remote sensing

Article

An Integrated Indicator Framework for the Assessment of Multifunctional Green Infrastructure — Exemplified in a European City

Jingxia Wang [1,2,*], Stephan Pauleit [2] and Ellen Banzhaf [1]

[1] UFZ - Helmholtz Centre for Environmental Research, Department Urban and Environmental Sociology, Permoserstraße 15, 04318 Leipzig, Germany; jingxia.wang@ufz.de (J.W.); ellen.banzhaf@ufz.de (E.B.)

[2] Technical University of Munich, TUM School of Life Sciences, Chair for Strategic Landscape Planning and Management, Emil-Ramann-Str. 6, 85354 Freising, Germany; jingxia.wang@tum.de (J.W.); pauleit@tum.de (S. P.)

* Correspondence: jingxia.wang@ufz.de (J.W.); jingxia.wang@tum.de; (J.W.); Tel.: +49-341-235-1557 (J.W.)

List of supporting materials

- Text S1: Synthetic evaluation of indicator framework I to III
- Figure S1: Relevant spatial extents of indicators from indicator framework I to III
- Figure S2: The percentages of supply and demand indicators from indicator framework I to III

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Text S1: Synthetic evaluation of indicator framework I to III, Figure S1: Relevant spatial extents of indicators from indicator framework I to III, Figure S2: The percentages of supply and demand indicators from indicator framework I to III.

Text S1. Synthetic evaluation of indicator framework I to III

These three indicator frameworks are also distinct considering further important aspects when applying in an assessment of multifunctional GI: 1) relevant spatial extent, 2) involved GI types (service provision units), 3) data availability, 4) their information regarding GI assessment (e.g. data sources and references/proved methods) and 5) whether it is a supply indicator or a demand indicator.

For the **relevant spatial** extent, the hierarchical system of NUTS [1] was taken (Nomenclature des Unités Territoriales Statistiques). It was generated by the EU to identify and classify the spatial units of the official statistics in all member countries. A distinction can be made between the regional scales R (NUTS 2; i.e. the basic region, and NUTS 3 is the smaller regional level; more details see Appendix S.1). Further differentiation refers to the EU-OECD functional urban area definition M (metropolitan scale and to the spatial database provided), U (urban scale, i.e. municipality) and S (site scale: site-based small scale, where only single site data is available). Fig. S1 shows that the spatial scales of each indicator from indicator framework I to III emphasize different scales. **Indicator framework I** mostly refers to the metropolitan and urban scales [2]. By searches on databases *(Web of Science, Scopus and Google scholar)* of all indicators and the analysis of each indicator and their respective scales one by one, we find that **indicator framework II** mainly addresses site and local scales, and **indicator framework III** presents mostly the site scale. For the latter our result shows that approximately 80% cannot be valued at the regional and metropolitan scales.

At these spatial scales, different datasets can be used to fulfil the AMGI: (i) Corine Land Cover (CLC) and High Resolution Layers (HRL) which enclose forests, grasslands, imperviousness zones, permanent water bodies and wetlands in Europe; (ii) national level, e.g. Natura 2000 (N2K) across 28 EU nations; (iii) the state or municipal level, e.g. Urban Atlas (UA) datasets and biotope mapping. AMGI will benefit from multiple spatial scales but it should not limit in the datasets we mentioned in this paper. More research ought to be engaged to bring higher resolution or even 3D datasets into GI assessment.

As to **whether it is a supply indicator or a demand indicator**, crucial parts when assessing multifunctional GI are assigning indicators to either supply (capacity) or demand of GI. Therefore each indicator from indicator framework I to III is associated to the one or the other. In total, the percentages of indicators from these three prominent frameworks are different (Fig. S2). In **indicator framework I** and **II**, more than 50% of indicators reflect the supply of GI from the ecological perspective. However, in **indicator framework III**, there are more demand indicators. From this perspective, indicators in **indicator framework III** enrich the demand indicators in our indicators pool.

Overall, conducting AMGI at multiple spatial scales is important to fully capture the benefits of GI and understand the interlinkages between GI at these scales. However, it is a big effort to do the entire assessment at all scales simultaneously, since a large number of compromises and conflicts should be handled according to above-mentioned aspects. One has to prioritize certain scales depending on the purpose of the use of the results. Is it to support a city wide strategy or is it for planning at more detailed levels, its spatial extent, data availability or the focus on supply or demand of GI will be determinants for AMGI deploying these results.

As common ground, these three frameworks have enhanced the development of GI concept and foster realization of GI assessment in urban areas from different aspects, shown in Figure 5. The multi-dimensional analysis underpins the individual contributions to the GI concept of these three indicator frameworks, i.e. **indicator framework I** contributes to inclusion of comprehensive ESS provided by GI, especially within a highly urban focus; **indicator framework II** provides multiple GI benefit groups and incorporates more human health aspects; **indicator framework III** is composed of more monetary valuated indicators and therefore potentially facilitates GI concept towards a shift in green economy. We hence suggest enclosing indicator framework I to III while undertaking an individual AMGI.

