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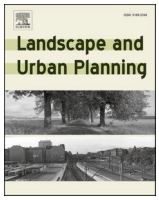

Review Article

# Policy instruments for green infrastructure

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## HIGHLIGHTS

- First comprehensive review of policy instruments for green infrastructure.
- Disentangling the literature reveals that policy instruments differ by spatial allocation needs.
- Price-type instruments used for GI without connectivity requirements.
- Procedural instruments used for contiguous but spread allocation of sites.

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## ABSTRACT

Developing a green infrastructure is a major environmental policy ambition in many countries around the world. However, green infrastructure objectives can vary, especially in terms of requirements on the spatial allocation of conservation sites. In this paper, we investigate which policy instruments are being used to pursue green infrastructure objectives with differing spatial needs. We do this by reviewing a set of 127 papers. Our findings suggest that price-type instruments are often used for green infrastructure objectives that have no particular requirements on the spatial allocation of conservation sites. Procedural instruments are commonly applied when the aim is to build a green infrastructure with a contiguous but spread allocation of sites. While spatial planning and the development of financing strategies were commonly mentioned for green infrastructure with high connectivity requirements, we were surprised to find little use of incentive mechanisms that internalize the benefit of clustering and pass it on to landowners. We suggest that such incentive mechanisms are underutilized and call for more pilots and case study work, for example on agglomeration bonus and threshold payments for green infrastructure development. We further call for more research on green infrastructure policies in the global South.

## 1. Introduction

Establishing a green infrastructure (GI) is a major environmental ambition in many regions of the world. However, what is meant by GI and which policy instruments are applicable can vary widely between jurisdictions. For example, in the USA, green infrastructure is mostly referred to in the context of stormwater runoff management and in Canada the emphasis of national GI investments is on climate change mitigation and adaptation, as well as environmental quality improvements especially related to water (Government of Canada, 2018). In 2013, a communication by the European Commission stated that the Natura2000 sites form the backbone of GI (European Commission, 2003), thus emphasizing GI as a strategy for biodiversity conservation. The EU Biodiversity Strategy for 2030 mentions GI mostly in the context of urban ecosystems and highlights the need to bring nature back into peoples' lives (European Commission, 2020).

GI definitions and policy recommendations in the academic literature are similarly diverse. The fuzziness of the literature complicates communication within the scientific community as well as dialogues at the science-policy interface (Chenoweth et al., 2018; Sussams et al., 2015). In this context, it is little surprising that a structured review of policy instruments in support of GI is still lacking. Open questions remain on which policy instruments are commendable for which type of GI and which constraints have been encountered during the implementation of GI. We argue that the complexity of the literature can be reduced by looking at the GI's needs in terms of the spatial allocation of

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conservation sites. Furthermore, the large body of case studies on GI bears a still unexploited potential to synthesize and learn how different policy instruments can foster green infrastructure in complex landscape settings.

Our contribution builds on previous attempts to structure the GI literature (Ying et al., 2022; Chatzimentor et al., 2020; Monteiro et al., 2020; Wang and Banzhaf, 2018; Koc et al., 2017), GI objectives (Pauleit et al., 2019; Honeck et al., 2020) and spatial arrangements (Davies et al., 2016). In this contribution, we differentiate between three GI types: (i) GI that generate local benefits on-site irrespective of a site's spatial allocation *vis-à-vis* other sites, (ii) GI for which connectivity between sites is essential, and (iii) GI that try to strike a balance between the first two. The latter can be understood as a network that branches out to provide benefits in many places of the landscape while maintaining some connectivity between sites. We hypothesize that the different spatial allocation needs of our three GI types are reflected in the policy instruments presented in case studies from around the world. To investigate our hypotheses, we conduct a broad literature review of case studies on GI. It allows us to derive findings on types of policy instruments already used for different GI objectives, policy instruments that bear potential but haven't been tested yet in the context of GI, as well as factors that constrained the instruments' deployment.

## 2. Three types of spatial allocation needs

As mentioned above, we distinguish between three GI types and argue that different policy instruments are best suited for each of them. For the first GI type, the total amount of conserved area matters, while the location of the conserved plots vis-à-vis each other is irrelevant. In other words, there is no connectivity requirement. For example, the ambition may be to implement stormwater retention measures such as rain gardens. In a given program area, the total rain garden surface matters, but juxtaposition of the rain gardens does not add value. For this first type, we hypothesize that efficiency is a major criterion for the choice of policy instrument. Landowners may have very heterogenous opportunity cost structures and growth objectives. Policy makers thus may wish to create incentives for more GI, while leaving it to the landowners to individually decide how to react to the incentive and where to concede space to the GI. Price-type instruments can be suitable for this purpose, such as taxes or fees on factors constraining the GI or subsidies for factors fostering the GI. If the administration wants to actively select the sites with the best benefit-to-cost ratio, a reversed auction is a policy instrument that can help make this selection, especially when there is asymmetric information on the land owners' true opportunity costs (Boxall et al., 2017).

