.org/10.1016/j.landusepol.2020.104864

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. *Journal of Homeland Security and Emergency Management, 7*(1), 51. https://doi.org/10.2202/1547-7355.1732

Cutter, S. L., Ash, K. D., & Emrich, C. T. (2016). Urban-rural differences in disaster resilience. *Annals of the American Association of Geographers, 106*(6), 1236–1252. doi: 10.1080/24694452.2016.1194740.

Dai, D. (2011). Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? *Landscape and Urban Planning, 102*(4), 234–244. https://doi.org/10.1016/j.landurbplan.2011.05.002

Davies, C., & Lafortezza, R. (2017). Urban green infrastructure in Europe: Is greenspace planning and policy compliant? *Land Use Policy, 69*, 93–101. https://doi.org/10.1016/j.landusepol.2017.08.018

Davis, A. Y., Belaire, J. A., Farfan, M. A., Milz, D., Sweeney, E. R., Loss, S. R., & Minor, E. S. (2012). Green infrastructure and bird diversity across an urban socioeconomic gradient. *Ecosphere, 3*(11), 105. https://doi.org/10.1890/ES12-00126.1

Davoudi, S. (2012). Resilience: A bridging concept or a dead end? *Planning Theory & Practice, 13*(2), 299–307. doi: 10.1080/14649357.2012.677124.

De Luca, C., Langemeyer, J., Vaňo, S., Baró, F., & Andersson, E. (2021). Adaptive resilience of and through urban ecosystem services: A transdisciplinary approach to sustainability in Barcelona. *Ecology and Society, 26*(4), 38. https://doi.org/10.5751/ES-12535-260438

Di Marino, M., Tiitu, M., Lapintie, K., Viinikka, A., & Kopperoinen, L. (2019). Integrating green infrastructure and ecosystem services in land use planning. Results from two Finnish case studies. *Land Use Policy, 82*, 643–656. https://doi.org/10.1016/j.landusepol.2019.01.007

Dorst, H., van der Jagt, A., Raven, R., & Runhaar, H. (2019). Urban greening through nature-based solutions – Key characteristics of an emerging concept. *Sustainable Cities and Society, 49*, Article 101620. https://doi.org/10.1016/j.scs.2019.101620

Elmqvist, T., Andersson, E., Frantzeskaki, N., McPhearson, T., Olsson, P., Gaffney, O., Takeuchi, K., & Folke, C. (2019). Sustainability and resilience for transformation in the urban century. *Nature Sustainability, 2*(4), 267–273. https://doi.org/10.1038/s41893-019-0250-1

Elmqvist, T., Folke, C., Nyström, M., Peterson, G., Walker, B., & Bengtsson, J. (2003). Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment, 1*(9), 488–494. https://doi.org/10.1890/1540-9295(2003)001[0488:RDECAR]2.0.CO;2

Ernstson, H. (2013). The social production of ecosystem services: A framework for studying environmental justice and ecological complexity in urbanized landscapes. *Landscape and Urban Planning, 109*(1), 7–17. https://doi.org/10.1016/j.landurbplan.2012.10.005

Ernstson, H., van der Leeuw, S. E., Redman, C. L., Meffert, D. J., Davis, G., Alfsen, C., & Elmqvist, T. (2010). Urban transitions: On urban resilience and human-dominated ecosystems. *Ambio, 39*(8), 531–545. https://doi.org/10.1007/s13280-010-0081-9

European Commission. (2013). *Communication from the Commision to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Green Infrastructure (GI) - Enhancing Europe's Natural Capital*. Retrieved from - http://ec.europa.eu/environment/nature/ecosystems/strategy/index_en.htm.

EU Copernicus Programme. (2012). *Urban Atlas LCLU 2012*. Retrieved from - https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012.

Feria Toribio, J. M., & Santiago Ramos, J. (2017). Naturaleza y ciudad. Perspectivas para la ordenación de la infraestructura verde en los planes territoriales metropolitanos en España. (Nature and city. Prospects for green infrastructure planning in territorial metropolitan plans in Spain.). *Boletín de La Asociación de Geógrafos Españoles, 74*, 117–141. https://doi.org/10.21138/bage.2447

Fernández de Manuel, B., Méndez-Fernández, L., Peña, L., & Ametzaga-Arregi, I. (2021). A new indicator of the effectiveness of urban green infrastructure based on ecosystem services assessment. *Basic and Applied Ecology, 53*, 12–25. https://doi.org/10.1016/j.baae.2021.02.012

Folke, C., Jansson, A., Larsson, J., & Costanza, R. (1997). Ecosystem appropriation by cities. *Ambio, 26*(3), 167–172.