Figure S1: Relevant spatial extents of indicators from indicator framework I to III

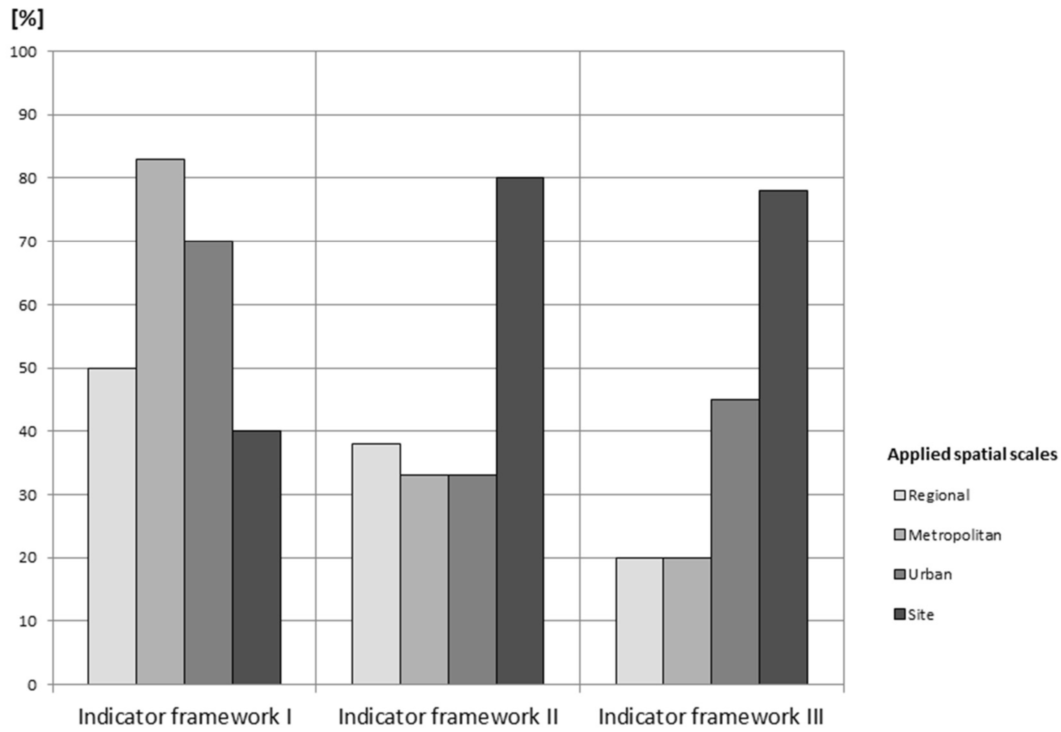

Figure S1 Relevant spatial extents of indicators from indicator framework I to III

Figure S2: The percentages of supply and demand indicators from indicator framework I to III

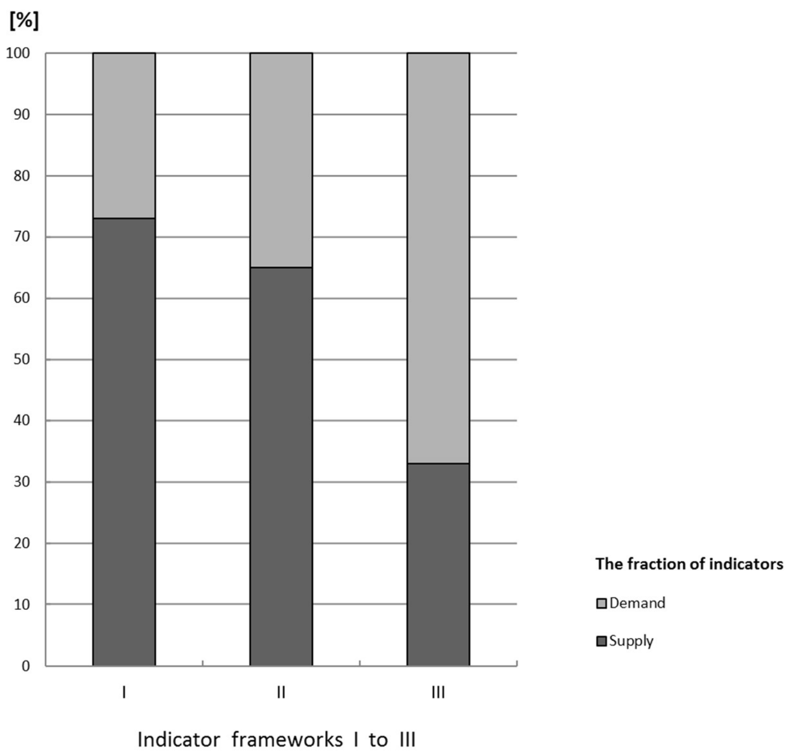

Figure S2 The percentages of supply and demand indicators from indicator framework I to III

References

1. European Commission (EC), Nomenclature of Territorial Units for Statistics. Available online: https://ec.europa.eu/eurostat/web/regions-and-cities/overview (accessed on 04.04.2019). **2016**.
2. Maes, J.; Teller, A.; Erhard, M.; Liquete, C.; Braat, L.; Berry, P.; Egoh, B.; Puydarrieux, P.; Fiorina, C.; Santos-Martín, F., Mapping and assessment of ecosystems and their services-Urban ecosystems 4th Report. **2016**.