The second GI type has high requirements on connectivity between the sites. For example biodiversity conservation often calls for clustered sites. Clustering of conservation sites countervails habitat loss and fragmentation which are key drivers of biodiversity decline (Haddad et al., 2015; IPBES, 2019). For the second type of GI, we expect that the administration integrates the added value of having neighboring conservation sites into the policy. This can for example be achieved through an agglomeration bonus, which provides land owners with individual incentives to offer contiguous sites for conservation (Parkhurst et al., 2002; Nguyen et al., 2022). Alternatively, there may be forms of threshold payments that are issued only if a threshold constraint is met (Nguyen et al., 2022). Such a threshold could, for example, be defined as a contiguous cluster of conservation sites of a certain size. The incentive for meeting the threshold can be offered as a bonus on top of a fixed payment or as an all-or-nothing payment (Nguyen et al., 2022).

The third GI type seeks to achieve a network that is spread as much as possible across the landscape, while remaining connected to some extent. Such a network can, for example, contribute to species conservation by improving the permeability of the landscape while providing ecosystem services and bringing nature back into peoples' lives. However, the relationship between biodiversity conservation and ecosystem service provision is often ambiguous and depends on the values assigned to the two goals (Jax and Heink, 2015). For this third type of GI, we thus argue that there is need for a societal debate on the underlying values, how to deal with potential trade-offs, and how to find a balance between the clustering and spreading of sites. Our hypothesis is thus that policy makers will organize deliberative processes to answer these questions and will then design incentive policies to implement the GI.

## 3. Method

### 3.1. Selection of search terms

To investigate our hypotheses, we conducted a literature review on policy instruments for the three GI types. We structured the search terms for the literature review along the lines of Sterner and Robinson's (2018) classification of major policy instrument groups (see left column of Table 1) but created separate categories for instruments to modify behavioral norms and procedural instruments (Bali et al., 2021).The right column of Table 1 lists the search term(s) that we used for each of the policy instrument groups. To cast the net wide and capture papers that these specific search terms did not pick up, we also searched for three broad terms: policy program, policy instrument, and policy incentive.

Regulations prescribe or ban certain activities, technologies or substances. They may apply generally in an entire jurisdiction or, for example in the case of zoning, to a spatially explicit area. From an efficiency perspective, regulations are considered rather clumsy because they fail to exploit the heterogeneity in land owners' marginal costs (Sterner and Robinson, 2018).

Price-type instruments create incentives through changes to prices. For example, environmentally motivated taxes and subsidies function as price signals through existing markets with the purpose of reducing the use of something that has a negative impact on the environment. Fees and fee-rebates are also often used to steer individuals' behavior to take environmentally desirable decisions. Taxes are compulsory, unrequited payments to the government that are used for general government expenditure whereas fees are compulsory requited payments that are tied to a specific purpose (OECD, 2016). Generally, when facing a tax or fee on a harming activity, companies or households will decrease the level of this activity until their marginal abatement cost equals the amount of the tax or fee (Sterner and Robinson, 2018). Compared to regulations that enforce the same solution on all members of the economy, price-type instruments are more efficient.

Payments for environmental services (PES) can also be placed in the group of price-type instruments. PES can be defined as "voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services" (Wunder, 2015). If some subsidy or PES program is offered to landowners for retiring parcels of land, an agglomeration bonus payment can be added as an incentive to create a contiguous conservation area across property boundaries. The agglomeration bonus is an incentive for landowners to voluntarily set aside those parcels of land that share a border with already retired parcels of land (Parkhurst

**Table 1**
Search terms used for the literature review.

| Policy instrument groups | Search terms |
|---|---|
| Regulation | Ban, Zoning |
| Price-type instruments | Tax, Subsidy, Fee, PES, Agglomeration bonus |
| Rights-based instruments | Auction, tradeable permit, offsetting |
| Legal-based instruments | Legal liability |
| Instruments to modify behavioral norms | Nudge |
| Procedural instruments | Stakeholder participation, bottom-up, top-down |
| **Broad search** | Policy, Policy program, Policy instrument, Policy incentive |

et al., 2002).

Rights-based instruments help clarify who has the property rights to environmental resources. In some cases, policy instruments can proxy for property rights and create a market on which these rights can be traded (Sterner and Robinson, 2018). Examples in this group of instruments include reversed auctions (also called conservation tenders), tradeable permit systems and offsetting markets. Reversed auctions are useful when the efficient allocation of funds is of high importance to the authorities or in cases of high variability and uncertainty on property owners' opportunity cost structures (Boxall et al., 2017). Tradeable permit systems have been designed for emissions but also for harvest rights such as for fisheries quotas (Sterner and Robinson, 2018). Offsetting is a policy that, for the sake of economic development, allows for environmental harm in one place, provided that the harm is compensated by an equivalent restoration project somewhere else. Offsetting policies usually involve a trading system for offset credits. The credits are generated by restoration projects and sold to those who harm the environment by developing a unit of land.