Folke, C., Pritchard, L. J., Berkes, F., Colding, J., & Svedin, U. (2007). The problem of fit between ecosystems and institutions: Ten years later. *Ecology and Society, 12*(1), 30. Retrieved from - https://www.ecologyandsociety.org/vol12/iss1/art30/.

Garmendia, E., Apostolopoulou, E., Adams, W. M., & Bormpoudakis, D. (2016). Biodiversity and Green Infrastructure in Europe: Boundary object or ecological trap? *Land Use Policy, 56*, 315–319. https://doi.org/10.1016/j.landusepol.2016.04.003

Goldstein, B. (2009). Resilience to surprises through communicative planning. *Ecology and Society, 14*(2), 33. Retrieved from - https://www.ecologyandsociety.org/vol14/iss2/art33/main.html.

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics, 86*, 235–245. https://doi.org/10.1016/j.ecolecon.2012.08.019

Grabowski, Z. J., McPhearson, T., Matsler, A. M., Groffman, P., & Pickett, S. T. A. (2022). What is green infrastructure? A study of definitions in US city planning. *Frontiers in Ecology and the Environment, 20*(3), 152–160. https://doi.org/10.1002/fee.2445

Green, T. L., Kronenberg, J., Andersson, E., Elmqvist, T., & Gómez-Baggethun, E. (2016). Insurance value of green infrastructure in and around cities. *Ecosystems, 19*(6), 1051–1063. https://doi.org/10.1007/s10021-016-9986-x

Gunderson, L. H., & Holling, C. S. (Eds.). (2002). *Panarchy: Understanding transformations in human and natural systems*. Island Press.

Hanson, H. I., Wickenberg, B., & Alkan Olsson, J. (2020). Working on the boundaries—How do science use and interpret the nature-based solution concept? *Land Use Policy, 90*, Article 104302. https://doi.org/10.1016/j.landusepol.2019.104302

Hasson, F., Keeney, S., & McKenna, H. (2000). Research guidelines for the Delphi survey technique. *Journal of Advanced Nursing, 32*(4), 1008–1015. https://doi.org/10.1046/j.1365-2648.2000.t01-1-01567.x

Hopkins, R. (2008). *The transition handbook. From oil dependency to local resilience*. Green Books.

INE (Spanish Statistical Office). (2021). *Official population figures from Spanish municipalities: Revision of the Municipal Register. Municipal breakdown.* Retrieved from - https://ine.es/dyngs/INEbase/es/categoria.htm?c=Estadistica_P&cid=1254734710990.

Jennings, V., Larson, L., & Yun, J. (2016). Advancing sustainability through urban green space: Cultural ecosystem services, equity, and social determinants of health. *International Journal of Environmental Research and Public Health, 13*(2), 196. https://doi.org/10.3390/ijerph13020196

Kabisch, N., & Haase, D. (2014). Green justice or just green? Provision of urban green spaces in Berlin, Germany. *Landscape and Urban Planning, 122*, 129–139. https://doi.org/10.1016/j.landurbplan.2013.11.016

Karabakan, B., & Mert, Y. (2021). Measuring the green infrastructure resilience in Turkey. *Chinese Journal of Urban and Environmental Studies, 9*(3), 1–20. https://doi.org/10.1142/S2345748121500147

Konijnendijk, C. C., Annerstedt, M., Nielsen, A. B., & Maruthaveeran, S. (2013). *Benefits of urban parks. A systematic review*. The International Federation of Parks and Recreation Administration. Retrieved from - https://www.worldurbanparks.org/images/Newsletters/IfpraBenefitsOfUrbanParks.pdf.

