Comparing the implicit valuation of ecosystem services from nature-based solutions in performance-based green area indices across three European cities

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Abstract

Performance-based green area indices are increasingly used as policy instruments to promote nature-based solutions in urban property development. We explore the differences and parallels of three green area indicators: Berlin's Biotope Area Factor (BAF), Stockholm's Green Area Factor (GYF) and Oslo's Blue Green Factor (BGF). As policy instruments they vary in their complexity and goals for green and blue structures. The urban planning literature devotes increasing attention to urban ecosystem services (ES) and its potential for utilitarian valuation including assigning preference weights, valuation and pricing of green and blue characteristics of urban development projects. Our comparison shows, however, that nature-based solutions in urban development projects in these three cities are largely planned, designed and implemented without using an explicit ES approach. Nevertheless, the choices of green structures and weighting of areas and structures in each city's performance-based index constitute implicit valuation of bundles of ecosystem services. By investigating how the three indicator systems' scores vary in parcel-scale development projects, we identify which ecosystem services each system implicitly promotes and neglects. We discuss how variation in the systems' complexity is the result of policy instrument design trade-offs between comprehensiveness and implementation costs. We argue that using physical proxies of performance in lieu of valuation of ecosystem services lowers site-specific information costs of green area indices at property level. In the absence of an explicit ES approach, performance-based green area indices in the three cities have been encouraging nature-based solutions in urban development without pricing of ecosystem services, without apologies.

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1. Introduction

Green area points, blue-green factor, biotope factor, green points, green space factor—which we here collectively call *green area indicators* (GAI)—have been designed to promote nature-based solutions at the property level in urban development for housing, commercial, or administrative purposes. GAI are all generally defined as the ratio of the area of biologically available surfaces (i.e., those covered by vegetation, open water, permeable paving and storm water infiltration, etc.) compared to total parcel area (Keeley, 2011; Kruuse, 2011; Peroni, Pristeri, Codato, Pappalardo, & De Marchi, 2020; Aamlid et al., 2019). Scores for surfaces types are weighted according to attributes such as permeability to water, runoff storage ability, relationship to soil functioning, naturalness of the vegetation, capacity to be suitable habitats for plants and animals, and green amenities for people (Kruuse, 2011). Surfaces with greater vegetation coverage, more permeability to rainwater and higher suitability as habitat for biological diversity will represent areas with higher ecological effectiveness and a range of ecosystem services in urban areas (Gomez-Baggethun & Barton, 2013).

Ecosystem services (ES) provide a conceptual framework to aid decision making in urban planning for green infrastructure (Gomez-Baggethun & Barton, 2013). For example, the ES cascade model (Potschin & Haines-Young, 2011) details how biophysical components of urban blue and green infrastructure perform ecological processes, which generate benefits to urban residents that can be valued and compared. Ecosystem service research is maturing towards policy applications (Chan & Satterfield, 2020), and performance-based planning approaches that integrate supply and demand of ES for urban planning are increasingly being demonstrated by research (e.g., Cortinovis & Geneletti, 2020; Langemeyer et al., 2020). An ES approach also suggests that economic valuation and pricing may be an instrument that can be used to promote urban nature-based solutions (Gomez-Baggethun & Barton, 2013).

A central purpose behind many of the GAIs is to establish a minimum standard for the proportion of blue and green elements that a developed parcel must contain (Figure 1). As most towns and cities have space constraints, there is a need to evaluate urban how blue and green elements contribute to ES to justify maintenance and expansion of urban blue-green infrastructure. Coupling GAI systems to the ES framework can extend the scope of benefits that urban planners consider (Hauck, Görg, Varjopuro, Ratamäki, & Jax, 2013), as well as provide a context for assessing spatial variation in benefits and corresponding value of ES provided by blue-green infrastructure. GAI systems constitute *performance-based indicators* that are capable of integrating a ES framework in municipal land use planning and project design without the use of economic valuation. To paraphrase a seminal paper by Vatn and Bromley (1994), land use planning choices can be made ‘without prices, without apologies’. Instead of explicitly valuing or pricing of ES, GAI systems value them implicitly through qualitative weighting of blue-green surfaces and structures.