Legal-based instruments largely refer to legal liability adjustments. Legal liability ideally creates incentives for firms to implement the efficient level of precaution. In case an accident does occur, compensation is provided to those harmed by the pollution (Boyer and Porrini, 2002).

Instruments to modify behavior, in particular nudges have more recently entered policy makers' toolkits. Nudges seek to influence peoples' behavior by providing a desired default option but unlike other instruments do not create economic incentives or decrease the choice set (Carlsson et al., 2021).

Finally, procedural instruments impact the mode of policy formulation and implementation. Their purpose is to establish good state-societal interactions in support of overarching goals. Examples for procedural instruments include public hearings as well as stakeholder consultation and participation that can be organized in a bottom-up or top-down manner (Howlett, 2000; Bali et al., 2021).

### 3.2. Technicalities of the review

The search commands were built using "green infrastructure" resp. "ecological infrastructure" with the search terms in Table 1 connected by the Boolean operator "AND" and the option to search "in topic". Only for the term "policy" we restricted the search to cases where the term was used in a paper's title. We conducted the literature search in April 2021 and used "Web of Science" as a search engine. The initial search retrieved 292 records, of which 165 were duplicates, irrelevant or in some cases we lacked access to the document. One of the authors screened the remaining set of 127 papers for policy recommendations. We then created three categories corresponding to the three GI types plus a category 'unclear'. We assigned each of the 127 papers into one of these four categories. This assignment was done by one of the authors and was based on the description of the GI types in the paper. For simplicity and without loss of detail, in the results section we pool the information found for the terms 'green infrastructure' and 'ecological infrastructure'.

We provide the quantitative results of the keyword searches and more qualitatively discuss our findings on policy recommendations put forward in the papers. The data on the keyword searches informs on the scope of the material that we analyzed. However, in some instances, keywords were used in the papers but in a context other than GI policy. In the qualitative overview of the findings, we thus focus on information that is relevant for confirming or refuting our hypotheses, but do not intend to provide a fully comprehensive meticulously detailed review of all the information on policy instruments contained in the papers.

## 4. Results

As mentioned above, we assigned the 127 papers in our sample to four categories based on their description of the GI type. We assigned 48 papers to the first category GI sites without connectivity requirements, 11 papers to the second category GI sites with high connectivity requirements, 50 papers to the third category GI as a widespread network, and 18 papers to a category unclear.

The quantitative results of the keyword search by category and policy instrument group are presented in Table 2. The absolute number of hits (156) is higher than the total number of papers (127) because some papers contained more than one of the keywords.

The broad search terms retrieved around half of the hits in each of the GI categories. The search neither found papers that referred to regulation (search terms ban and zoning) nor legal-based instruments (search term legal liability).

Papers that we placed in the category of GI sites without connectivity requirements especially contained keywords from the policy instrument groups price-type instruments and procedural instruments. The distribution of keywords is similar for the papers that we placed in the category GI sites with high connectivity requirements. Keywords from the group of procedural instruments were often found in the papers that we placed in the category GI as a widespread network.

In the more qualitative review by GI category below, we also include the papers that were found by the broad search terms and those that we couldn't assign to one of the three main GI categories. Often these papers still contained relevant information that contributes to the understanding of policies for GI and issues of policy implementation. The data presented in Table 2 thus should only be understood as an interim result.

### 4.1. Policy instruments for GI sites without connectivity requirements

Among the papers that refer to GIs with no particular requirements on connectivity, several case studies are on urban stormwater runoff management (Drescher and Sinasac, 2021; Neumann et al., 2020; Malinowski et al., 2020; Qiao et al., 2018; Shade and Kremer, 2019; Liu and Jensen, 2018; Shafique and Kim, 2018), green roofs and walls in urban areas (Liberalesso et al., 2020; Irga et al., 2017), measures to countervail heat islands in urban areas (Iping et al., 2019; Parsaee et al., 2019), civic or allotment gardens (Zwierzchowska et al., 2019; Langemeyer et al., 2018; Poniży and Stachura, 2017; Camps-Calvet et al., 2016), green spaces in urban areas to expose people to nature and avoid an extinction of experiences (Soga and Akasaka, 2019; Beery et al., 2017), as well as vacant land in depopulating cities (Kim et al., 2020; Rupprecht, 2017).

