Cities 154 (2024) 105348

Contents lists available at ScienceDirect

Cities

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

Identifying suitable policy instruments to promote nature-based solutions in urban plans

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ARTICLE INFO

Keywords:
Urban greening
Green infrastructure
Urban policies
Urban planning
Planning instruments
Policy mix

ABSTRACT

Urban plans can promote the implementation and scaling up of nature-based solutions (NbS) through the adoption of specific policy instruments. These can be applied to different typologies of NbS interventions, depending on the transformations allowed by the plan and property regime of the different areas. Through a review of real-world applications, we provide an overview of policy instruments that can be used to promote NbS implementation in urban plans. We identify eighteen types of policy instruments divided into five main categories and linked them to eight overall typologies of NbS interventions to which they can be applied. The matrix linking policy instruments and NbS interventions includes fifty-nine matches corresponding to documented real-life applications. Regulations can be especially used to integrate NbS early on in new development areas, while incentive-based instruments are suitable to promote NbS in retrofitting and renovating the built environment. Notably, more than one instrument can be applied to each NbS typology. We discuss the differences among the instruments and how they can be combined to achieve the desired policy goals. Moreover, we illustrate how the matrix can be used to expand the range of policy options in a specific planning context, supporting a wider implementation and scaling up of NbS through urban planning.

1. Introduction

Current processes of urbanisation and climate change urge cities to reconsider the sustainability of urban planning approaches and resulting development patterns (Dorst et al., 2019). At the same time, there is increasing evidence showing how Nature-based Solutions (NbS), defined as actions that utilize ecosystem processes of green and blue infrastructure to safeguard or enhance the delivery of ecosystem services (Albert et al., 2019), can contribute to counteract or alleviate many of today's societal challenges (Babí Almenar et al., 2021). These include challenges associated with adapting to climate-related impacts, reducing air pollution, improving water quality and quantity, reversing biodiversity loss, and offering nature-based recreation and education opportunities, among others (e.g., Raymond et al., 2017).

Integrating NbS in the planning and design processes that steer spatial development is therefore promoted as a sustainable and cost-effective strategy to address multiple challenges and enhance human health, equity, and well-being (Czúcz et al., 2018; Kato-Huerta & Geneletti, 2022; Lafortezza et al., 2018; Maes & Jacobs, 2017). Despite the importance of regional, national, and international institutional, financial, and legislative settings in facilitating the adoption of NbS, city-level planning policies play a crucial role (Droste et al., 2017) and are usually considered more effective drivers for NbS implementation than superordinate legislation (O'Donnell et al., 2021). In many countries, most of the land planning and design activities relevant to NbS are enforced by cities, including land-use planning, zoning and building codes, and stormwater management policies (Dhakal & Chevalier, 2017; Flynn & Davidson, 2016).

In particular, urban plans provide a valuable platform for policy integration and spatialization (Stead & Meijers, 2009). By considering NbS in the formulation of urban-planning-related policies (e.g., stormwater management, public green space design, land use, and building

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https://doi.org/10.1016/j.cities.2024.105348
Received 27 January 2022; Received in revised form 29 July 2024; Accepted 3 August 2024
Available online 26 August 2024

development regulations, etc.), urban plans can ensure the systematic incorporation of NbS and their scaling up across the city and surrounding areas (Orta-Ortiz & Geneletti, 2023). This spatial and systemic approach fostered by urban plans is even more needed when considering the potential cumulative impacts of NbS implementation, for example on the ecological connectivity of green and blue infrastructures (Xie & Bulkeley, 2020) and on equity in the distribution of and access to green areas (Cousins, 2021). For these reasons, NbS planning is often considered to be an integral part of urban planning processes and instruments (McQuaid et al., 2021).

In urban plans, decisions are typically formalized through dedicated policies which are implemented through specific policy instruments (Bouwma et al., 2015). Policy instruments are concrete tools used to achieve the objectives and targets stated in the urban plan (Ali, 2013), and are considered as the link between policy formulation and implementation (Rogge & Reichardt, 2016). Many opportunities to implement NbS exist within and outside cities (e.g., Castellar et al., 2021). These include building greening (e.g., green roofs and walls), greening interventions on private open spaces (e.g., renaturing community spaces and garden areas) and public areas (e.g., street trees and urban parks), as well as rural and natural land management actions (Dushkova & Haase, 2020; Gutiérrez et al., 2017). New urban developments, as well as urban regeneration interventions, offer the possibility of an early integration of NbS when project proposals are formulated (Gutiérrez et al., 2017). More difficult is the integration of NbS into the existing built-up spaces, which requires retrofitting and renovating existing buildings and open spaces (Grace et al., 2021).

Some frontrunner cities have started to incorporate in their plans several policy instruments to explicitly promote the implementation of specific NbS (Zabel & Häusler, 2024). Examples include incentives and technology standards for green roofs in Chicago, Minneapolis, and Portland (US), Tokyo (Japan), Linz (Austria), and Basel (Switzerland) (e.g., Carter & Fowler, 2008); regulations for on-site stormwater retention in Toronto (Canada) (Johns, 2019); and indices to measure the "green performance" of interventions and set minimum criteria for green-blue surfaces in new developments in Oslo (Norway) (Kronenberg et al., 2021). However, the use of policy instruments to implement NbS is still quite exploratory, especially in the European context, and the 'toolbox' of instruments that policy-makers might use in cases of NbS is often overlooked or underutilized (Kirsop-Taylor et al., 2022). This is due to the lack of innovation, as well as to limited knowledge and practical experience of NbS planning and implementation (Grace et al., 2021), which act as barriers to their wider uptake (Naumann et al., 2020).

This study aims to identify the policy instruments that can be adopted in urban plans to promote the implementation of NbS, and to investigate their suitability to different typologies of NbS interventions. The article therefore addresses the following two research questions:

- What policy instruments exist to promote the implementation of NbS in urban plans?
- What typologies of NbS interventions can be promoted by each of the existing policy instruments?

To answer these questions, we review real-world cases of policy instrument applications to promote NbS implementation in cities, collect information about the typologies of NbS implemented and the policy instruments applied, and summarize the findings in a matrix that shows what types of NbS can be promoted by each instrument. The results can be used by policy- and decision-makers to better understand the range of existing opportunities to promote the implementation of NbS through urban plans, but also by other categories of actors who advocate for a more effective scaling up of NbS. The remainder of the paper is organized into four main sections. Section 2 presents a brief overview of the categories of policy instruments that can be used to promote NbS implementation in cities, with a focus on the policy instrument literature addressing the spatial and urban planning domain. Section 3 describes the methodology adopted to review real-world cases and to analyse the suitability of policy instruments to promote the implementation of different typologies of NbS interventions. Section 4 presents the results of the review and a matrix that links typologies of NbS interventions with the suitable instruments identified. Section 5 discusses the results of the review and the usefulness of the proposed matrix to support decision-making, including an example of its application to reveal gaps and further opportunities. Finally, Section 6 provides the conclusions of our study.

2. Classification of policy instruments to promote NbS implementation: state of the art

In environmental policy, policy instruments are typically classified according to the degree of coerciveness (Pacheco-Vega, 2020), following the popular threefold classification proposed by Vedung (1998) and derived from Etzioni's classification of power (Etzioni, 1961). Accordingly, they can be classified into regulations, incentives and economic means, and information instruments (e.g., Lieberherr & Green, 2018). Regulatory instruments are usually legally binding and entail mandatory actions through prescriptions or prohibitions. Incentive-based instruments (economic and non-economic) are usually applied on a voluntary basis (i.e., the target groups are free to react (or not)) to encourage and promote or discourage and restrain certain activities and are non-legally binding until agreement. Information-based instruments (also known as knowledge-based or soft instruments) are not legally binding too and mostly focus on the transfer of knowledge and meaningful information.