Labib, S. M., Browning, M. H. E. M., Rigolon, A., Helbich, M., & James, P. (2022). Nature's contribution in coping with a pandemic in the 21st century: A narrative review of evidence during COVID-19. *Science of the Total Environment, 833*, Article 155095. https://doi.org/10.1016/j.scitotenv.2022.155095

Lafortezza, R., Davies, C., Sanesi, G., & Konijnendijk, C. C. (2013). Green infrastructure as a tool to support spatial planning in European urban regions. *IForest, 6*(1), 102–108. https://doi.org/10.3832/ifor0723-006

Langemeyer, J., Madrid-Lopez, C., Mendoza Beltran, A., & Villalba Mendez, G. (2021). Urban agriculture – A necessary path to urban resiliency and global sustainability? *Landscape and Urban Planning, 210*, Article 104055. https://doi.org/10.1016/j.landurbplan.2021.104055

Łaszkiewicz, E., Kronenberg, J., & Marcińczak, S. (2018). Attached to or bound to a place? The impact of green space availability on residential duration: The environmental justice perspective. *Ecosystem Services, 30*, 309–317. https://doi.org/10.1016/j.ecoser.2017.10.002

Leslie, P., & McCabe, J. T. (2013). Response diversity and resilience in social-ecological systems. *Current Anthropology, 54*(2), 114–143. https://doi.org/10.1086/669563

Madrid City Council. (2018b). *Plan de infraestructura verde y biodiversidad de la ciudad de Madrid. Resumen ejecutivo del diagnóstico de situación del plan estratégico. (Green infrastructure and biodiversity plan for Madrid City. Executive summary of the situation diagnosis of the strategic plan)*. Retrieved December 13, 2022 from - https://www.madrid.es/UnidadesDescentralizadas/ZonasVerdes/TodoSobre/PlanInfraestructuraVerdeYBiodiversidad/DocumentacionAsociada/Resumen%20ejecutivo%20del%20diagn%C3%B3stico%20de%20situaci%C3%B3n.pdf.

Madrid City Council. (2018b). Madrid Recupera. Estrategia de Regeneración Urbana. *(Madrid Restores Plan: Urban Regeneration Strategy)*.

McPhearson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. *Ecosystem Services, 12*, 152–156. https://doi.org/10.1016/j.ecoser.2014.07.012

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning, 147*, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011

Mell, I. (2015). Green infrastructure planning: Policy and objectives. In D. Sinnett, N. Smith, & S. Burgess (Eds.), *Handbook on green infrastructure: Planning, design and implementation* (pp. 105–123). Edward Elgar Publishing.

Mendonça, R., Roebeling, P., Fidélis, T., & Saraiva, M. (2021). Policy instruments to encourage the adoption of nature-based solutions in urban landscapes. *Resources, 10*(8), 81. https://doi.org/10.3390/resources10080081

Monteiro, R., Ferreira, J. C., & Antunes, P. (2020). Green infrastructure planning principles: An integrated literature review. *Land, 9*(12), 525. https://doi.org/10.3390/land9120525

Moser, S., Meerow, S., Arnott, J., & Jack-Scott, E. (2019). The turbulent world of resilience: Interpretations and themes for transdisciplinary dialogue. *Climatic Change, 153*(1–2), 21–40. https://doi.org/10.1007/s10584-018-2358-0

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., & Giovannini, E. (2005). *Handbook on Constructing Composite Indicators: Methodology and User Guide* (No. 03; OECD Statistics Working Papers). https://doi.org/10.1787/533411815016.

Nordin, A. C., Hanson, H. I., Alkan Olsson, J., & Olsson, J. A. (2017). Integration of the ecosystem services concept in planning documents from six municipalities in southwestern Sweden. *Ecology and Society, 22*(3), 26. https://doi.org/10.5751/ES-09420-220326

Ostrom, E. (2005). *Understanding Institutional Diversity*. Princeton Univeristy Press.

Pineda-Pinto, M., Nygaard, C. A., Chandrabose, M., & Frantzeskaki, N. (2021). Mapping social-ecological injustice in Melbourne, Australia: An innovative systematic methodology for planning just cities. *Land Use Policy, 104*, Article 105361. https://doi.org/10.1016/j.landusepol.2021.105361

Pope, K., Bonatti, M., & Sieber, S. (2021). The what, who and how of socio-ecological justice: Tailoring a new justice model for earth system law. *Earth System Governance, 10*, Article 100124. https://doi.org/10.1016/j.esg.2021.100124

Potschin, M., Kretsch, C., Haines-Young, R., Furman, E., Berry, P., & Baró, F. (2016). Nature-based solutions. In M. Potschin & K. Jax (Eds.), *OpenNESS Ecosystem ServicesReference Book.* EC FP7 Grant Agreement no. 308428.

