# Green Infrastructure and Private Property: The Crucial Relationship for the Sustainable Future of Cities

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**Abstract.** Over the past decades, intense urbanization processes have generated built environments with a low energy efficiency and a severe lack of green spaces. These represent the main providers of ecosystem services in cities, especially for the regulation of local microclimate. Despite their importance, the implementation of a green infrastructure from public administrations often faces the lack of economic resources to acquire and manage the land to be used as new green spaces.

This article investigates the suitability of open spaces located in private residential areas to be components of a green infrastructure through a trees planting strategy. A high-res GIS Land Cover analysis models the potential of private residential areas to host new greenery by comparing the actual availability of open spaces near residential buildings and the mutual position between buildings and new trees. The method is tested in a portion of the Metropolitan Area of Catania (Italy).

Results for private residential areas, which represents a relevant percentage of the built environment, show that the implementation of the Green Infrastructure depends on the configurations of buildings and open spaces, and is limited by the actual room of open space around residential buildings. The work allows identifying different scenarios and alternatives for a Green Infrastructure to better balance public and private costs and generated benefits.

**Keywords:** Green infrastructure · Land cover · Energy saving · Private property · Urban planning

## 1 Introduction

Cities are widely considered as the places where behavioral, economic, and technological interventions for climate change adaptation and mitigation have the best potential to be implemented and scaled up (van der Heijden 2019; IPCC 2018). Cities can also be considered as key victims of climate change, as it is in cities that the effects of climate change will be experienced most severely by humans (Tyler and Moench 2012). Seeking to utilise their climate mitigation and adaptation potential, cities have developed as sites of innovative and experimental governance to spur on climate actions (Martinico et al. 2013; Rosenzweig et al. 2018).

In urban contexts, natural ecosystems are increasingly used to provide solutions to many urban issues and improve the overall sustainability of urban environments

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(Cohen-Shacham et al. 2016). These nature-based solutions provide sustainable, cost-effective, multi-purpose, and flexible alternatives for various planning objectives and are able to enhance significantly the resilience of cities.

Among Nature-based solutions, Green Infrastructure (GI) is a 'natural, semi-natural and artificial network of multifunctional ecological systems within, around and between urban areas, at all spatial scales (Nesshöver et al. 2017). This definition emphasizes the holistic ecosystem vision of urban environments (including the abiotic, biotic and cultural functions) and claims for multi-scale approaches able to take into account the scale-dependent relationships of ecological processes occurring in cities, with particular reference to the human health and well-being of residents.

Among the services provided by GI, climate regulation is of utmost importance in cities, where the microclimatic benefits of urban vegetation can contribute to the mitigation of the urban heat island effect. Vegetation contributes to regulate the urban temperature through three main actions: shading the built environment, modifying the airflow around it and directly lowering the outdoor air temperature through evapotranspiration processes (Hwang et al. 2017).

Climate regulation potential of vegetation has relevant positive impacts on the energy demand of buildings, as demonstrated by a growing body of research and experimental measurements (Simpson and McPherson 1998; Konarska et al. 2015) and confirmed in different climate conditions and type of buildings (Laband and Sophocleus 2009; Palme et al. 2017).

Shade effect by trees reduces the amount of solar energy a building absorbs and therefore reduces the energy required for cooling. Vegetation also cools the air around buildings and this has an indirect effect on the need of energy for cooling the inner parts of buildings. If looked at city or district level, effects of vegetation can generate relevant electrical energy savings (Simpson 1998; Wang et al. 2019) with energy performances that can be further increased by the evapotranspiration effect (Hsieh et al. 2018). The positive effect depends on the multiple different configurations among urban environments, land-use configurations, and micro-climate conditions (Calcerano and Martinelli 2016).

Different approaches and models have been developed for evaluating the potentiality of trees on cooling energy reduction, but limited research has focused on the different relations between buildings and trees in the urban environment (Farhadi et al. 2019; Wang et al. 2019). This is a crucial issue, in instances when the availability of open spaces for planting trees is limited and when the feasibility of planning and design alternatives for GI must deal with the private property.

Indeed, planting trees and other forms of greenery requires availability of suitable open spaces located just in the surrounding of the buildings. These kind of open spaces can be found in private setback yards, reduced in size and characterised by different land cover types such lawns, shrubs, bare soil, impervious surfaces and trees as well. The actual chance to implement a public and accessible GI is strongly affected by the private asset of landownership and the limited physical and geometrical features of the open spaces close to the buildings.