Performance-based GAI combine two complementary mechanisms for screening urban development projects: criteria weighting and performance thresholds. By differentiating importance weights for blue-green structures, the design of projects in inner or outer cities can be flexibly adapted to existing vegetation, plantable area and water surfaces. Planners can also accommodate for less available space for green infrastructure in, for example, inner cities by lowering the minimum required GAI value thresholds. Cities' vary in how their policy instrument designs combine weights and minimum performance scores.

Several variations of GAI systems have been developed in Europe and North America, although not all of them are presently in use. The precursor and inspiration to them all is the *Biotopflächenfaktor* (Biotope Area Factor, or BAF) which was developed for Berlin in 1990 (Becker & Mohren, 1990a). Several of the GAI systems that have come since are strikingly like the BAF. Others vary in terms of the themes they were intended to address, the weighting and complexity of factors that go into calculating their indicator score, and the minimum target scores that development projects must meet (Stavset, 2013). A common policy driver of GAI systems is to address stormwater management challenges. Urbanization increases the extent of impervious surfaces that seal the soil, thus changing the urban hydrological cycle and preventing infiltration of stormwater. Depending on the percentage of artificial impervious cover, between 30-55% of rain falling in a city can run into its stormwater drains (Haase, 2009). This creates considerable demand for costly technical infrastructure that may not be dimensioned for extreme weather events, as well as producing substantial negative effects on both aquatic and terrestrial habitats located downstream from stormwater management outlets (Barnes, Morgan, & Roberge, 2002). An implicit preference for stormwater management services is therefore 'built in' to GAI systems using importance weights for structures with high storage and infiltration capacities.

Finding similar physical proxies for multiple ecosystem service benefits is technically challenging and requires costly monitoring. Therefore, performance-based systems that wish to promote ES in urban land use development face trade-offs familiar to environmental policy instrument design between outcome efficiency and process efficiency (Sterner & Coria, 2012; Vatn, 2016). The information costs become greater, and process efficiency lower, with both increasing spatial resolution and as ecosystem service valuation passes from informative to decisive and technical policy design purposes (Barton et al. 2018). Quantifying ES for different property level configurations of nature-based solutions, while accounting for existing landcover on-site, and in the surrounding service areas, can be prohibitively expensive for the individual property developer. Area-based landcover types are therefore used as proxy indicators for the benefits of each nature-based solution. The greater the resolution at which structures and qualities are classified and weighted, the closer area-based indicators get to proxying individual ES. Based on urban ecosystem service assessment literature (e.g., Cortinovis & Geneletti, 2020; Langemeyer et al., 2020), we expected to find the green area indices framed within an ES rationale. If ES are used explicitly for targeting nature-based solutions, we would expect property users' demand for ES—and the green structures that provide them—to determine weights. The assessment contributes to the wider literature analyzing the uptake of ecosystem service science in policy design (Chan & Satterfield, 2020; Laurans, Rankovic, Billé, Pirard, & Mermet, 2013; Lautenbach et al., 2015).

Set against this background, this paper explores different GAI systems to seek answers to the following research questions: (i) To what extent is the ES framework evident within either the motivating rationale or the operational structure of a GAI system? (ii) Which elements are included in GAI systems, what are their values and how are they determined? (iii) Do GAI differentiate minimum requirements spatially, if so, why? (iv) What have been main experiences of the system from the point of view of practitioners?

2. Method and Materials

2.1 Ecosystem service design of GAIs

We assessed the three cities' regulations and guidance documents for implementing GYF (Stockholm's Green Area Factor), BGF (Oslo's Blue Green Factor) and BAF (Berlin's Biotope Area Factor) systems, looking for evidence of the explicit use of the ES framework and associated blue-green infrastructure benefits and values. Berlin, Stockholm and Oslo are capital cities, and thus provide comparability in terms of implementation resourcing in municipal governments. Their respective GAI systems were selected to capture a representative complexity gradient.

Berlin's BAF is strikingly simple—with low criteria detail—whereas Oslo's BGF and Stockholm's GYF have, respectively, medium and high criteria detail. The three cities are also standardizing, evaluating, and benchmarking their systems with other cities as GAI system use becomes more widespread. The GAI systems provide an opportunity for implementing ES in municipal planning and decision-making, allowing for diversity in adaption across cities despite a general consistency in the approach. Our results include qualitative descriptions of all three GAI systems, structured around the research questions identified above, including brief descriptions of the historical planning and design context for each.