Subsidies and tax rebates are often discussed as viable instruments in the context of GI for urban stormwater management and roof greening (Fu et al., 2019; Gostieva et al., 2020; Liberalesso et al., 2020; Ekness and Randhir, 2015). Examples include a subsidy funding 50 % for green roofs on skyrise buildings in Singapore, a bonus based on a floor-to-area ratio for green roofs in Portland and Seattle, decreased rates for properties with green roofs in San Francisco and tax abatements for green spaces integrated in buildings in New York (Irga et al., 2017).

A tender was implemented in Ohio to cost effectively distribute resources for rain gardens while minimizing social and legal entanglements (Shuster and Rhea, 2013). The ambition was to increase the number of retrofit stormwater retention measures on private properties (Green et al., 2012). The options were to install rain barrels and/or rain gardens, receive free material and installation, 3 years of maintenance as well as access to education material. Given that many property owners submitted 0$ bids, the authors conclude that the program was cost effective. At the same time the education material increased human capital which spread through social capital within the community (Green et al., 2012). The installation of the rain gardens and barrels was found to be sufficient to have a small, but statistically significant, effect on stormwater retention capacity (Shuster and Rhea, 2013). A case study from the Netherlands provides a further example of a tender used in the context of GI (Fliervoet et al., 2017). However, in the paper it does not become entirely clear whether the tender's purpose was explicitly

**Table 2**
Keyword search results.

| Policy instrument groups | | Search terms (*absolute numbers in italics*) | GI categories | | | |
|---|---|---|---|---|---|---|
| | | | GI sites without connectivity requirements | GI sites with high connectivity requirements | GI as a widespread network | Unclear |
| Regulation | Share of column total | | 0 % | 0 % | 0 % | 0 % |
| | | Ban | – | – | – | – |
| | | Zone | – | – | – | – |
| Price-type instruments | Share of column total | | 21 % | 21 % | 5 % | 5 % |
| | | Tax | *3* | *2* | *1* | – |
| | | Subsidy | *4* | – | *1* | – |
| | | Fee | *6* | – | – | – |
| | | PES | – | *1* | *1* | *1* |
| | | Agglomeration bonus | – | – | – | – |
| Rights-based instruments | Share of column total | | 3 % | 7 % | 2 % | 0 % |
| | | Auction | *2* | – | – | – |
| | | Tradeable permit | – | – | – | – |
| | | Offsetting | – | *1* | *1* | – |
| Legal-based instruments | Share of column total | | 0 % | 0 % | 0 % | 0 % |
| | | Legal liability | – | – | – | – |
| Instruments to modify behavioral norms | Share of column total | | 2 % | 0 % | 0 % | 0 % |
| | | Nudge | *1* | – | – | – |
| Procedural instruments | Share of column total | | 24 % | 21 % | 51 % | 45 % |
| | | Stakeholder participation | *7* | *1* | *17* | *6* |
| | | Bottom-up | *4* | *2* | *7* | *3* |
| | | Top-down | *4* | – | *5* | *1* |
| Broad search | Share of column total | | 51 % | 50 % | 42 % | 50 % |
| | | Policy | *16* | *4* | *17* | *9* |
| | | Policy program | – | – | – | *1* |
| | | Policy instrument | *5* | *2* | *4* | *1* |
| | | Policy incentive | *11* | *1* | *3* | – |
| | Column total | | *63* | *14* | *57* | *22* |

for ecological infrastructure or more general nature conservation.

Although concealed in the keyword search, regulations are discussed in the context of conserving existing GI for biodiversity conservation and ecosystem service provision when there is strong conversion pressure, in particular from the building sector. For example, Poniży and Stachura (2017) argue for developing spatial planning legislation to maintain allotment gardens in Poznan rather than selling the land to investors. Conservation of the allotment gardens is important because they serve as hotspots of local biodiversity and provide many services to local people (Poniży and Stachura, 2017). A case study from Istanbul provides an example of how urban green infrastructure vanished when, in a time of low interest rates, regulations were reformed in favor of the construction sector (Cengiz et al., 2019). Green areas, parks as well as gardens were opened for property development and roadside strips and trees were removed to expand roads.

Other case studies discuss regulations together with price-type instruments, in particular taxes. Some argue for a policy mix of both instrument types while others refer to them as competing strategies. For example, in the context of depopulating cities with very little development potential, Kim et al. (2020) argue for a mix of regulations and tax incentives to promote GI on vacant land. In the context of runoff management, a case study from Chicago reports that in policy circles there is an unresolved debate on whether data-driven approaches with stricter laws and regulations or new institutions and price-setting instruments are more promising (Cousins, 2017). In a global review of policies in support of green roofs and walls as elements of urban GI, Liberalesso et al. (2020) find that obligations by law as well as financial subsidies are the most frequently used instruments. For the specific European context, Brudermann and Sangkakool (2017) argue that enforcement of roof greening and subsidies are direct approaches but may often be politically or financially infeasible, especially in cities in which fiscal conservatism prevails. An example for such a situation is provided by a case study from Athens on green roofing which finds that survey respondents expected subsidies, but no such program was available (Tsantopoulos et al., 2018). In cases of fiscal conservatism, Brudermann and Sangkakool (2017) put forward that stormwater runoff fees may be an effective alternative that does not require additional budget.