In this article we evaluate the potential of open spaces located in private residential areas to host new trees to be planted and which can become new components of a local GI aimed at i) providing local temperature cooling effects resulting in a considerable decrease of energy demand of adjacent buildings and ii) implementing public and accessible green spaces for the neighboring community.

## 2 Study Area, Materials and Method

### 2.1 Study Area and Materials

We have tested the methodology presented in a portion of the municipality of Aci Castello, a small municipality located within the metropolitan area of Catania (Italy), the largest in Sicily. The location of the test area is shown in Fig. 1.

### 2.2 Land Cover Analysis

A land cover map was derived by a pixel-based, supervised classification of high resolution (0.25 m) regional aerial photograph, done with ERDAS Imagine. The following land cover categories were used: Trees and Shrubs, Grass, Bare soil, Building, Impervious surface. These represent typical categories for urban and peri-urban contexts, as well as for the tested area (La Rosa and Wiesmann 2013; Myant et al. 2011). Maximum likelihood classification algorithm was used.

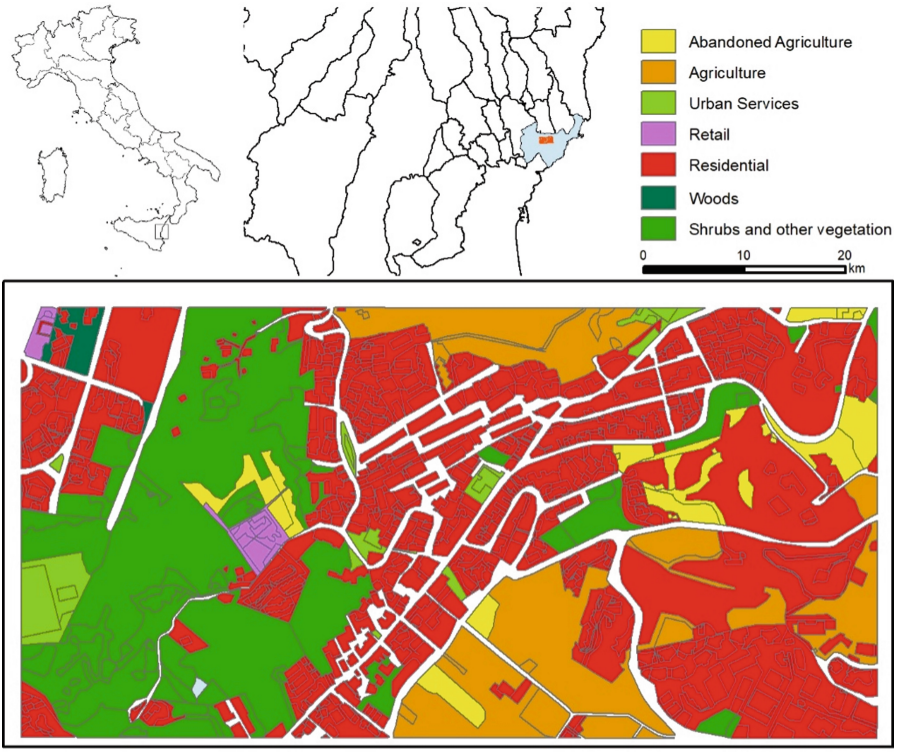


**Fig. 1.** Location of the study area in the municipality of Aci Castello, metropolitan area of Catania (Italy)

For the training step, a small-block sampling procedure was chosen. A total of 30 polygons of different sizes and shapes were sampled, with all pixels within each polygon belonging to the same land cover category. The sample data set contains around 11,000 pixels, which is a sufficient number according to existing heuristic rules for multiband images (Congalton and Green 2009).

### 2.3 Distance Analysis

In the second step, two distance rasters were derived from the residential buildings extracted from regional topographic maps (at the scale of 1: 10,000). Residential buildings were then divided into two main categories following a morphological analysis and representative of the most common type in the area (Privitera and La Rosa 2018): detached, semi-detached and terraced houses (usually with available private open spaces) and multi-storey buildings (with shared open spaces) (Fig. 2).