With specific reference to the concept of NbS, Bhardwaj et al. (2020, 414) described the three categories of instruments as follows: "Regulatory instruments are compulsory measures imposing regulations, restrictions, limits and caps on activities (sectoral) that have implications on ecosystems and their services. [...] Economic and financial instruments encourage stakeholders to reduce or limit the impact of their activities on ecosystems/environment. These instruments often provide financial/budgetary support for adopting solutions/alternatives which can reduce the impact of their activities. [...] Information and education-based instruments ensure that stakeholders are well-informed about the approach [NbS] and its benefits".

Several authors attempted to review and/or systematically analyse the application of policy instruments for implementing NbS or similar approaches (e.g., ecosystem-based actions, green infrastructure, low-impact development interventions, etc.). However, most studies focused solely on solutions that address a specific problem (e.g., for managing stormwater and flood risk (e.g., Cousins & Hill, 2021; Dhakal & Chevalier, 2017)), on a specific type of NbS (e.g., green roofs (Irga et al., 2017; Liberalesso et al., 2020)), or on a specific category of instruments (e.g., incentives (Grant, 2018; Zeadat, 2021)). Only a few studies provide a more comprehensive overview of the different typologies of instruments that can be used to promote NbS implementation (e.g., Mendonça et al., 2021; Zabel & Häusler, 2024). Among them, studies specifically focusing on the different instruments that can be used for this purpose in the spatial or urban planning domain are even more rare (Stead, 2021).

The authors working in this niche of literature classified the policy instruments that can be used to promote the implementation of NbS (or similar approaches) in spatial and urban plans mostly using the three categories (i.e., regulations, incentives, information-based instruments) mentioned above, sometimes proposing variations in their definitions or adding new ones. For example, Bengston et al. (2004) identified and classified the main policy instruments for managing urban growth and protecting open space in the United States into regulations, incentives, and land acquisition programs. Brody et al. (2004) used the same categories, with the addition of information-based instruments, to classify policy tools adopted to implement ecosystem-based actions at the municipality and county scale in Florida. More recently, Bush and Hes

(2018) analysed policy mechanisms for urban green space implementation in Melbourne (Australia), classifying them into regulations, incentives and awards, and information and engagement. They also added the 'government provision and demonstration' mechanism type, which consists of the direct realization of projects by the public (e.g., in public land and buildings), thus independently from the enforcement of policy instruments for implementation.

Starting from Brody and colleagues' categorization Brody et al. (2004), Cortinovis and Geneletti (2018) analysed the state of ecosystem services inclusion in Italian urban plans and identified five categories of policy instruments adopted to implement nature-based actions: regulatory instruments, design-based instruments, land acquisition programs, incentive-based instruments (including economic and non-economic incentives), and information-based instruments. While regulatory, incentive-based, and information-based instruments are applied in public policies in general, design-based instruments and land acquisition programs are specific of spatial planning. Both are based on command-and-control regulations. The former is used to control new developments through a masterplan that defines developers' obligations, either negotiable or non-negotiable (Turk, 2018), to realize on-site interventions. The latter is used by the public authorities to purchase private undeveloped land.

3. Methods

3.1. Reviewing existing applications of policy instruments to promote NbS implementation

This study reviews practical applications (i.e., real-world cases) of policy instruments that have been adopted to promote NbS implementation in cities. Given the paucity of published literature/research in this field, confirmed by the systematic review by Kirsop-Taylor et al. (2022) who found limited research attention to the NbS scaling up process through substantive policies and (policy) instruments, we decided to not perform a systematic literature review using scientific databases (e.g., Scopus, Web of Science) and rather search for both scientific and grey literature in Google Scholar. We used a combination of relevant keywords that included terms related to NbS (i.e., "nature-based", "green infrastructure", "green space*", "greening", "ecosystem-based", "ecosystem service*") and policy-instruments (i.e., "policy instruments", "policy tools", "implementation instruments", "implementation tools", "policy mechanisms", "implementation mechanisms", "policy mix*"). We searched for all types of documents – not only scientific articles – and in the whole text, to increase the possibility of finding real cases of policy instrument applications that may not be captured in the title and abstract.

Given the large number of search results (i.e., more than 18,000), we sorted them by relevance and screened the abstract and full text of the first 500 results. We considered this sample as sufficient to capture the majority of the relevant literature, since documents to retain for further analysis were rarer and rarer while progressing with the screening. Information recorded from the reviewed studies (when present) was: the specific type of instrument used, the type of NbS intervention promoted by the instrument, and the city in which it was realized, if explicitly mentioned (alternatively, a reference to a city-level real-world implementation case was considered enough). The presence of all these three details together was imperative to consider the policy instrument application a 'practical application' and to include it in our review.

3.2. Classifying policy instruments and analysing their suitability to different typologies of NbS interventions

The analysis of the suitability of existing policy instruments to promote the implementation of different typologies of NbS interventions was carried out by developing a matrix that links each typology of NbS with the policy instruments that have been adopted for its implementation. The cells of the matrix are filled based on the information about the real-world examples of policy instrument applications collected through the review (see Section 3.1).

Policy instruments were classified into an extended version of the classification proposed by Cortinovis and Geneletti (2018). We retained the five main categories (Section 2) but progressively enriched the subcategories with additional types of policy instruments found in our literature review. Eventually, each application reviewed was linked to one of the policy instruments described in Section 4.1.

The NbS interventions were classified into different typologies (see Table 5 in Section 4.2) starting from the three main categories proposed by Eggermont et al. (2015) based on the intensity of intervention: "no or minimal intervention" (type 1), "management approaches that develop sustainable and multifunctional ecosystems and landscapes" (type 2), and "managing ecosystems in very intrusive ways or even creating new ecosystems" (type 3). These three categories reflect three different aims that urban plans can pursue concerning green areas and related ecosystem services by implementing NbS: safeguarding existing green areas to maintain ecosystem services provision (type 1), improving existing green areas to increase their multifunctionality and enhance ecosystem services provision (type 2), and creating new green areas to provide ecosystem services (type 3).

Within this overall classification, different typologies of NbS interventions can be identified based on the areas in which they are applied. Despite different – more or less prescriptive – approaches (Cortinovis & Geneletti, 2020), all urban plans divide the municipal territory into areas where different transformations are allowed (Lambin et al., 2014). This affects the typology of NbS that can be promoted in each area. For example, areas for new development offer the opportunity to both conserve existing green spaces and elements (type 1) and create new green areas (type 3), while actions on existing built-up areas are mostly aimed at improving the existing area's greenery (type 2). Crucially for our analysis, different permitted transformations correspond to different instruments that can be put in place to promote NbS in the different areas identified by the plan. Furthermore, among types 2 and 3, we distinguished between interventions located in public and private areas, as property regimes affect the applicability of policy instruments to different areas (e.g., Wang & Chan, 2019).

Overall, we identified eight typologies of NbS interventions and linked them to the available policy instruments in the matrix, where we marked the suitability for each combination of policy instrument and type of NbS intervention based on the information about real-world applications found in the scientific and grey literature.

4. Results

4.1. Policy instrument applications to promote NbS implementation in urban plans

The real-world applications of policy instrument found through the literature review are reported in the subsequent paragraphs divided by category of instrument. The tables list the specific types of policy instruments in each category, together with a description and some examples of real-world applications for NbS implementation. The full list of real-world applications found in the literature is provided in Supplementary data.

4.1.1. Regulatory instruments

Table 1 describes the six types of regulatory instruments found in the review.

Quantitative targets or standards (R1) are objectives that must be achieved in urban development/redevelopment areas, without specifying the technology to achieve them. Exemplary cases are the minimum share of available (private) and accessible (public) green open spaces (e.g., Cortinovis & Geneletti, 2018; Naumann et al., 2020), and the minimum volume of stormwater to retain on-site in the property area (Johns

Table 1
Regulatory instruments, with examples of real-world applications to promote NbS implementation (the full list of real-world applications and references is in Supplementary data).