Similar to taxes and subsidies, fees and fee-rebate systems are also frequently used as incentives for decentralized stormwater management and roof greening on private properties (Fu et al., 2019; Qiao et al., 2018; Cousins and Hill, 2021; Godyń et al., 2020; Ureta et al., 2021; Wong-Parodi and Klima, 2017; Boguniewicz-Zabłocka and Capodaglio, 2020). For example, in the City of Charlotte, all property owners are obliged to pay a stormwater fee relative to their properties' impervious area. Rebates can be granted for stormwater control measures and ponds on the property (Malinowski et al., 2020). A similar program for non-

residential properties is run by the Philadelphia Water Department (Zidar et al., 2017). There, property owners who install GI for stormwater retention that exceeds their own regulatory requirements can sell credits to others who fail to meet their requirements on-site (Zidar et al., 2017). For a city in Italy, Privitera and La Rosa (2018) discuss a hypothetical tradeable permit system. In their thought experiment, development rights could be exchanged for green infrastructure on private land.

While most case study examples are based in OECD countries, Tauhid et al. (2018) argue that the private sector may be interested in investing in GI projects in developing countries, provided that authorities can make financial resources available, for example through proceeds from stormwater fees.

However, financial incentives alone may not always be a game changer. Drescher and Sinasac (2021) find that normative beliefs and subjective norms are important factors determining decisions on whether to install GI stormwater infrastructure on residential property in Canada. They argue that it is important to create *meaningful* financial instruments.

Some also argue that educational instruments are important for creating awareness of the possibilities for stormwater management (Drescher and Sinasac, 2021; Bo et al., 2018) while again others highlight the need for good governance, engaging locals and fostering trust (Dhakal and Chevalier, 2017; Travaline et al., 2015; Herslund et al., 2018; Parsaee et al., 2019).

For the special case of exposing urban populations to green spaces, Beery et al. (2017) argue that good GI design may nudge people into encounters with nature. Such encounters are important to countervail the extinction of experiences with nature. The extinction of experiences is an issue because there is risk that if people do not experience nature, their interest in and understanding for the need for conservation is likely to decrease (Soga and Akasaka, 2019).

### 4.2. Policy instruments for GI sites with high connectivity requirements

Spatial planning and the development of restoration strategies stand out as policy instruments for GI with high connectivity requirements. For Finnish conditions, Salomaa et al. (2017) argue that the role of ecology needs to be strengthened in GI land-use planning by focusing on core areas and strengthening policy instruments that have the potential to improve connectivity. However, related to all three types of GI, there appears to be agreement in the literature, that top-down planning alone won't do the job. For example, Smets et al. (2020) argue that a blueprint from a higher planning level can help improve coherence to the benefit of decreasing fragmentation and increasing connectivity, but it needs to be complemented with a participative approach. Stakeholders may oppose the creation of a clustered GI (Valasiuk et al., 2018). If excluded, their demands and competing interests in the GI land may cause frictions that foreclose the implementation of the planned GI, while their inclusion can foster broad acceptance (Smets et al., 2020; Tauhid et al., 2018; Jones-Walters and Çil, 2011).

The European Green Belt, a unique conservation cluster along the former iron curtain is an example of a GI that incorporates integrative and segregative conservation approaches and high coordination between countries (Zmelik et al., 2011). The combination of a large-scale vision, voluntary agreements with farmers, collaboration and facilitation were also conducive for the creation of GI and ecological networks in Italy (Magaudda et al., 2020).

One case study discusses a price-type instrument for a clustered GI. Valasiuk et al. (2018) investigate residents' willingness to pay a tax from which the proceeds would be used for forest landscape restoration in a border region of Sweden and Norway.

Administrators planning this type of GI may seek to incorporate areas based on connectivity considerations rather than economic efficiency. The cost of creating a cluster of sites is thus likely to be higher than for a GI in which the spatial allocation of the sites matters less. To cope with the cost, Borie et al. (2014) discuss a fiscal transfer system that allocates more resources to communities in Southern France that have a high share of GI protected areas on their territory. For Biscay, a province of Spain, Rodríguez-Loinaz et al. (2018) propose a PES scheme to deal with the high GI cost. A PES scheme is expected to set GI on the municipalities' agenda and would consequently foster a sustainable territorial planning transition. Offsetting is a further policy instrument that can direct resources to GI (Corbera et al., 2021). Most of the case studies directly or indirectly assume that financial resources are provided by the government. Whether the private sector can take on a role in financing this type of GI is doubtful (McWilliam and Balzarova, 2017).