**Fig. 2.** Example of the morphological categories for residential buildings: detached house (left) and multi-storey buildings (right)

The distance raster allowed to identify those areas ranging from 5 to 8 m from the buildings, where the shading effects of trees can maximise its cooling effect and energy savings potential on the buildings (Palme et al. 2019; Privitera et al. submitted). These areas thus represent optimal places where new trees can be planted.

The Land Cover map was then overlaid with the distance raster, to select the land covers present in the distance range 5–8 m only. Trees and Shrubs were excluded from the land cover categories to be extracted, as it would make no sense to plant new trees where trees or shrubs are present already.

# 3 Results

## 3.1 Land Cover Mapping

Table 1 reports the accuracy matrix after the supervised classification, with an overall accuracy of 88%, while Table 2 shows the distribution of the different categories for the two morphological buildings categories.

Figure 3 shows the produced Land Cover map for the study area. In general, Bare soil is the most critical category because of its spectral similarity to other impervious surfaces and their limited extent in the study area. Best accuracies were obtained by the classification of Trees and Shrubs and Grass (the most frequent).

**Table 1.** Accuracy table for the land cover categories.

| | Trees & Shrubs | Grass | Bare soil | Building | Impervious | Shadows | ROWS TOT | Producer accuracy % |
|---|---|---|---|---|---|---|---|---|
| Trees and Shrubs | 370 | 10 | 5 | 2 | 10 | 5 | **402** | *0.92* |
| Grass | 13 | 211 | 2 | 3 | 2 | 4 | **235** | *0.91* |
| Bare soil | 2 | 1 | 44 | 4 | 4 | 2 | **57** | *0.79* |
| Building | 2 | 2 | 1 | 309 | 20 | 5 | **339** | *0.88* |
| Impervious | 7 | 3 | 3 | 30 | 270 | 5 | **318** | *0.86* |
| Shadows | 7 | 4 | 1 | 5 | 7 | 60 | **84** | *0.74* |
| COLUMNS TOT | **401** | **231** | **56** | **353** | **313** | **81** | **1435** | |
| **User accuracy %** | *0.92* | *0.90* | *0.77* | *0.91* | *0.85* | *0.71* | | **0.88** |

**Table 2.** Shares of Land Cover categories in the study area

| Land cover category | % |
|---|---|
| Buildings | 23.6% |
| Bare soil | 7.2% |
| Impervious | 22.6% |
| Trees and Shrubs | 34.6% |
| Grass | 0.9% |
| Shadows | 11.2% |