Instrument type (code)	Description	Examples of real-world applications
Quantitative targets or standards (R1)	Definition of quantitative targets/standards that must be met when developing or redeveloping an area.	• (Unsealed) open space requirements, such as share or amount of pervious/ green areas to maintain or include in the property areas (e.g., several municipalities in Italy (Cortinovis & Geneletti, 2018)). • A minimum volume of stormwater to retain and manage on-site in the property area (e.g., Toronto, Canada (Johns et al., 2018)). • Minimum plant size (e.g., height, trunk diameter) for newly planted vegetation (e.g., City of Auburn, US (Zhang et al., 2009)).
Technological requirements (R2)	Definition of specific elements or technologies that must be included when developing or redeveloping an area.	• Mandatory installation of green roofs (e.g., Portland, US (Carter & Fowler, 2008)). • Mandatory installation of on-site stormwater management measures offering the opportunity to install NbS for rainwater management (e.g., Berlin, Germany (Naumann et al., 2020)). • Mandatory tree/vegetation planting in housing gardens (e.g., one municipality in Brimbank City Council, Australia (Furlong et al., 2018)). • Prescriptions for permeable surfaces in gateways, walkways, and parking areas (e.g., Dresden, Germany (European Commission, 2011)).
Compensation measures (R3)	Definition of mandatory ecological compensation actions that must be realized when developing or redeveloping an area.	• (Monetary) compensation for tree removal/damages by developers (e.g., Melbourne, Australia (Bush & Hes, 2018)). Fees are then used to directly realize or finance NbS. • Off-site compensation schemes (e.g., mitigation banking) for developing nature-based off-site measures in situations where on-site implementation is cost-prohibitive or not feasible (e.g., several municipalities in North America (Cousins & Hill, 2021)). • Mandatory land property transfers to retain open space and/or realize public greenery to compensate for environmental impacts occurred elsewhere (e.g., several municipalities in Italy (Cortinovis & Geneletti, 2018)). • Definition (in order of priority) of compensation (on-site) or replacement (off-site) measures through NbS in new building developments or expansion projects (e.g., enforced by German municipalities according to superordinate legislations (Ngan, 2004)).
Performance-based approaches with point systems (R4)	Definition of a minimum performance score that must be gained by attaining defined levels of green and blue surfaces when developing or redeveloping an area.	• Performance-based green area indicators and point systems setting minimum green coverage requirements (achieved through retaining the existing and integrating new green spaces), also called green factor tools or green area factors, among others (e.g., Oslo, Norway (Kronenberg et al., 2021)).
Conservation zones or protected areas and sites (R5)	Identification of specific sites or green elements to be preserved and definition of restrictions to their use and transformation.	• Definition of a (zoning) boundary for a protected area (e.g., urban natural park area, significant biotopes) together with the rules setting restrictions and limitations (e.g., Berlin, Germany (Fischer et al., 2013)). • Tree protection regulatory schemes (e.g., tree protection ordinances) as a standalone city law or enforced in city zoning regulations (e.g., Seattle, US (Ordóñez-Barona et al., 2021)).
Other instruments related to zoning regulations (R6)	Other types of rules enforced through zoning regulations.	• Cluster zoning to allow for wider open space preservation (e.g., several municipalities in the US (Milder & Clark, 2011)). • Definition of permitted and forbidden uses/management activities related to specific land uses, especially in non-urbanized land (e.g., several municipalities in Italy (Cortinovis & Geneletti, 2018)). • Special overlay zones (or districts) to enforce protection of sensitive natural areas/vegetation (e.g., Tucson, US (Duerksen et al., 1997)).

et al., 2018). This instrument type can be also applied on a case-by-case basis to specific projects, such as in the re-development project of Potsdamer Platz in Berlin (Germany), for which a requirement of managing 99 % of stormwater on-site was enforced by the municipality (Carter & Fowler, 2008). On the contrary, regulatory instruments that define technological requirements (R2) prescribe the adoption of a specific technology in the case of new constructions. They include requirements for installing rainwater retention/infiltration systems or green roofs, as well as vegetation barriers to buffer against the impacts of developments occurring adjacent to environmentally sensitive natural land (Duerksen et al., 1997). For green roofs, usually, there are rules defining the cases in which the requirement is applied, including the specific building types or minimum size, with large commercial buildings often identified as candidates (Carter & Fowler, 2008). These requirements can be applied to the whole city or just in limited zones identified in the city zoning scheme and related codes/ordinances (e.g., in Minneapolis, US), or can sometimes involve the exemption from other requirements (e.g., the use of green roofs exempts buildings from cool roof requirements in Chicago, US) (Carter & Fowler, 2008).

Compensation measures (R3) refer to ecological compensation through greening interventions, such as mandatory replanting of removed trees (Coria & Sterner, 2011). Compensations originate from the environmental impacts produced by new urban development/ redevelopment and can be applied on-site or off-site (Kravchenko, 2019). Ecological compensation may be associated with a wide range of NbS, from open space protection (Cortinovis & Geneletti, 2018), to the improvement of existing or creation of new green spaces such as green roofs, tree planting, and public green areas (Ngan, 2004), also through restoration interventions (e.g., restoring sealed areas to compensate for new soil sealing projects (e.g., Tobias, 2013)). Interventions can be implemented directly by the developers or, in some cases, a monetary compensation (a fee) can be paid to the competent authority that will use it to realize greening actions.

Examples of performance-based approaches (R4) include a variety of green area scoring and accounting systems used to set minimum requirements to be achieved through NbS. Such approaches are used to regulate urban development primarily by setting limitations on its impacts rather than on densities or uses (Cortinovis & Geneletti, 2020).

This grants to the developers a certain freedom of choice in the selection of green and blue elements – which are scored based on their ecosystem services provision – and in their location within the project area, as long as the minimum performance score is achieved (Juhola, 2018). In many cases, scores are also gained by preserving existing vegetation (e.g., Helsinki green factor (City of Helsinki Environment Centre, 2016)), protecting environmentally sensitive areas (e.g., Breckenridge and Boulder, US (Duerksen et al., 1997)), or greening adjacent public spaces (e.g., Seattle green factor (Roehr & Kong, 2010)). They can be mandatory everywhere in the city or just in some specific sites (Stange et al., 2022).

The definition of conservation zones or protected areas/sites (R5) can be applied to preserve open spaces from development and to protect valuable ecosystems. This instrument can be also applied to specific green areas and elements in public and private spaces including, among others, historic gardens and single heritage trees (Jim, 2017). Many cities and regional administrations around the world have enacted specific regulations to protect urban trees of outstanding value from development and bad management (see e.g., Government of South Australia, 2012). Even when approved outside the planning process, urban plans usually play a key role in enforcing such regulations, as well as in creating and updating the related inventories.

Finally, among the other instruments related to zoning regulations (R6), an example is the use of cluster zoning (also known as open space developments, cluster developments, and conservation subdivisions (Milder, 2007)) in new development projects. This instrument (which sometimes can be optional) provides flexibility for developers to construct buildings in clusters on smaller lots than would ordinarily be allowed while remaining within the maximum overall average density allowed by zoning, thus designating greater part of the site to be green open space that gains the conservation status (Duerksen et al., 1997; Milder, 2007). A similar approach has been used also as a voluntary tool in rural areas, with the aim of preserving farmland, environmentally sensitive areas, and open space areas in large parcels by clustering rural uses and activities affecting the open space character and ecological functions of the area (e.g., policy n. 8420 "Rural land-use subdivision" in the Land Use and Development Code of Summit County, USA (Summit County, 1995)). Another example involves the definition of permitted and forbidden uses and activities related to specific zones with the primary aim to safeguard and/or better manage undeveloped and environmentally sensitive spaces (Cortinovis & Geneletti, 2018; Duerksen et al., 1997), such as rural and natural areas. Special overlay zones (or districts) can be considered among this type of instruments, too. They are adopted to supplement, without replacing, the basic zoning regulations with superimposed additional regulations for all properties within the specially zoned area, for example to protect environmentally sensitive areas and designate strict(er) open space requirements (Duerksen et al., 1997), or to require mandatory (nature-based) measures to counteract specific problems (e.g., urban heat island (Bush & Hes, 2018)).