### 4.3. Policy instruments for GI as a widespread network

For case studies in this group, ecosystem service provision and connectivity matter. Often, contiguity of sites is necessary, because the GI involves transportation ways, e.g. for fresh water (Kušar, 2019; O'Donnell et al., 2018; Amaral et al., 2021; Fliervoet et al., 2017; Vierikko and Niemelä 2016), waste water (Prescott et al., 2021), recreational pathways (Rolf et al., 2019; Eckerberg et al., 2020; Vaňo et al., 2021; Panagopoulos et al., 2018; Stubbs, 2008), or corridors that provide connectivity for species between larger protected areas (Schmidt and Hauck, 2018; Hermoso et al., 2019; Hermoso et al., 2020).

Many case studies on contiguous but spread GI stress the importance of stakeholder processes as procedural policy instrument (Kušar, 2019; O'Donnell et al., 2018; Fliervoet et al., 2017; Vaňo et al., 2021; Rolf et al., 2019). A range of methods to engage with stakeholders is presented from professional moderation (Pauleit et al., 2019; Smets et al., 2020), over computer mediated visualization tools, e-participation, and the use of social media (Campbell-Arvai and Lindquist, 2021; Leonard et al., 2019; Wilker et al., 2016), to learning labs and learning alliances (Pauleit et al., 2019; van der Jagt et al., 2019; O'Donnell et al., 2018; Rolf et al., 2019).

Because stakeholder processes are frequently mentioned in this body of literature, we discuss them here. However, they are also recommended for the GIs without connectivity needs as well as those with high connectivity requirements. The benefits of stakeholder processes for GI can be structured into three groups: substantive benefits, instrumental benefits, as well as normative benefits (Nesshöver et al., 2017). Substantive benefits generally refer to direct improvements, such as an increased sustainability of the GI due to stakeholder involvement (Molla, 2020; Neumann et al., 2020; Langemeyer et al., 2018; Dhakal and Chevalier, 2017; Hansmann et al., 2015). Examples include positive effects on the physical quality of greenspaces (Vaňo et al., 2021), better care and management of the GI by stakeholders and less dependency on government funding (Dhakal and Chevalier, 2017), and notions of more success in GI implementation and biodiversity conservation (Jones-Walters and Çil, 2011; Bissonnette et al., 2018).

Instrumental benefits arise when stakeholders' acceptance of and support for GI increase due to their involvement (Nesshöver et al., 2017; Wilker et al., 2016). Examples for such instrumental benefits are greater satisfaction, improved community resilience, or the avoidance of green gentrification (Campbell-Arvai and Lindquist, 2021). Bottom-up, local stakeholder processes with participatory decision making can foster social inclusion and social capital which can contribute to a dissemination of experience and practice on GI (Vaňo et al., 2021; Pauleit et al., 2019; Langemeyer et al., 2018; Davies and Lafortezza, 2017; Finka et al., 2017). However, it is important to consider the modes of integrating stakeholders' inputs with scientific knowledge (Faehnle et al., 2014). Stakeholder inputs should not simply be put in a separate box and then forgotten about.

Finally, stakeholder involvement can give rise to normative benefits in the sense of increased legitimacy and a democratization of the GI planning and implementation process (Nesshöver et al., 2017; Campbell-Arvai and Lindquist, 2021; Hansmann et al., 2015; Wilker et al., 2016; Finka et al., 2017). This is particularly important in cases

with issues related to trust and inequality (Travaline et al., 2015; Schifman et al., 2017).

Some case studies compare bottom-up stakeholder approaches to their top-down counterparts. For example, a case study from China reports on the top-down implementation of greenways as GI along rivers for flood prevention. Although efficient in terms of planting many trees, the top-down approach is criticized of falling short of scientific foundation and public participation to the detriment of long-term management by locals and thus tree survival (Yu et al., 2006). A case study from Belgium argues that top-down blue-print approaches have been widely accepted for grey infrastructure but failed in the context of GI (Smets et al., 2020). The failed top-down approach is now being replaced by a participatory stakeholder approach (Smets et al., 2020). Similarly, Herslund et al. (2018) put forward that top-down master plans fail to reflect the reality of informal urban development forms. Thus, for GI there should be more focus on experimentation and social learning.

Others, see advantages and disadvantages in bottom-up stakeholder approaches as well as in top-down approaches and promote the idea of hybrid approaches (Prescott et al., 2021; Liu and Jensen, 2018).