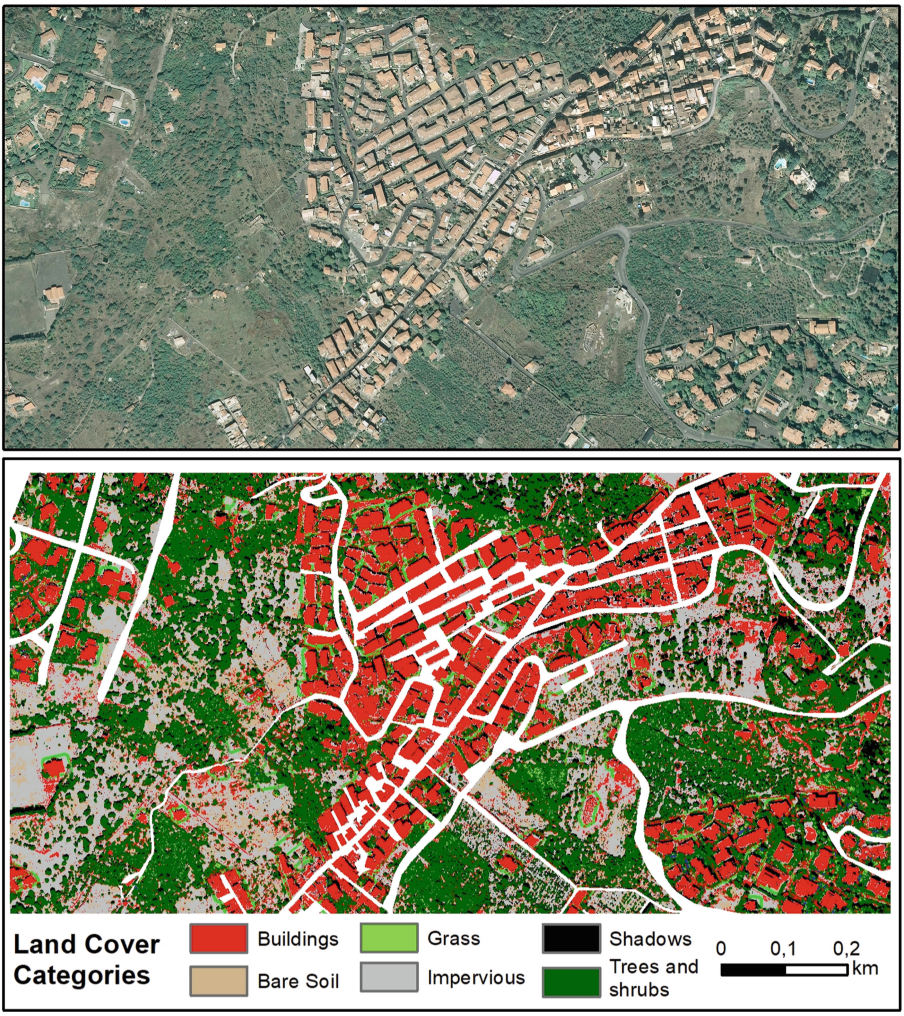


**Fig. 3.** Aerial photo and land cover map after the supervised classification

### 3.2 Distance Analysis

Figure 4 and 5 are the result of the intersection between the distance raster and the Land Cover map of Fig. 3. They map the different categories of permeable land covers located at a distance ranging between 5 and 8 m from detached/semi-detached and terraced houses and multi-storey buildings respectively.

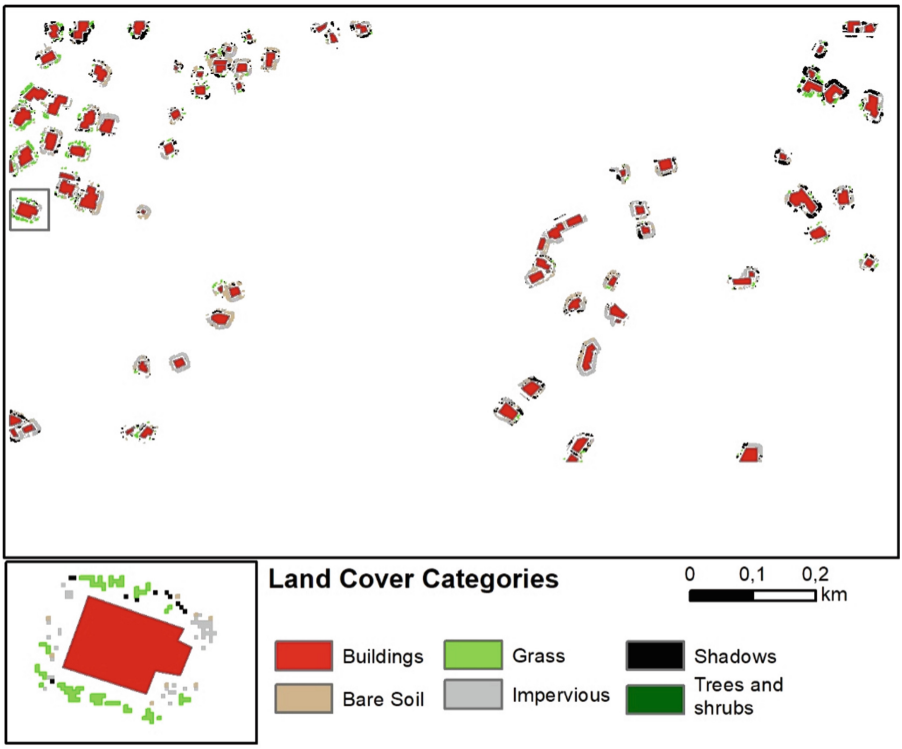


**Fig. 4.** Land cover categories within the distance range 5–8 m for detached/semi-detached and terraced houses

Table 3 shows the extent of each category of land cover (not including Trees and Shrubs) in the distance range for the 2 types of buildings considered. A first evidence from this analysis is the high difference of the shares of the land cover categories that are located within the distance range. For multi-storey buildings, the most frequent category is given by impervious category and this represents an indication of a highly urbanised residential built environment, where different types impervious surfaces can be present (terraces, internal roads, parking areas, etc.). For detached/semi-detached and terraced buildings, a lower extent of land covers can be found, mainly because there is a good presence of Trees and Shrubs at the distance range considered. This is a typical feature of low density urban environment, also for Italian metropolitan contexts (La Rosa and Wiesmann 2013), where set-back yards often include different types of green and permeable covers. Overall, grass is the category most frequently found.