4.1.2. Design-based instruments and land acquisition programs

Still among command-and-control instruments are design-based instruments (D1) and land acquisition programs (L1) (Table 2). The former are applied in specific large development projects (with land subdivision) where the public administration wants to control action implementation with a quite high level of detail (Cortinovis & Geneletti, 2018), for instance by providing detailed design and dimensional parameters that may include specific greening interventions, open space requirements, and habitat protection. They are usually part of a development agreement between the public administration and the developers, and negotiated on a project by project basis (see e.g., Hanssen, 2012 and Oppio et al., 2019 for urban development agreements). Land acquisition programs concern the definition of a program by the public administration to acquire private land not – yet – developed, in order to realize a public project such as a public park (Lawrence et al., 2013) or to prevent urban development and maintain the area as natural as possible (Duerksen et al., 1997). Land acquisition can be mandatory (i.e., compulsory acquisition without the consent of the owner) or by negotiation (i.e., voluntary acquisition) (Sheenan & Brown, 2021).

4.1.3. Incentive-based instruments

Incentive-based instruments include seven different types of policy instruments that have been applied to promote NbS implementation (Table 3). Among preferential tax treatments (F1), an example is the "imperviousness fee". This fee aims to reduce the amount of rainwater reaching the sewage system by making property owners pay based on the property's actual imperviousness, which influences the amount of rainwater allowed to naturally infiltrate within the property rather than entering the public sewage system (Naumann et al., 2020). It may include a discount for the presence of stormwater source controls such as green roofs (Ngan, 2004). Preferential tax treatments can also be applied to new developments, taking the form of a reduction or waiving of the planning fees in exchange for NbS integration into the development project (Bush & Hes, 2018).

As concerns the provision of direct or indirect subsidies and grants (F2), some examples are given by the green roof subsidy programs targeting existing and new buildings adopted in various cities (e.g., Carter & Fowler, 2008). Similar programs are also implemented to promote other solutions (e.g., installing nature-based stormwater management measures, planting trees, and protecting natural areas (see Table 3)). Instead, cases of density bonuses (F3) relevant for NbS consist of allowing developers to increase the maximum permitted buildable area or volume on a property in exchange for public greening interventions for the community, such as parks and street trees, and the provision/preservation of open and green space in general (Morris, 2000). Density bonus regulations can also include green roofs as compensation for higher density (Ngan, 2004). In some cases, bonuses can be applied to

Table 2
Design-based instruments and land acquisition programs, with examples of real-world applications to promote NbS implementation (the full list of real-world applications and references is in Supplementary data).

Instrument type (code)	Description	Examples of real-world applications
Design-based instruments (D1)	Definition of specific design solutions and regulations to apply to a specific development area, which are formalized in a (master)plan that identifies the approximate location, typology, and size of the main elements over the entire project.	• Masterplan/detailed action plan indicating the location and typology of permitted building, infrastructure, and green/blue space development (e.g., Bradford, US (Willems et al., 2020)).
Land acquisition programs (L1)	The public administration (e.g., municipality) buys the land from the owners to prevent development or to realize public (green) projects (also called "fee simple" acquisition programs).	• Land acquisition for realizing urban parks or other public NbS (e.g., Krakow, Poland (Kwartnik-Pruc & Trembecka, 2021)). • Land acquisition for preserving from development, restoring, and protecting environmentally sensitive non-urbanized land (e.g., City of Boulder, US (Duerksen et al., 1997)).

Table 3
Incentive-based instruments, with examples of real-world applications to promote NbS implementation (the full list of real-world applications and references is in Supplementary data).

Instrument type (code)	Description	Examples real-world applications
Preferential tax treatments (F1)	Definition of tax incentives and fee reductions under certain property conditions or actions.	• Tax incentives (e.g., tax rebates, tax credits, tax allowances) for properties with green roofs or other NbS (e.g., New York, US (Neumann & Hack, 2019)). • Reduced permit (or building-construction-related) fees for developers including green roofs or other NbS (e.g., Chicago, US (Irga et al., 2017)). • Stormwater fee rebates relative to the share of impervious area or the presence of nature-based stormwater management measures (on buildings or on the ground) in the property (e.g., Minneapolis, US (Grant, 2018)).
Subsides/grants (F2)	Direct and indirect subsidies and grants as payment for the public benefits of private investments attached to private properties.	• Direct subsidies/grant programs for installing green roofs or other nature-based stormwater management measures (e.g., Seattle, US (Dhakal & Chevalier, 2017)). • Direct subsidies for planting trees in the private property (e.g., Philadelphia, US (Dhakal & Chevalier, 2017)). • Direct subsidies for nature-based watershed restoration activities (e.g., Portland, US (Dhakal & Chevalier, 2017)). • Grant payments to property owners that safeguard and manage their areas to maintain ecosystem services provision (e.g., water supply and purification), also known as Payment for Ecosystem Service (PES) schemes (e.g., Syracuse, US (Mercer et al., 2011 cited in Dhakal & Chevalier, 2017)). • Indirect subsidies (e.g., reduction of interest rates for loans demanded to finance new constructions) for developers/owners installing green roofs or other green spaces (e.g., several municipalities across the globe, especially in North America and Europe (Liberalesso et al., 2020)).
Density bonuses (F3)	Increase in the floor area/building volume allowed in the site in exchange for meeting certain criteria.	• Building volume, floor-to-area ratio, or height bonuses for green space provision (e.g., Melbourne, Australia (Bush & Hes, 2018)).
Transfer of development rights (TDR) mechanisms (F4)	Giving rights to build in another area or to sell the development rights in exchange for the preservation from development (through a conservation easement) of the original area.	• TDR programs for preserving natural/agricultural land from development (e.g., several municipalities in Italy (Cortinovis & Geneletti, 2018)). • TDR programs for realizing public projects integrating NbS (e.g., the High Line project in New York, US (Dyca et al., 2020)).
Purchase of development rights or development rights acquisition programs (F5)	Direct payment from public administration to the landowners to forgo land development rights, which are transferred to a public agency or organization. A conservation easement is recorded on the title of the property that limits development permanently.	• Purchase of development rights programs for preserving natural/agricultural land from development (e.g., Seattle, US (Duerksen et al., 1997)).
Conservation easements (F6)	Legal agreement placed on a piece of property to restrict the development, management, or use of the land. It involves the voluntary selling or gifting of one or more of rights (e.g., occupy, use, lease, sell, and develop the land, as well as harvest the vegetation and minerals on it) from the landowner to a public agency or organization.	• Works as the "purchase of development rights" instrument (but mainly targeting other rights associated with land management) (Duerksen et al., 1997).
Fast-tracking approval process (F7)	Fast-tracking of approvals (or expedited/agile permitting processes) for projects that incorporate greening interventions.	• Expediting the permitting process for projects incorporating urban greenery features in buildings and open spaces (e.g., Melbourne, Australia (Bush & Hes, 2018)).

specific zones of the city identified in the city land use zoning scheme and related codes/ordinances (e.g., in Chicago (Carter & Fowler, 2008)). Several examples of incentive-based instruments concern mechanisms for preventing development on and protecting private farmland and natural/seminatural areas by transferring or buying land development rights that are attached to such areas (i.e., "transfer of development rights" (F4) and "purchase of development rights" (F5)), or restricting the management or use of the land (i.e., "conservation easements" (F6)). While often voluntary, they can also be mandatory (Duerksen et al., 1997). These mechanisms are usually linked to the land use zoning scheme of the city (Droste et al., 2017). Exemplary cases on the use of such instruments are for implementing greening programs (e.g., city greenbelts (Bengston et al., 2004)), protecting wildlife habitats (Duerksen et al., 1997), or preserving non-urbanized land for flood risk management (e.g., Dyca et al., 2020; Löschner et al., 2021).