Price-type instruments are rarely discussed for the third type of GI. An exception is a case study from Greece, in which residents expressed their reluctance to pay more public taxes for the construction and maintenance of pedestrian and cycling streets which would have co-benefits for GI (Panagopoulos et al., 2018). Hermoso et al. (2020) indirectly refer to taxes in the context of spending EU-level tax proceeds for landscape-scale GI. To foster GI with a focus on biodiversity, they call for the complete release and adequate use of funds available in several policy programs, including: actions under target 2 of the EU biodiversity strategy such as the restoration of degraded habitats or the no-net-loss; structural and cohesion funds; European Agricultural Fund for Rural Development; European Fund for Strategic Investment; and Ecological focus areas in agricultural land such as margins or buffer strips.

### 4.4. Constraints to GI implementation

Constraints can arise at all levels of interaction between people and agencies involved in the implementation of GI. Between higher and lower levels of government, a lack of standards, guidelines, and timeframes for GI implementation and deficient communication on the co-benefits of GI can complicate implementation (Liberalesso et al., 2020; Qiao et al., 2018; Vaňo et al., 2021). A general lack of awareness and appreciation of GI by the authorities (Molla, 2020; Afionis et al., 2020) as well as deficient coordination between different administrative departments can further hamper implementation (Afionis et al., 2020; Smets et al., 2020). A lack of horizontal administrative coordination can be especially devastating for GI when economically stronger sectors such as the construction sector or agriculture challenge or even overpower environmental GI interests (Hodge et al., 2015; Poniży and Stachura, 2017; McWilliam et al., 2015; Aubrechtová et al., 2020; Camps-Calvet et al., 2016; Cengiz et al., 2019; Smets et al., 2020). McWilliam and Balzarova (2017) find that in the absence of government-led implementation, it can be difficult for the private sector to take the lead in advancing the development of GI networks. Apart from red tape and competition from other sectors, high costs and insufficient financial resources are frequently mentioned constraints for GI implementation (Grashof-Bokdam et al., 2017; Shafique and Kim, 2018; Shackleton et al., 2017; Smets et al., 2020).

Several reasons have been reported to give rise to resistance to implement GI among non-governmental stakeholders. Importantly, social acceptance of GI decreased when it was too narrowly focused on one function (Bissonnette et al., 2018) and neglected the plurality of values, particularly peoples' attachment to place (Vierikko and Niemelä 2016). A special case from the Netherlands is reported by Fliervoet et al. (2017), where a competitive tender policy caused tensions because it was misaligned to locally accustomed collaborative codes of conduct and thus impinged on intrinsic motivations to act cooperatively.

Finally, mutual mistrust between authorities and stakeholders (Travaline et al., 2015; Qiao et al., 2018) and frustration over expected and realized levels of implementation (so-called Arnstein gaps) (Wilker et al., 2016) can constrain GI implementation.

## 5. Discussion

The literature review of policy instruments revealed that distinctly different instruments are used for the three GI types. For the first, our hypothesis was that efficiency considerations will guide the selection of policy instruments. The literature review largely confirmed this hypothesis. Taxes, fees, fee-rebate systems and subsidies, partly in combination with regulations, are frequently used for GIs that do not require a specific spatial pattern of the conservation sites. Reversed auctions also formed part of the set of selected policy instruments. Somewhat unexpectedly, nudges and educational measures, and stakeholder engagement were also proposed as policy instruments for this GI type. However, the proposition for nudges was directed at people benefiting from the GI rather than the landowners.

The second GI type requires high connectivity, e.g. a cluster of GI sites. We expected to find case studies on policy instruments that pass the added value of agglomeration on to landowners in incentive packages. However, we neither found any empirical examples in support of this hypothesis when looking at the keywords nor when screening the texts for policy recommendations. The keywords rather point to price-type and procedural instruments. The qualitative review revealed that case studies in this group rather report on landscape planning and possibilities to finance the high cost of a clustered GI. It is unclear why incentive mechanisms are not covered and whether this is a result of our sample selection or whether GI for biodiversity conservation simply hasn't transitioned from planning to implementation yet.

For the third GI type, we hypothesized that there needs to be a deliberative process to determine the optimal balance between contiguity and spreading of the sites. The literature review revealed that, indeed, stakeholder processes are widely discussed and advocated for in this context and diverse methods are presented. These processes are not least necessary to legitimize the GI development process. Through co-creation, the authorities can gain stakeholders' acceptance of and support for the GI which in turn will likely improve the GI's long-term sustainability.