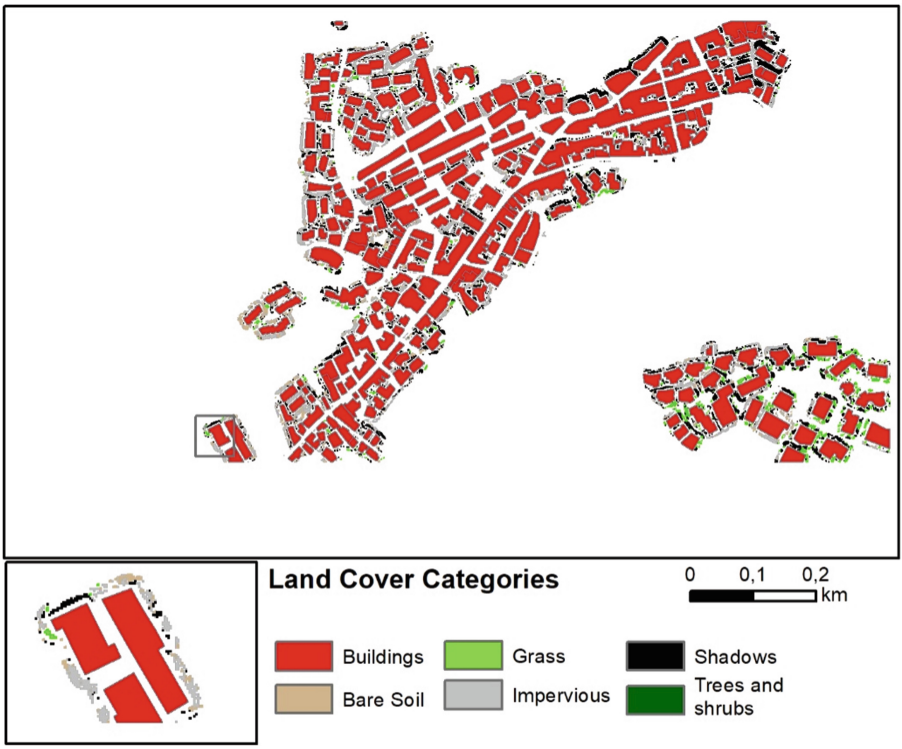


**Fig. 5.** Land cover categories within the distance range 5–8 m for multistorey buildings

**Table 3.** Shares of available land cover at the distance range 5–8 m for detached/semi-detached and terraced houses and multistorey buildings

| | Area ($m^2$) Detached/semi-detached and terraced houses | Area ($m^2$) Multi-storey buildings |
|---|---|---|
| Bare soil | 1607 | 2063 |
| Impervious | 6157 | 12508 |
| Grass | 2717 | 1442 |
| Shadows | 1278 | 10789 |
| **Total** | **11.759** | **26.802** |

## 4 Policies and Planning Implications

A strategy of planting street trees for shading buildings and reducing their energy demand should be included in a wider strategy aimed at designing larger and accessible public green spaces equipped with pathways, bike lanes, playgrounds, benches to be enjoyed by local residents. Nevertheless, the complexity and variety of different types of urban environment with fragmented and scattered patches of greenery could hamper the implementation of a new public GI.

In this paper we focused on two morphological types of residential areas: multi-storey apartment buildings and detached/semi-detached and terraced houses. Within both of these private assets, the implementation of GI must deal with land acquisition of those private plots where GI could be designed. Effectively, land acquisition strongly influences the economic feasibility of the implementation of GI, as direct public acquisitions of land are often economically unsustainable for local administration and face resistance from private landowners (Bengston et al. 2004). The issue of economic feasibility for managing public intervention and providing accessible public green spaces could be addressed through the Transfer of Development Rights (TDR) approach (Brabec and Smith 2002). In this approach, landowners can transfer the assigned rights to develop one parcel of land to another one, which could be located in different part of the municipality. As a consequence, the parcel from which the development rights are being transferred can no longer be developed and private landowners will get economic incentives or compensation from selling their developing rights.