Pozoukidou, G. (2020). Designing a green infrastructure network for metropolitan areas: A spatial planning approach. *Euro-Mediterranean Journal for Environmental Integration, 5*(2), 1–15. https://doi.org/10.1007/s41207-020-00178-8

Rayan, M., Gruehn, D., & Khayyam, U. (2021). Green infrastructure indicators to plan resilient urban settlements in Pakistan: Local stakeholder's perspective. *Urban Climate, 38*, Article 100899. https://doi.org/10.1016/j.uclim.2021.100899

Rees, W., & Wackernagel, M. (1996). Urban ecological footprints: Why cities cannot be sustainable–And why they are a key to sustainability. *Environmental Impact Assessment Review, 16*, 223–248.

Rieiro Díaz, A. M. (2018). *Estrategias de construcción de resiliencia urbana en el sur de Madrid. Intervenciones en el sistema de espacios libres urbanos de Usera y Villaverde desde el punto de vista de la resiliencia urbana. (Urban resilience building strategies in the south of Madrid. Interventions in the system of urban open spaces of Usera and Villaverde from the point of view of urban resilience.)*. Madrid City Council. Retrieved December 13, 2022 from - https://patrimonioypaisaje.madrid.es/FWProjects/monumenta/contenidos/Ficheros/Estrategias de construcción de resiliencia urbana en el sur de Madrid - Amaya Rieiro Díaz.pdf.

Romero-Lankao, P., Gnatz, D., Wilhelmi, O., & Hayden, M. (2016). Urban sustainability and resilience: from theory to practice. *Sustainability, 8*(12), 1224. https://doi.org/10.3390/su8121224

Rosenfeld, J. S. (2002). Functional redundancy in ecology and conservation. *Oikos, 98* (1), 156–162. https://doi.org/10.1034/j.1600-0706.2002.980116.x

Saaty, T. L. (1980). *The Analytic Hierarchy Process*. McGraw Hill.

Schlosberg, D. (2004). Reconceiving environmental justice: global movements and political theories. *Environmental Politics, 13*(3), 517–540. https://doi.org/10.1080/0964401042000229025

Seiwert, A., & Rößler, S. (2020). Understanding the term green infrastructure: Origins, rationales, semantic content and purposes as well as its relevance for application in spatial planning. *Land Use Policy, 97*, Article 104785. https://doi.org/10.1016/j.landusepol.2020.104785

Sharifi, A., & Yamagata, Y. (2014). Resilient urban planning: major principles and criteria. *Energy Procedia, 61*, 1491–1495. https://doi.org/10.1016/j.egypro.2014.12.154

Slovic, A. D., & Ribeiro, H. (2018). Policy instruments surrounding urban air quality: The cases of São Paulo, New York City and Paris. *Environmental Science & Policy, 81*, 1–9. https://doi.org/10.1016/j.envsci.2017.12.001

Smets, J., De Blust, G., Verheyden, W., Wanner, S., Van Acker, M., & Turkelboom, F. (2020). Starting a participative approach to develop local green infrastructure; from boundary concept to collective action. *Sustainability, 12*(23), 1–25. https://doi.org/10.3390/su122310107

Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface, 4*(15), 707–719. https://doi.org/10.1098/rsif.2007.0213

Suárez, M., & Alba, D. (2017). Urban ecosystem services assessment for urban and regional planning. A methodological framework for Madrid City. In M. González-Bereziartua, & I. Aseguinolaza Braga (Eds.), *International research seminar in urban processes and natural morphologies: 7–8 September, 2017 Donostia-San Sebastián, Spain* (pp. 195–212). Universidad del País Vasco / Euskal Herriko Unibertsitatea, Argitalpen Zerbitzua = Servicio Editorial.

Suárez, M., Barton, D. N., Cimburova, Z., Rusch, G. M., Gómez-Baggethun, E., & Onaindia, M. (2020). Environmental justice and outdoor recreation opportunities: A spatially explicit assessment in Oslo metropolitan area, Norway. *Environmental Science and Policy, 108*, 133–143. https://doi.org/10.1016/j.envsci.2020.03.014

Suárez, M., Gómez-Baggethun, E., Benayas, J., & Tilbury, D. (2016). Towards an urban resilience index: a case study in 50 Spanish Cities. *Sustainability, 8*, 774. https://doi.org/10.3390/su8080774

Suárez, M., Gómez-Baggethun, E., & Onaindia, M. (2020). Assessing socio-ecological resilience in cities. In M. A. Burayidi, A. Allen, J. Twigg, & C. Wamsler (Eds.), *The Routledge Handbook of Urban Resilience* (pp. 197–216). Routledge.