2.2 GAI performance

We used a set of nine examples of development, infill or revitalization projects drawn from the three cities to explore how scoring varies across the BAF, GYF and BGF systems. The nine cases represent a variation of situations and constitute a stress test for the three GAI systems with typical projects for the three case study cities. Descriptions of the developments' site plans are provided in the Appendix A. We further explored the degree of consistency to which projects met or failed to meet minimum requirements. We evaluated both whether more detailed and differentiated criteria systems—with criteria more aligned to individual ES—lead to higher or lower acceptance rates, and what role minimum performance criteria play in each system.

Digitized site plans provided data on area, composition and quantities of relevant surface cover and blue-green structural elements for each project. For Stockholm and Oslo projects, we used area calculations for surface categories provided from developers' site plans (presumably generated by planning software) and/or reproduced in municipalities' supporting documentation for their GAI system (Appendix A). For Berlin projects, we used data from Liebmann (2017), which were generated by creating shapefiles (polygons) from parcels' raster images. Liebmann (2017) does not specify the resolution of the raster layers, but the detail in the resulting polygons indicates it was at least 0.5 m. We then used parcel and project attributes (% area occupied by building, buildings intended use and parcel location) to determine the GAI systems' applicable minimum score, as specifics by each system (see 3.2.1-2.2.3 for descriptions of criteria each system uses) . Finally, we assigned point values to projects surfaces and structural elements, as specified by each of the three GAI (see criteria categories and weights in Table S1), and assessed whether project GAI point totals met the applicable minimum score.

The three GAI systems use different point score scales, which makes direct comparisons of the systems' target scores inappropriate. For example, BAF values do not exceed 1 because the system uses sub-factor weights ≤ 1 and only one additional factor. In contrast, both GYF and BGF allot considerable points for additional factors, such that projects' final values can theoretically be as high as 2 for BGF or 4 for GYF.

The site plans from the development projects we included in this study provided most of the information needed to calculate an estimate for each systems' GAI point scores. We opted to be conservative when awarding point scores, and assumed that project parcels did not contain elements unless they were explicitly included in project plans. For example, the GYF system uses a higher score for oak trees than other tree species. We used this higher score only if the project plans explicitly identified trees as oaks.

2.3 Policy instrument design

Finally, we discuss the performance of projects under the three GAI systems in relation to three policy instrument design criteria (Sterner, 2003): (i) targeting effect of criteria weights and minimum performance requirements; (ii) information and transaction costs due to complexity; (iii) and flexibility. These criteria help us evaluate how each city's system seeks a balance between disaggregated targeting, implementation costs and instrument flexibility.

1. 3. Results

3.1 Adaptive ecosystem service design of GAIs

The supporting documentation for the GAIs emphasize the multifunctionality of urban green infrastructures. The cities' systems cite improvements in air quality and local climate regulation, together with enhancing conservation of biological diversity, as additional benefits that can result from increasing proportion of green areas (Stavset 2013). The original BAF includes eight sub-factors that correspond to categories of surface types with fairly intuitive connections to variation in their hydrological function. The more recently developed GYF and BGF systems include either more sub-factors or involve more detailed additional factors to better account for how various green infrastructure components contribute to various environmental benefits. The total number of sub factors and additional factors within the GAI systems range from 9, for the original BAF, to 53 for Stockholm's GYF (Table 1). A complete comparison of the criteria hierarchy for the GAI of Berlin, Oslo and Stockholm is visualised in Table S1 (Supplementary material).

3.1.1 Berlin – Biotope Area Factor (BAF)

Berlin´s *Landscape Program* (LaPro; Landschaftsprogramm - Berlin.de) describes the basic objectives and measures for promoting high quality urban development with respect to ecosystem function, biotope and species protection, landscape aesthetics and recreational use for the entire city (SenStadt, 2016b). At a secondary planning level, sections of Berlin have *Landscape Plans* that establish and define objectives and measures from the LaPro for specific sub-areas of the city. Just under half of Berlin's Landscape Plans (15 out of 32) use BAF as an ordinance for building permits. Even in these areas, however, implementation of the BAF cannot restrict or hinder commercial use or development as specified by the LaPro or Landscape Plans (Becker & Mohren, 1990a). In sections of Berlin where BAF is not a binding component of a Landscape Plan, BAF can serve as a voluntary guideline for encouraging environmental/ greening measures in parcels' landscape design when changes to the existing building structures are proposed.