Finally, fast-tracking, expedited, or agile processes for approving projects and licensing building permits (F7), can be used as a non-financial incentive to stimulate NbS integration and open space provision in new urban developments (e.g., Bush & Hes, 2018).

4.1.4. *Information-based instruments*

Among the three types of information-based instruments identified (Table 4), examples of non-statutory guidelines and criteria targeting public and private areas (I1 and I2, respectively) can be found in several cities to encourage NbS integration (see Table 4). Concerning the "Other information-based instruments" (I3) we can mention the preparation of tree inventories and registers that can be used to support the identification of valuable species and significant trees (also known as heritage, notable, exceptional, or landmark tree registers (see Clark et al., 2020)) that deserve protection or to define suitable management practices, such as in Sweden where they are especially used by municipalities for managing existing trees and suggesting species selection in public and private spaces (Östberg et al., 2018). Another example is the promotion of (voluntary) green certification schemes that include the assessment of NbS integration in masterplans or in building construction projects (e.g., LEED, BREEAM, and 'Building with Nature' (Bowen et al., 2020; Xie et al., 2022)). Information-based instruments are usually not part of the urban plan's formal policy documents, but are explicitly used to supplement the urban plan's policies and regulations (Drumond et al., 2020) and can serve to raise citizens' (and developers') awareness on the importance of protecting and enhancing urban green spaces.

4.2. A matrix linking policy instruments to typologies of NbS interventions

The matrix summarizing the findings (Table 5) links policy instruments (columns) and typologies of NbS interventions (rows), and provides the references that led to the assignment of the suitability.

NbS in new development areas, including conservation of existing and implementation of new (private) green spaces, can be promoted through most of the command-and-control (regulatory, design-based, land acquisition) instruments, and – to a lesser extent – incentive-based instruments, including both economic (e.g., subsidies) and non-economic incentives (e.g., fast-tracking approval process). NbS for improving the greenery of existing built-up areas (including buildings) can be almost exclusively promoted using incentive-based instruments (e.g., preferential tax treatments). For NbS aimed at protecting non-urbanized areas, command and control (regulatory, land acquisition) and incentive-based instruments targeting property rights (e.g., transfer of development rights) can be applied, while for improving and/or promoting sustainable management of rural and natural areas a few regulations (e.g., based on allowed uses related to zoning or compensation mechanisms) and incentives (e.g., direct subsidies and fast-tracking approval process) can be used. Finally, the creation of new public green areas can be promoted through regulations and incentives that force or incentivize private developers to deliver public green spaces alongside their private developments, or through instruments that allow the public administration to directly realize the planned green spaces (i.e., land acquisition programs).

5. Discussion

5.1. Policy instruments to mainstream and scale up NbS

The synthesis provided by the matrix shows that each typology of NbS corresponds to more than one possible instrument. This is especially important considering that a mix of different policy instruments is deemed necessary for the long-term stability and scaling up of NbS projects (Kabisch et al., 2017), as well as for advancing policy shift from grey to green (Johns et al., 2018). Integrating different instruments for NbS implementation, some of which typically used in other sectors (e.g., incentives), alongside more traditional regulatory instruments allows promoting different typologies of NbS interventions and targeting different areas and potential developers or investors. An effective mainstreaming of NbS in urban plans should therefore adopt a mix, or portfolio, of policy instruments with interactive effects – complementary or supplementary – among them (Capano & Howlett, 2020). Several authors argue that a mix of different categories of instruments (i.e., regulations, incentives, and information instruments) would more likely promote larger and more effective outcomes (e.g., van der Jagt et al., 2023). For instance, incentives alone may not be a game changer (e.g., Zabel & Häusler, 2024) and the citizens' voluntary participation in their use is difficult to predict (Wang & Chan, 2019). Regulations alone may instead hinder options to retrofit existing development (e.g., Malinowski et al., 2020) given the impossibility of enforcing interventions retrospectively (Zuniga-Teran et al., 2019). Others point out the need for municipalities to (also) draw on a range of other financial instruments (i.e., not covered in this study since not properly enforced through urban plan's policies) to find alternative revenue sources to finance NbS, such as stormwater credit trading and green bonds to fill existing gaps in funding (e.g., Cousins & Hill, 2021). However, the choice of the policy instrument mix to adopt may also depend on specific contextual conditions, such as the financial resources available, with incentives based on tax and fee rebates that may be enforced without additional budget (Zabel & Häusler, 2024). To this aim, a close collaboration with other responsible actors may be required (e.g., urban drainage utility company (Naumann et al., 2020)).

Possible combinations of policy instruments may involve instruments of the same category, such as the definition of density bonuses within transfer of development rights programs (both incentive-based) (Linkous, 2016), or from different categories. Regulatory instruments, for example, can be combined with incentives to make them more effective, such as exempting targets from other regulations if specific performance criteria are met (Henstra, 2016). A practical example comes from Toronto, where besides the mandatory requirement of a certain share of on-site stormwater retention for all new development applications, a higher level of performance can be voluntarily achieved allowing access to a financial incentive (Johns et al., 2018). Information-based instruments can promote or push innovation supporting the development of knowledge and building broader community support, but can also be used to reinforce regulations (e.g., targets and standards) (Bush & Hes, 2018). For example, a list of nature-based actions that can be implemented to achieve minimum scores or standards set by regulatory instruments could be provided by the municipality to support developers in integrating suitable solutions into their projects (Cortinovis & Geneletti, 2018). They can also be used to encourage people to take advantage of incentive-based instruments or to explain the rationale for authoritative regulations (Henstra, 2016). Although all these possible combinations are not explicitly included in our matrix, the list of suitable policy instruments that can be used for each specific typology of NbS provides the basis for formulating combinations of

Table 4
Information-based instruments, with examples of real-world applications to promote NbS implementation (the full list of real-world applications and references is in Supplementary data).

Instrument type (code)	Description	Examples of real-world applications
Guidelines and criteria for public space design and management (I1)	Guidance documents providing design guidelines and/or criteria that should be applied when realizing and/or managing public spaces.	• Definition of stormwater performance standards to apply in sidewalk/road space construction (e.g., New York, US (Neumann & Hack, 2019)). • Guidelines for designing public parks (e.g., Gold Coast City, Australia (City of Gold Coast, 2018)). • Definition of design principles and guidelines for realizing and greening public spaces (e.g., several municipalities in Italy (Cortinovis & Geneletti, 2018)).
Guidelines for promoting good practices in private spaces (I2)	Guidance documents and manuals providing information on (nature-based) principles, best practices, and techniques to apply in private areas.	• Guidance documents and manuals on the design, installation, and maintenance of multiple NbS techniques/practices (e.g., Adelaide, Australia (Irga et al., 2017)).
Other information-based instruments (I3)	Other instruments aimed at supporting green space planning activities by providing relevant information, knowledge, and monitoring tools.	• Inventories/registers of significant trees (e.g., several municipalities in Sweden (Östberg et al., 2018)). • Green certification schemes granted by the municipality to certify NbS integration in masterplans or in building construction projects (e.g., local green certification schemes developed in Rio de Janeiro, Brazil (Liberalesso et al., 2020)). • Definition of (ecologically-oriented) assessment criteria for proposed interventions (e.g., several municipalities in Italy (Cortinovis & Geneletti, 2018)).

Table 5
Matrix linking suitable policy instruments (marked with ✓) to promote the implementation of different typologies of NbS interventions in urban plans (codes are described in Tables 1 to 4) with the references relative to the real-world applications.