According to this approach, local policy makers can identify the portions of private land parcels to be acquired for the GI and propose to the private landowners different economic incentives/compensation according to the specific morphological and property assets of urban fabric.

Multi-storey apartment buildings and tower blocks compounds are often characterised by large number of private landowners sharing the same common spaces or setback yards such as walkways, park plots and green spaces. In such a multiple property asset any potential intervention for improving the quality of buildings and other facilities is often affected and limited by the single landowner ability to pay and contribute to the overall urban transformation. In these cases, the most suitable economic incentive could be to monetise the gained development rights and provide a cash flow to adopt specific measures to improve the conditions of the multi-storey apartments buildings, including energy/seismic/aesthetic retrofitting interventions. As a consequence, open spaces acquired by public administrations (i.e. the municipality) thanks to Transfer of Development Right approach could be turned into new components of the public GI.

Differently, detached/semi-detached and terraced houses are characterised by private assets of landownership and usually include green back yards. In this case the most effective economic incentives could be to assign development rights to strips of private land parcels for increasing the square footage or height of existing buildings within the same parcel. Single private landowners could be also restored through tailored Tax Credits for collecting the earned revenues from the development rights and channeling it into a tax credit fund for local tax bills and other fiscal duties (Tapp 2019). In urban districts characterised by detached/semi-detached and terraced houses, the demand for green spaces from residents could be lower than the one of more compact district, where residents do not have private yards or garden. For this reason, the land strips acquired by the municipality in detached/semi-detached and terraced houses could be used not to implement new public green spaces, but rather to design new connecting cycling and pedestrian tracks, therefore improving the accessibility to other urban gardens and green areas.

Results from the application of the methodology presented, show that the actual implementation of GI according to the above proposed mechanisms and policies is highly dependent on the physical configurations of the open spaces where the GI can be implemented. The actual configuration of land covers represents a fundamental information to understand if and where new forms of greenery (trees above all) can be planted and if the planting could be suitable according to the current land cover situation and how much can the planting costs be.

Results of our analysis showed a different possibilities of GI implementation for the two types of morphological categories considered. For the category of multi-storey apartment buildings, which are present in the more central and compact parts of the urban context, a good extent of open spaces around residential buildings is available. However, these spaces are characterised by impervious land cover, and this will make the planting of new trees more complicated and costly. On the other hand, for the category of detached/semi-detached and terraced houses, the available spaces for planting trees is more limited in extent. However, the plantation could be more feasible and less expensive, as it will involve mostly permeable land covers (i.e. bare soils or grass).

## 5 Conclusions

The relationship between GI and energy is crucial for the sustainable future of the cities. The importance of nature-based solutions in providing urban climate regulation and, more specifically, the potential of vegetation to deliver positive impacts on the energy demand of buildings are increasingly being demonstrated in cities.

This study analysed the complex relation between open spaces and buildings within private compounds of highly dense multi-storey apartments and low-density urban fringes made of detached/semi-detached and terraced houses. The paper explored the morphological relation between buildings and land covers, spatially identifying the opportunities and limitations for planning a new GI around residential buildings through a high resolution land cover analysis. The limited data required for this analysis also allows its easy replicability of the method to other urban and metropolitan areas.

The complex relation among different land covers in the built environment requires a better understanding of the morphological features and the different property assets to develop feasible and effective policies aimed at implementing GI while reducing the energy demand of cities. This is even more important for cities where greenery is lacking or where the access to green spaces is low or unequal in the different districts of the city.

To this end, comprehensive planning policies should be based on an assessment of the economic viability of public investment and related public benefits (such as provision of ecosystem services) as well as private costs (loss of private/shared open spaces, parking plots, view blocking, cleaning costs and storm drains obstructing due to the falling leaves and bird droppings) and benefits (building energy savings, gained development credits, etc.). Such policies should also be tailored to different parts of the urban environment and take into account the different possibilities and limitation offered by private open spaces around residential buildings. This would allow identifying different scenarios and alternatives of a Green Infrastructure to better balance public and private costs and generated benefits.

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