Townshend, I., Awosoga, O., Kulig, J., & Fan, H. (2015). Social cohesion and resilience across communities that have experienced a disaster. *Natural Hazards, 76*, 913–938. https://doi.org/10.1007/s11069-014-1526-4

Vaňo, S., Stahl Olafsson, A., & Mederly, P. (2021). Advancing urban green infrastructure through participatory integrated planning: A case from Slovakia. *Urban Forestry & Urban Greening, 58*, Article 126957. https://doi.org/10.1016/j.ufug.2020.126957

Venter, Z. S., Shackleton, C. M., Van Staden, F., Selomane, O., & Masterson, V. A. (2020). Green Apartheid: Urban green infrastructure remains unequally distributed across income and race geographies in South Africa. *Landscape and Urban Planning, 203*, Article 103889. https://doi.org/10.1016/j.landurbplan.2020.103889

Villatoro, P., & Ribera, E. (2007). La cohesión social en los países desarrollados: conceptos e indicadores. (Social cohesion in developed countries: concepts and indicators.) CEPAL. Retrieved from – https://www.cepal.org/sites/default/files/publication/files/4759/S0700669_es.pdf.

Voskamp, I. M., & Van de Ven, F. H. (2015). Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. *Building and Environment, 83*, 159–167. https://doi.org/10.1016/j.buildenv.2014.07.018

Walker, B., & Salt, D. (2006). *Resilience thinking. Sustaining ecosystems and people in a changing world*. Island Press.

Washington, H., Chapron, G., Kopnina, H., Curry, P., Gray, J., & Piccolo, J. J. (2018). Foregrounding ecojustice in conservation. *Biological Conservation, 228*, 367–374. https://doi.org/10.1016/j.biocon.2018.09.011

Walker, B., Holling, C.S., Carpenter, S., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. Ecology and Society, 9(2), 5. Retrieved from http://www.ecologyandsociety.org/vol9/iss2/art5/inline.html.

Winstanley, A., Hepi, M., & Wood, D. (2015). Resilience? Contested meanings and experiences in post-disaster Christchurch, New Zealand. *Kōtuitui: New Zealand Journal of Social Sciences Online, 10*(2), 126–134. https://doi.org/10.1080/1177083X.2015.1066402

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities "just green enough". *Landscape and Urban Planning, 125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

Yaka, Ö. (2019). Rethinking justice: Struggles for environmental commons and the notion of socio-ecological justice. *Antipode, 51*(1), 353–372. https://doi.org/10.1111/anti.12422

Yao, N., Konijnendijk van den Bosch, C. C., Yang, J., Devisscher, T., Wirtz, Z., Jia, L., Duan, J., & Ma, L. (2019). Beijing's 50 million new urban trees: Strategic governance for large-scale urban afforestation. *Urban Forestry and Urban Greening, 44*, Article 126392. https://doi.org/10.1016/j.ufug.2019.126392

Yumagulova, L., & Vertinsky, I. (2021). Managing trade-offs between specific and general resilience: Insights from Canadas's Metro Vancouver region. *Cities, 119*, Article 103319. https://doi.org/10.1016/j.cities.2021.103319

Zuniga-Teran, A. A., Gerlak, A. K., Elder, A. D., & Tam, A. (2021). The unjust distribution of urban green infrastructure is just the tip of the iceberg: A systematic review of place-based studies. *Environmental Science and Policy, 126*, 234–245. https://doi.org/10.1016/j.envsci.2021.10.001

Zuniga-Teran, A. A., Gerlak, A. K., Mayer, B., Evans, T. P., & Lansey, K. E. (2020). Urban resilience and green infrastructure systems: Towards a multidimensional evaluation. *Current Opinion in Environmental Sustainability, 44*, 42–47. https://doi.org/10.1016/j.cosust.2020.05.001

Zuniga-Teran, A. A., Staddon, C., de Vito, L., Gerlak, A. K., Ward, S., Schoeman, Y., … Booth, G. (2020). Challenges of mainstreaming green infrastructure in built environment professions. *Journal of Environmental Planning and Management, 63*(4), 710–732. https://doi.org/10.1080/09640568.2019.1605890