	Typologies of NbS interventions	Policy instrument types																	
		R1	R2	R3	R4	R5	R6	D1	L1	F1	F2	F3	F4	F5	F6	F7	I1	I2	I3
TYPE 1	Conserving green elements and open spaces in new development areas	✓[1]		✓[4]	✓[12]	✓[15]	✓[17]	✓[21]				✓[36]				✓[43]			✓[52]
	Protecting non-urbanized land (agricultural, natural, seminatural, and urban green spaces)			✓[5]		✓[16]	✓[18]		✓[25]	✓[28]			✓[39]	✓[41]	✓[42]				✓[53]
TYPE 2	Improving existing greenery in private open spaces			✓[6]						✓[29]	✓[32]							✓[48]	✓[54]
	Improving existing public green areas			✓[7]													✓[46]		✓[55]
	Ensuring sustainable management and multifunctionality of rural and natural areas			✓[8]			✓[19]		✓[26]		✓[33]							✓[49]	✓[56]
TYPE 3	Greening existing buildings			✓[9]						✓[30]	✓[34]							✓[50]	✓[57]
	Ensuring the integration of private greenery in new development projects	✓[2]	✓[3]	✓[10]	✓[13]		✓[20]	✓[23]		✓[31]	✓[35]	✓[37]				✓[44]		✓[51]	✓[58]
	Creating new public greenery and green areas			✓[11]	✓[14*]			✓[24]	✓[27]			✓[38]	✓[40]			✓[45]	✓[47]		✓[59]

[1]Zhang et al., 2009; Cortinovis & Geneletti, 2018. [2]Zhang et al., 2009; Cortinovis & Geneletti, 2018; Johns et al., 2018; Dhakal & Chevalier, 2017. [3]Anderson & Gough, 2022; Irga et al., 2017; Carter & Fowler, 2008; Dhakal & Chevalier, 2017; European Commission, 2011; Liberalesso et al., 2020; Brudermann & Sangkakool, 2017, Berardi et al., 2014, and Chen, 2013 cited in Zeadat, 2021; Clar & Steurer, 2021; Mees et al., 2014, Lawlor et al., 2006, and Snow, 2016 cited in Clar & Steurer, 2021; Bathgate et al., 2020; Burszta-Adamiak & Fialkiewicz, 2019; Castro & Carvalho, 2023; Ngan, 2004; Neumann & Hack, 2019; Nickel et al., 2013; Naumann et al., 2020; Furlong et al., 2018; Zhang et al., 2009; Cortinovis & Geneletti, 2018; Bush & Hes, 2018. [4]Bush & Hes, 2018; Cortinovis & Geneletti, 2018. [5]Cousins & Hill, 2021. [6]Ngan, 2004 (in the case of building expansion projects with on-site compensation). [7]Bush & Hes, 2018; Ordóñez-Barona et al., 2021; Bathgate et al., 2020; Hansen et al., 2019; Cortinovis & Geneletti, 2018 (in the case the municipality uses the collected compensation fees to improve existing public green areas); Ngan, 2004 (in the case of off-site compensation directed to improve existing public green areas). [8]Cousins & Hill, 2021. [9]Ngan, 2004 (in the case of building expansion projects with on-site compensation). [10]Ngan, 2004 (in the case of new building projects with on-site compensation). [11]Bush & Hes, 2018; Ordóñez-Barona et al., 2021; Bathgate et al., 2020; Hansen et al., 2019; Cortinovis & Geneletti, 2018 (in the case the municipality uses the collected compensation fees to create new public green areas); Ngan, 2004 (in the case of off-site compensation directed to create new public green areas). [12–14]Stange et al., 2022; Kronenberg et al., 2021; Ordóñez-Barona et al., 2021; Carter & Fowler, 2008; Nickel et al., 2013; Burszta-Adamiak & Fialkiewicz, 2019; Castro & Carvalho, 2023; Ngan, 2004; Duerksen et al., 1997. [15]Ordóñez-Barona et al., 2021; Schmied & Pillmann, 2003; Clark et al., 2020; Bush & Hes, 2018; Duerksen et al., 1997. [16]Cortinovis & Geneletti, 2018; Fischer et al., 2013; Livingstone et al., 2018 and Donaldson et al., 2016 cited in Slätmo et al., 2021; Ordóñez-Barona et al., 2021; Schmied & Pillmann, 2003; Clark et al., 2020; Bush & Hes, 2018; Duerksen et al., 1997. [17]Milder & Clark, 2011; Milder, 2007; Ordóñez-Barona et al., 2021. [18]Duerksen et al., 1997. [19]Cortinovis & Geneletti, 2018. [20]Bush & Hes, 2018. [21–23]Willems et al., 2020; Cortinovis & Geneletti, 2018. [25, 26]Pienaar et al., 2019; Duerksen et al., 1997. [27]Kwartnik-Pruc & Trembecka, 2021; Cortinovis & Geneletti, 2018. [28]Ordóñez-Barona et al., 2021. [29, 30]Malinowski et al., 2020 cited in Zabel & Häusler, 2024; Dhakal & Chevalier, 2017; Bush & Hes, 2018; European Commission, 2011; Carter & Fowler, 2008; Nickel et al., 2013; Bathgate et al., 2020; Grant, 2018; Burszta-Adamiak & Fialkiewicz, 2019; Castro & Carvalho, 2023; Ngan, 2004; Irga et al., 2017; Neumann & Hack, 2019; Liberalesso et al., 2020; Clar & Steurer, 2021. [31]Irga et al., 2017; Bush & Hes, 2018; Cortinovis & Geneletti, 2018; Castro & Carvalho, 2023. [32]Dhakal & Chevalier, 2017. [33]Dhakal & Chevalier, 2017; Mercer et al., 2011 cited in Dhakal & Chevalier, 2017. [34]Anderson & Gough, 2022; Neumann & Hack, 2019; Irga et al., 2017; Dhakal & Chevalier, 2017; European Commission, 2011; Carter & Fowler, 2008; Tayouga & Gagné, 2016 cited in Zuniga-Teran et al., 2019; Brudermann & Sangkakool, 2017, Berardi et al., 2014, Getter & Rowe, 2006, Kohler & Keeley, 2005, and Brenneisen, 2002 cited in Zeadat, 2021; Clar & Steurer, 2021; Mees et al., 2014 cited in Clar & Steurer, 2021; Nickel et al., 2013; Bathgate et al., 2020; Grant, 2018; Burszta-Adamiak & Fialkiewicz, 2019; Castro & Carvalho, 2023; Ngan, 2004; Landskron, 1998 cited in Ngan, 2004. [35]Liberalesso et al., 2020. [36]Morris, 2000. [37]Cortinovis & Geneletti, 2018. [38]Irga et al., 2017; Dhakal & Chevalier, 2017; Carter & Fowler, 2008; Grant, 2018; Castro & Carvalho, 2023; Liberalesso et al., 2020; Bush & Hes, 2018. Morris, 2000. [39]Pruetz, 2016 cited in Dyca et al., 2020; Cortinovis & Geneletti, 2018. [40]Dyca et al., 2020. [41, 42]Duerksen et al., 1997. [43]Dhakal & Chevalier, 2017; Bush & Hes, 2018. [44]Dhakal & Chevalier, 2017; Bush & Hes, 2018; Liberalesso et al., 2020. [45]Dhakal & Chevalier, 2017; Bush & Hes, 2018. [46, 47]Neumann & Hack, 2019; City of Gold Coast, 2018; Cortinovis & Geneletti, 2018. [48]Dhakal & Chevalier, 2017; Nickel et al., 2013; Cortinovis & Geneletti, 2018. [49]Cortinovis & Geneletti, 2018. [50]Anderson & Gough, 2022; Irga et al., 2017; Bathgate et al., 2020; Contreras & Castillo, 2015; Cortinovis & Geneletti, 2018. [51]Dhakal & Chevalier, 2017; Nickel et al., 2013; Anderson & Gough, 2022; Irga et al., 2017; Bathgate et al., 2020; Contreras & Castillo, 2015; Cortinovis & Geneletti, 2018. [52, 53]Ordóñez-Barona et al., 2021; Östberg et al., 2018; Clark et al., 2020; Duerksen et al., 1997. [54]Liberalesso et al., 2020. [55, 56]Cortinovis & Geneletti, 2018. [57]Liberalesso et al., 2020. [58]Liberalesso et al., 2020; Cortinovis & Geneletti, 2018. [59]Cortinovis & Geneletti, 2018.

