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## Performance assessment indicators for green infrastructures: a comparison between international guidelines

### Indicateurs d'évaluation de la performance des infrastructures vertes : comparaison des directives internationales

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#### RÉSUMÉ

Le concept d'infrastructure verte est de plus en plus considéré comme une solution gagnant-gagnant pour résoudre une grande variété de problèmes urbains liés à l'eau. À cet égard, une évaluation complète des performances des infrastructures vertes peut contribuer à les rendre plus attrayantes pour de multiples secteurs et à améliorer les perspectives de financement. Des directives ont été élaborées ces dernières années afin d'aider à sélectionner les indicateurs de performance et d'impact les plus appropriés. Afin d'évaluer ces directives internationales traitant de divers aspects fonctionnels de ces infrastructures, cette étude propose un examen détaillé et une comparaison de certaines d'entre elles. Notre revue confirme les différences considérables entre les directives disponibles, par exemple : la directive de l'UE est la plus complète compte tenu du nombre d'indicateurs de performance abordés, tandis que la norme chinoise n'inclut aucun des indicateurs suivants : "social", "qualité de l'air" ni la plupart des indicateurs "services écologiques" ; se concentrant principalement sur les performances hydrauliques.

#### ABSTRACT

The concept of green infrastructure is increasingly seen as a win-win solution for addressing a wide variety of water related urban issues. In this regard, a comprehensive performance assessment of said infrastructure can help make them more appealing to multiple sectors and improve funding prospects. Guidelines to aid in selecting the most appropriate performance and impact indicators have been developed in recent years. To evaluate the status of international guidelines dealing with various functional aspects of green infrastructures, this study critically examines various representative ones and compares them. Our review shows considerable differences between the available guidelines, for example: the EU guideline is the most comprehensive one considering the number of addressed performance indicators, while the Chinese standard does not include any of the "Social", "Air quality" and most of the "Ecological services" indicators; mostly focusing on hydraulic performance.

#### MOTS CLES

Analyse comparative, Infrastructure verte, Évaluation d'impact, Indicateurs de performance, Urbanisme

#### KEYWORDS

Comparative analysis, Green Infrastructure, Impact Assessment, Performance Indicators, Urban planning

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## 1 MULTI-FUNCTIONAL URBAN GREEN INFRASTRUCTURE

During the 1980s, urban planning and development began considering natural water and nutrient cycles, with water flows managed in a way to replicate the original ecosystem (Radcliffe, 2019). In North America, these philosophies were developed as *Low Impact Development (LID)*, then as *Best Management Practice (BMP)*, and *Green Infrastructure (GI)*. In Britain, the term *Sustainable Urban Drainage Systems (SuDS)* has been adopted. Similar policies were developed in Australia under the frame of *Water Sensitive Urban Design (WSUD)* philosophy (Fletcher et al., 2015). Taking inspiration from concepts used worldwide, the *Sponge City* concept was developed in China to redefine the relationship between people, water, and cities. Herein, components and drivers vary among communities, each emphasizing different aspects based on the catchments, infrastructure, seasonal climate, local water cycles, and social expectations.

By definition, all-natural, semi-natural, and artificial networks of multifunctional ecological systems within, around, and between urban areas, at all spatial scales are called GIs (Tzoulas et al., 2007). The GIs' ability to deliver multiple benefits makes them particularly attractive. However, GIs planning and evaluation tend to focus on one or a few functions, mostly related to stormwater management (Finewood et al., 2019). In this regard, a comprehensive performance evaluation of GIs currently in place can help to build trust in such new technologies and leverage the appeal of green solutions to different sectors and unlock funding opportunities.

## 2 CURRENT PRACTICE FOR ASSESSING THE PERFORMANCE OF A GI AND RAISING THE STANDARDS

Performance indicators (PIs) are essential pillars in the assessment process, and they are defined as: "An item of the information collected at regular intervals to track the performance of a system" (Fitz-Gibbon, 1990). Particularly, they are useful in assessing how well a project meets its objectives before, during, and after implementation. In the case of stormwater infrastructures, for instance, a cost-benefit comparison between grey and green infrastructure would be incomplete and unrealistic if it does not factor in the various functions of GI.

In the current approach for GI performance assessment, only one or a few important PIs are examined (Fu et al., 2021). However, a key element of the successful adoption and implementation of GIs as an alternative to grey infrastructure is the comprehensive assessment of the advantages they offer. It is very rare to find studies indicating how and how much GIs affect intangible benefits such as quality of life and well-being, aesthetics, and recreation (Manso et al., 2021). One of the factors of this deficiency can be the lack of a comprehensive performance evaluation system (including well-defined PIs and how to monitor them). In recent years, some pioneering societies (e.g., China, USA, Colombia) in GI implementation have developed guidelines to help choose the most appropriate performance and impact indicators. This study aims to critically examine guidelines from Asia, Australia, Europe, North and South America (to have geographical representativeness) and compare them to evaluate their status in dealing with various functional aspects of GIs.

## 3 AVAILABLE PERFORMANCE INDICATORS FOR GREEN INFRASTRUCTURES

First, we reviewed publicly available literature and materials to find out the most repeated and world-widely accepted PIs (e.g., Pakzad and Osmond, 2016; Gordon et al., 2018). In total, 37 PIs were extracted and classified into four broad categories: Hydrological, Economic, Environmental, and Social. Moreover, inspired by Viti et al. (2022), their "Functional response to environmental stressors" were distinguished between "only people" benefits, "only nature" benefits, and "people and nature" benefits<sup>1</sup>. In the next step, we analyzed the performance assessment of the GIs in the different guidelines to determine: 1) their proposed indicators to assess the performance of a GI project; and 2) their comprehensiveness across a range of social, environmental, and economic contexts to find out which performance evaluation standard addressed each benefit in which way and depth. In the current study, we focus specifically on five regions around the globe: Australia, China, Colombia, Europe, and USA.