The spatial patterns that distinguish our three GI types have parallels to previous work on GI, in particular the GI archetypes defined by Schifman et al. (2017). The first of Schifman et al.'s archetypes are 'lone rangers' who independently of others implement a GI element, e.g. a rain barrel. This corresponds to our first GI type in which no spatial pattern is required for the conservation sites. Our second GI type corresponds to Schifman et al.'s 'specialized' archetype, which they define as an 'arrangement among a few individuals or organizations that has a single objective'. Finally, their archetype 'Situated GI' has parallels to our third GI type. The situated GI is described as a group of individuals or organizations with diverse interests that collaborate on a multifunctional environmental project (Schifman et al., 2017). Interestingly, they argue that lone rangers have high versatility and capacity for adaptation but provide little scope for participation and on their own have little impact. Specialized GIs have potential for high impact but score low on adaptive capacity, versatility and participation. Situated GIs have high versatility and high potential for participation but compromise on adaptive capacity and impact. Their ranking of the archetypes in terms of potential for participation is consistent with our finding that procedural instruments were most frequent in the case studies that we attribute to the third GI type. Moreover, in Schifman et al.'s comparison of the archetypes, lone rangers have the highest capacity for adaptation. This matches our finding that price-type instruments are often used for GIs with no requirements on their spatial pattern. Price-type instruments such as taxes and fees allow landowners to choose whatever technology is best adapted to their context for improving compliance with the GI

objective.

Impact evaluations were scarce in our set of reviewed papers. However, if Schifman et al's proposition of high impact among specialized GIs applies to biodiversity conservation, then there are prospects that GI as a strategy for conservation will be implemented more often in the future.

Our study has several weaknesses that we would like to point out. The screening of the papers for information on policy instruments as well as the attribution of the case studies to the three GI types was conducted by one of the authors. Although this ensures consistency, it lacks peer-proofing and despite striving for the greatest diligence, there may be mistakes. Moreover, we included only English peer-reviewed papers into our review which may exclude findings from other knowledge systems.

Yet beyond these technical issues, our review of instruments does not touch upon the prevailing governance arrangements and capacity for adaptive management which can be decisive for the actual implementation of an instrument (Sainz-Santamaria and Martinez-Cruz, 2022). Green infrastructure, environmental justice and the need to account for social as well as ecological sustainability (Zuniga-Teran et al., 2021; Wolch et al., 2014) are further important issues that we do not explicitly cover.

We see several avenues for future research. Firstly, there is scope to investigate the potential of incentive policies for GI, especially when biodiversity conservation is the main objective. More pilot approaches and case study analyses are needed especially on the use of agglomeration bonus payments and threshold payments for GI. Secondly, more research is needed on how to integrate inequity safeguards into GI policy. For example, future research could investigate how policy mixes could be designed that foster GI while also taking into account green gentrification risks. Thirdly, given that stakeholder processes are resource consuming, an avenue for future research could be to investigate if upfront analysis of social media could help direct deliberative processes to the most pressing issues from the start. For example Sainz-Santamaria et al. (2023) show how Twitter data can be analyzed to reveal societal concerns and contentious issues related to the accessibility of urban green infrastructure during the COVID-19 crisis. Fourthly, apart from a few notable exceptions, much of the literature on GI policies covers case studies in the global North. To obtain a more balanced understanding of the suitability of GI policies in different global contexts, more case study research is needed from countries of the global South.

## 6. Conclusion

Sussams et al. (2015) argue that GI has an "inconsistent definition at its core, deficiencies in its understanding and conflicts within its governance". In this paper, we distinguish between three GI types with differing needs for the spatial allocation of GI sites: no need for connectivity between sites, a high need for connectivity between sites, and a contiguous but spread allocation of sites. Taking these three GI types as points of departure, we investigated which policy instruments dominate for which GI type. For GIs that have no particular requirements on the spatial allocation of conservation sites, price-type instruments were often used. This choice of instrument is reasonable because price-type instruments are more efficient compared to alternatives such as regulations. Procedural instruments were commonly applied for GIs that aim for a contiguous but spread allocation of the sites. This is also consistent with our hypothesis that there is need for a discourse on how to balance the competing objectives of high connectivity between sites and spreading sites for ecosystem service provision in many places of the landscape. There were a few papers that reported on novel approaches such as urban living labs and learning alliances that allow for co-creation. More case studies and syntheses are needed to develop best practices for these instruments in the realm of GI implementation.

While spatial planning and the development of restoration strategies were commonly mentioned for GIs with high connectivity needs, we were surprised to find little use of incentive mechanisms that internalize the benefit of clustering and pass it on to landowners. We see potential in testing instruments such as agglomeration bonus or threshold payments more, e.g. in the context of biodiversity conservation.

The literature review revealed that there is no "one size fits all" solution for GI implementation but a wide variety of approaches. Even when a policy instrument has been carefully selected, policy implementation can be constrained by deficient communication and coordination between different administrative departments and stakeholders. We conclude that no matter what GI objective policy makers are pursuing, a well-developed governance plan that brings all stakeholders on board is at least as important as the choice of the policy instrument.

## 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

No data was used for the research described in the article.

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