*According to the possibility given by some municipalities of achieving points through greening adjacent public spaces (e.g., in the scoresheet of Seattle green factor it is stated: "You may count landscape improvements in rights-of-way contiguous with the parcel. All landscaping on private and public property must comply with the Landscape Standards Director's Rule (DR XX-2020)". See also: https://www.seattle.gov/sdci/codes/codes-we-enforce-(a-z)/seattle-green-factor).

instruments that can be possibly deployed in each specific decision context.

With our work, we aimed to partly responding to the knowledge needs and gaps related to the design of NbS implementation processes and their institutional embedding and operationalisation, especially concerning the direct inclusion of NbS approaches into urban plans (Frantzeskaki et al., 2020). By providing locally adaptable policy implementation options to support NbS scaling up, the matrix can contribute to more systematic incorporation and promotion of NbS into urban governance instruments, policies, and regulations. In this regard, it should be noted that the study focused on substantive policy instruments, namely those affecting the delivery of policy goals, rather than procedural instruments, which instead support the process and procedures of policy formulation (Howlett, 2000; Stead, 2021). The latter are equally important for the successful mainstreaming of NbS in planning policies (Frantzeskaki et al., 2020).

Despite a match in the matrix reveals that, from the mere technical point of view, the instrument has been already applied somewhere to promote that specific NbS intervention, this does not guarantee that the example can be smoothly replicated elsewhere. Several factors can hamper or invalidate the practical usage of a policy instrument in a specific context. This may happen in the case of conflicts with or barriers created by other policies/regulations. For example, Dhakal and Chevalier (2017) found that several regulations constitute a barrier to the implementation/effectiveness of NbS, such as the fact that some city codes do not allow off-site ecological compensation (thus preventing NbS implementation when it is technically or financially unfeasible on-site). Another example concerns stormwater management, which was explicitly mentioned as the primary challenge that cities seek to address with NbS in many of the applications reviewed. It is often the case that building regulations prohibit the installation of pervious materials on streets, sidewalks, parking lots, driveways, and other surfaces; or do impose the installation of curbs that prevent surface runoff to flow from roads into adjacent vegetated areas. For this reason, in parallel with the adoption of policy instruments for promoting NbS implementation, cities should act to remove or amend policy barriers to NbS provisions (Hostetler et al., 2011).

Another important aspect worth mentioning is the quality of NbS interventions. Despite being technically suitable to promote NbS, some policy instruments may not be sufficient to ensure high-quality NbS interventions that provide the desired benefits. For example, only prescribing the share of green areas that should be maintained in different zones without providing further details on qualitative aspects of green spaces (e.g., vegetation type, accessibility, etc.) could result in regulations with limited capacity to capture the multiple qualities and benefits of different types of NbS (Cortinovis & Geneletti, 2020; Ronchi et al., 2020). As stated by Contesse et al. (2018), housing developments must comply with green space requirements, but a strip in the middle of the street can count as a green space, which provides very different ecological functions, ecosystem services, and benefits than a densely vegetated area or a green space where children can play. Indeed, many regulations risk leading to a pattern of "routinization" (Capano & Lippi, 2017) in planning, where most of the greening interventions are conceived as a "toll" to be paid by developers rather than a proactive strategy to address societal challenges (Ronchi et al., 2020), thus ultimately limiting the options to effectively integrate NbS in everyday planning decisions. Finally, among the main challenges of NbS is the aspect of maintenance (e.g., costs and responsibilities for the long-term management of vegetation and NbS components) (e.g., Wright et al., 2022), which may be a challenging task since strongly associated with NbS performance over time (DelGrosso et al., 2019). Among the real-world applications we reviewed, this theme is not extensively covered, even if we found some cases of information-based instruments in which the provision of NbS maintenance guidelines was explicitly mentioned. Only in one other case we found that a regulatory instrument (i.e., Seattle green factor) also requires that a Landscape Management Plan is prepared to ensure that the NbS established in the project area are well managed and continue to function over time, thus possibly working as a best practice in this field (see also: https://web.seattle.gov/DPD/DirRulesViewer/Rule.aspx?id=11-2020).

5.2. Discussing the results against a real case study

The matrix proposed in this study (Table 5) can help practitioners and policy-makers to identify the range of suitable policy instruments that can be deployed to promote NbS implementation in urban plans. Besides suggesting options for new policy development, it can be a useful tool to analyse existing policies and reveal what instruments (among the available and suitable ones) are not considered in specific contexts, as in Heurkens et al. (2018). To illustrate the potential of the matrix to reveal gaps in current practices and identify opportunities to promote NbS, we applied it to review a real case study. We selected two spatial plans that cover the urban area around Valletta, the capital city of Malta (see Longato et al., 2022 for a map and detailed description of the area; Balzan et al., 2020, 2021 for the main socio-environmental challenges; Longato et al., 2023 for an analysis of NbS needs): the North Harbours Local Plan (Malta Environment and Planning Authority, 2006) and the Grand Harbour Local Plan (Malta Environment and Planning Authority, 2002).

In Malta, local plans regulate land uses and functions through zoning and related indexes and parameters, define standards to which development must conform, and indicate where development can take place or land protection is instead enforced, the type of development, and the criteria against which development proposals are to be assessed (Fomosa & Gauci, 2021; Government of Malta, 2016). They are therefore comparable to (comprehensive) urban plans used in other planning contexts (e.g., OECD, 2017) and can be considered the most appropriate planning instrument and decision-making context to pursue NbS mainstreaming in urban areas (e.g., Bush & Doyon, 2019; Cortinovis & Geneletti, 2019).

From the review of the two plans, we identified 56 policies that promote 69 NbS interventions through 71 specific instruments (in Supplementary data, see Table S1 for a list of policy instrument application examples found in the two plans and Tables S2 and S3 for the full list of policies identified and classified). Many NbS interventions target public spaces and focus on creating new green areas (29 %) or improving existing ones (28 %). No policy addresses the greening of existing buildings.

Among the 18 typologies of policy instruments identified in Tables 1 to 4, only 8 are adopted in the two plans (Table 6). Information-based instruments are the most common category (62 %), followed by regulatory and design-based (25 % and 11 %, respectively). This is in line with the systematic review of Kirsop-Taylor et al. (2022), who found that information-based is by far the most widely utilized policy instrument typology for pursuing NbS experimentation in European cities. No incentive-based instruments and land acquisition programs were recorded. The definition of guidelines and criteria for public space design and management is the most widespread instrument, e.g., providing details on the design of tree lines and other landscaping elements to introduce in selected streets and public spaces. Regulations mostly concern the definition of quantitative targets or standards (e.g., the minimum share of a development site to retain as open space) and the designation of conservation zones or protected areas and sites (Table 3).

The analysis reveals several options of policy instruments to promote NbS implementation overlooked by the plans. First, the complete lack of incentive-based instruments stands out from the results and can probably be explained by the higher level of uncertainty associated with this category of instruments compared to regulatory and design-based instruments. However, while the applicability of the latter is mostly limited to areas undergoing urban development or redevelopment, and their effectiveness may be hampered by ineffective monitoring and enforcement by the responsible authorities (Steinebach, 2019), voluntary incentive-based instruments can be directed to areas where NbS implementation cannot be promoted otherwise, such as private green spaces (Dhakal & Chevalier, 2017). Existing residential areas cover most of the city's built-up areas and are recognized as being difficult for governments to manage (Lin et al., 2015). In a high-density urban area with a high presence of fragmented private landownership, such as in Valletta urban area, instruments that promote NbS implementation in existing private spaces through economic incentives and fee charges would be very important to stimulate private property owners to pursue alternative interventions than those that offer them the best value for money (Droste et al., 2017), investing in interventions that provide more benefits to the community.