## 4 INTERNATIONAL MANUALS ON GI PERFORMANCE INDICATORS

For Australia, as it is composed of several states, and they each have developed their own local standards for the

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<sup>1</sup> It should be noted that considering the PI-table size and the page-limits of the conference, a detailed table will be provided on the poster/presentation.

performance evaluation of GIs, only one specific example of their state standards is examined in this study. The state of New South Wales (NSW) has published a framework for valuing public space and green infrastructure (NSW department of planning and environment, 2022). The framework can be used to prepare economic evaluations, including cost-benefit analyses. In China, the Ministry of Housing and Urban-Rural Development (MOHURD) published the *Sponge City Performance Evaluation Index System* (MOHURD, 2016) and divided the evaluation into four grades (from “Excellent” to “Disqualified”). Besides the index system, seven items, including runoff volume control, water quality, and ecological conservation are used to assess project benefits (MOHURD, 2018).

Figuroa Arango (2020) specifically addressed the Colombian environment when recommending indicators that should be considered to evaluate and monitor GIs. The guideline is organized in 7 steps in which the last step is dedicated to various types of indicators to monitor GIs and classified them into 7 broad groups. A handbook on assessing NBS performance and impact was published by the European Commission in 2021 (Dumitru & Wendling, 2021). The handbook is designed to be applicable to GIs implemented across a wide geographic area and at a wide scale. It provides decision-makers with a set of indicators and methodologies to evaluate the impacts of GIs across 12 societal challenges, including climate resilience, water management, biodiversity, etc. In the USA, AECOM prepared the “Green infrastructure resource guide” (AECOM, 2017) for the United States Agency for International Development (USAID). They categorized the benefits of GIs in 11 classes and for each of them provided relevant indicators to aid in monitoring the performance of a GI solution.

## 5 RESULTS OF THE COMPARISON

Based on the findings, the EU guideline is the most comprehensive one considering the number of addressed PIs. Only a few indicators like “Grey infrastructure expansion/repair cost reduction” are missing in the current version. However, the term “indicator” is not well-defined and sometimes mixed up with “functions of GIs” and resulting in a long indicator list. As an example, “Citizen involvement in environmental education activities” is considered as a PI (while it is a function). Also, some of the indicators are not clearly defined and in the current state, their assessment may prove difficult and varying for each application (e.g., “Encouraging a healthy lifestyle”). Following the European document, USAID guideline has the second-most comprehensive PI list by addressing nearly two thirds of the indicators. In this document, PIs related to social benefits are somewhat neglected. Besides, some of the indicators are defined in an overly general way: e.g., “Air quality” or “Air temperature variations”. As a strength, in this guideline benefits gained from GIs are color-coded to identify the highest-impact design options. Also, all the PIs are combined with up/down arrows to show the direction of the index’s desirability.

In the Australian guideline everything is translated into the monetary scale (e.g., Value in \$ per m<sup>2</sup> of tree canopy); which could facilitate the decision-making process, especially in cost-benefit analysis. The most serious shortcoming of this guide is not addressing some of the significant benefits of these infrastructures, such as “Watershed Sustainability”. In contrast, the performance assessment standard for the Chinese sponge cities addresses “Watershed sustainability” and “Water quality” indicators in a detailed way, while it avoids evaluating the microbial and toxic material concentration. On the other hand, this document does not inscribe any of the “Social”, “Air quality” and most of the “Ecological services” indicators. In the Colombian guideline, there is still room for improvement of defining the PIs. As an example, for “Soil erosion control” function, instead of “Area conserved to prevent erosion processes” which might seem slightly unclear for decision maker, “Soil loss rate” can be adopted as a PI or instead of “Planting trees to reduce the effect of the urban heat island”, “Land surface temperature” can be used as a PI. Moreover, some of the suggested PIs are not related to monitoring the performance of a GI itself but they are rather suitable to evaluate the performance of the city planners/managers; like “Number of GIs that include participation of different stakeholders in the design”. Besides, this guideline emphasizes assessing the social and environmental (partially) performances of GIs and neglect their other important beneficial categories like watershed sustainability and water quality.

It should be noted that in some cases, different guidelines translated similar indicators differently: for instance, the “Prevalence of cardiovascular disease” indicator is suggested by the EU standard for evaluating “Human health and well-being” while the Australian standard uses “Physical activity and morbidity rate”, USA standard utilizes “No. of doctor visits” and in Colombia “Number of people using the GI to do sports” is adopted. Moreover, for some of the GI’s functions there is more than one indicator suggested by the literature (e.g., for “Managing stormwater runoff”: “Surface runoff in relation to precipitation quantity”, “Peak flow variation”, “Flood peak reduction”, “Height of flood peak”, “Runoff score”, etc.). Considering the available budget, the purpose of the project, the availability of data, and so on, one or more of them can be adopted by the practitioners.

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Furthermore, it is neither possible nor logical to evaluate some of the extracted indicators at the individual infrastructure level and for all types of GIs. For instance, bioswales may not have any special effect on tourism or the assessment of greenhouse gases reduction makes sense when several GIs function together. Generally, it is important to select the right set of indicators, depending on the decision context at which the indicators will be used.

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