If this finding about the lack of incentive-based instruments were valid for most urban plans beyond the specific case study, and this may be particularly relevant in some contexts (e.g., Cortinovis and Geneletti (2018) for several urban plans in Italy) and less in others (e.g., the many application examples found in the US and Germany; see Section 4.1), there would be a risk for NbS to be implemented mostly in combination with new developments, either on greenfield or brownfield sites. This would leave behind large portions of urban areas, especially high-density ones where the opportunities for interventions on public spaces are also scarce. Such areas are the most vulnerable to several environmental and social issues that NbS can contribute to address, from climate-related impacts (e.g., urban heat island (Longato & Maragno, 2024)) to environmental (in)justice aspects (e.g., Balzan et al., 2022; Kato-Huerta & Geneletti, 2023), hence in a sense the most in need of NbS implementation. Overlooking policy instruments that can support NbS implementation in these areas would therefore undermine the impacts of NbS scaling up and likely promote or strengthen existing inequalities in access to green and benefit from ecosystem services (Cousins, 2021). To this regard, high attention should be paid to avoid that this approach leads to exacerbating economic inequalities, with wealthier population groups benefitting more from such schemes and potentially leading to further gentrification (e.g., Anguelovski & Corbera, 2023; Camerin & Longato, 2024).

Another missing opportunity in the analysed plans is the lack of instruments that promote the integration of NbS at the building scale. This emerges even for new development projects, which could integrate greening elements during the planning process more easily (e.g., through specific regulations, thus paid off by private developers) compared to existing built-up areas that require retrofitting interventions (e.g., through economic incentives provided by the public). This finding is in line with what discussed by Pearlmutter et al. (2020), who found very little prioritization of policies promoting design strategies that involve the greening of built surfaces. Similarly, the analysis of NbS integration in urban policies in Poznan (Poland) revealed building green as one of the opportunities not yet explored (Zwierzchowska et al., 2019).

The lack of incentive-based and building-related instruments promoting NbS in local plans might be compensated by other policies. This is partly the case also in the area of Valletta, where more recent schemes at regional and national scale (e.g., the Local Action Groups under the LEADER Program of the Rural Development Program 2014–2020, the Development Planning funds, and the BELLUS call issued under the Environment Fund) have provided subsidies for NbS implementation on private buildings and spaces, and supported the establishment of NbS in public buildings. The use of instruments outside of the planning domain for promoting NbS (often applied in a limited period) is not new, such as in the case of a tender implemented in Ohio, US to support retrofit stormwater retention measures on private properties (Zabel & Häusler, 2024). However, integrating policies and policy instruments for NbS implementation in a more systematic way into the local urban plans could be beneficial to enhance their coordinated implementation and scaling up, including a prioritization of interventions to address the specific socio-environmental challenges and sustainability goals of the plan.

5.3. Limitations of the study

Our study is mainly based on information provided by the literature that still is in its infancy regarding the topic of NbS implementation. However, our search was not limited to NbS as a keyword, and to policy instruments used exclusively in urban plans: it included other concepts (e.g., green infrastructure, ecosystem services, and green spaces in general, among others) and relevant fields of application (e.g., sectoral policies, such as stormwater management). Considering that most of our references rely on reviews and analyses of real-life policies and applications, the list of policy instruments that we identified reflects the ones most frequently used in real-life practices. However, we might have missed instruments (or variations of them) that are not extensively adopted or studied, especially in non-Western countries, considering that most of the applications we found pertain to cities located in North-America (US and Canada), Europe, and Australia. Only a few applications were found in countries in Asia and in the Global South (i.e., China, South Korea, Hong Kong, Singapore, Japan, India, Brazil, South Africa, and Mexico) (see Supplementary data for the detailed list of cities/countries). This prevalence of applications in Western countries is also confirmed by other recent reviews of policy instruments for green infrastructure (e.g., Liberalesso et al., 2020; Zabel & Häusler, 2024). Further research involving practitioners (e.g., through interviews, workshops, etc.) who are experienced in the use and formulation of policy instruments can be useful to expand the list of instruments and verify their contexts of application, as well as to understand the extent to which the findings of the case study can be generalized.

Finally, the possibility to use instruments in each NbS case is assigned based on a binary choice (yes/no). This might not fully represent the complexity faced by users in reality, thus resulting in an oversimplification of the decisions. For example, the use of certain instruments may be restricted by other rules/policies (e.g., the use of specific regulations only in areas larger than a given size or with specific land use), or by “hybrid” situations concerning the land tenure of the target areas (e.g., semi-private or semi-public areas, private areas with

Table 6
Number of policies promoting NbS identified in the two local plans of Malta, classified according to the typologies of NbS interventions and policy instruments used to promote their implementation, among the suitable ones (all shaded cells).

	Typologies of NbS interventions	Policy instrument types							
		R1	R2	R3	R5	D1	I1	I2	I3
TYPE 1	Conserving green elements and open spaces in new development areas	1		0	2	2			1
	Protecting non-urbanized land (agricultural, natural, seminatural, and urban green spaces)			0	6				0
TYPE 2	Improving existing greenery in private open spaces			0				4	0
	Improving existing public green areas			0			18		1
	Ensuring sustainable management and multifunctionality of rural and natural areas			0				0	2
TYPE 3	Greening existing buildings			0				0	0
	Ensuring the integration of private greenery in new development projects	5	1	1		2		0	3
	Creating new public greenery and green areas			1		4	13		2

public use, etc.). While the restrictions coming from other rules/policies can be addressed solely by complementing the matrix with such information, further research to improve our work should focus on addressing the complexity of "hybrid" land tenure situations, as well as on depicting the possible combinations of instruments among the available options.

6. Conclusions

Recent studies have highlighted the lack of suitable, locally adapted policy instruments to promote NbS implementation (Naumann et al., 2020). Identifying policy levers that can support the integration of NbS in urban plans has been defined as a priority knowledge need for NbS mainstreaming (Grace et al., 2021). This is even more relevant in light of their attitude and flexibility to be potentially supported by multiple revenue sources other than general revenue funds, which still is an unexpressed potential (Dhakal & Chevalier, 2017). In this paper, we reviewed real-world policy instrument applications and proposed a matrix to guide the identification and selection of suitable instruments that can be used in urban plans to promote the implementation of different types of NbS interventions. Planning has long recognized the importance of green spaces for cities and their inhabitants, but policies that incorporate NbS are rather recent additions to public policy suites (Bush & Doyon, 2019). As such, city plans, especially those approved some time ago, often overlook the potential positive impacts of greening interventions and the available policy options to ensure their implementation at scale, as also revealed in the case of the two urban plans of Malta.

With our matrix, we provide practitioners with the knowledge base to widen the (policy) options for promoting NbS implementation. Different instruments can be applied to promote each typology of NbS interventions. This variety makes it possible to identify the most suitable options for implementing NbS in different contexts, as well as to diversify and combine more instruments to better secure the scaling up of NbS, which represents one of the ambitions of European policies, among others (e.g., European Environmental Agency, 2021). To this aim, urban plans have a fundamental role in pushing policy innovation towards NbS mainstreaming and scaling up in cities. Future lines of investigation should focus on co-developing instruments with practitioners and decision-makers, monitoring their application to different city areas and typologies of NbS interventions, and assessing their effectiveness in delivering high-performing NbS, as well as on barriers and constraints as reported by the involved stakeholders.

CRediT authorship contribution statement

Davide Longato: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Chiara Cortinovis:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization. **Mario Balzan:** Writing – review & editing, Validation, Investigation. **Davide Geneletti:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization.

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.

Acknowledgments

This publication is based on work partially supported by the Renature project (European Union's Horizon 2020 research and innovation programme, grant no. 809988). CC and DG acknowledge support from the Alexander von Humboldt Foundation.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2024.105348.

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