Berlin's municipal governance regimes and urban planning and design have used an ES approach in many of the recent documents and policy instruments—such as the Berlin strategy 2.0 (SenStadt, 2016a), the current LaPro (SenStadt, 2016b) and the climate change adaptation plan (www.stadtentwicklung.berlin.de/planen/stadtentwicklungsplanung). However, earlier planning documents and policy instruments, including the BAF itself, referred to "ecosystem-friendly systems or areas" but did not use ES-specific terminology. Although the ES concept was introduced relatively late to Berlin's public planning vernacular, Berlin's public administration and planners have used several common ES indicators for decades—just without reference to the ES framework (Kabisch, 2015; Rall, Kabisch, & Hansen, 2015).

German academics innovated a variety of standards in the 1980s for promoting adoption of more ecologically functional site design within the built environment (Keeley, 2011 and references within). The BAF came about towards the end of this period to address growing soil impermeability and create green amenities on both public and private property. According to its authors, the BAF was designed to meet three objectives: (1) improvement of the microclimate and air hygiene quality; (2) safeguarding soil function and the efficiency of water management; and (3) increase in the availability of areas as a habitat for plants and animals (Becker & Mohren, 1990a). The BAF was first implemented in 1997 (Keeley, 2011), and was used in its original form until December, 2019, when additional categories were added to differentiate between two types of green walls and three types of green roofs (Knaus & Haase, 2020).

The BAF preference weights/ scores were established based on five criteria of environmental performance: (1) evapotranspiration capacity; (2) ability to hold and bind airborne particulates; (3) capacity to retain and infiltrate stormwater; (4) potential to maintain and support natural soil functions; and (5) availability as plant and animal habitat (Becker & Mohren, 1990a). While these parameters imply several regulating ES, the terminology does not explicitly invoke an ES approach. BAF developers then identified a list of relevant green elements and then scored each based on their cumulative impact with regard to these parameters, with factors ranging from 0 (impervious surfaces) to 1 (vegetated surfaces with full soil depth). The newest BAF system uses 12 surface types, with scores that vary with respect to surfaces' permeability, soil depth and the presence of vegetation. The BAF does not differentiate by vegetation form (i.e., grass, bush or tree) or its taxa. Valuation of surfaces contribution to the urban environments thus captures green surfaces' capacity to retain and infiltrate stormwater, with less emphasis placed on other environmental criteria.

Berlin planners established BAF scores with reference to environmental targets in German Environmental and Planning Law, and the process included roundtable discussions involving interdisciplinary expertise (Becker & Mohren, 1990a). However, the reports that describe the process provide no references to specific scientific studies to support either the selection of environmental performance criteria or individual rankings of the green infrastructure elements (Becker & Mohren, 1990b). The reports also do not identify either the participants in the roundtable discussions or which disciplines they represented. The current performance scores are the same as those from the original assessment, although the new BAF documentation now includes more detailed descriptions of the categories of green infrastructures (Keeley, 2011).

As stated earlier, Berlin administrators do not use BAF as an ordinance throughout all areas of the city. In areas where achieving a minimum BAF score is a requirement, the system's targets are not differentiated by parcel location. The BAF system's designers established minimum score target values for individual sites by considering the underlying urban development model of the city and recent planning concepts from the Landscape Plan, with a goal of setting realistic targets that are achievable for the vast majority of sites. Target scores vary according to land uses (i.e., commercial, residential, etc.), occupancy index (i.e., the proportion of the site covered by buildings) and whether projects constitute either new construction or modifications of existing buildings. For example, residential projects on sites that involve modifications or expansions of existing structures on sites with higher occupancy indexes (> 0.5) must meet a BAF score of 0.3. The targets for such projects on sites with intermediate occupancy (0.38 to 0.49) and low occupancy (< 0.37) are 0.45 and 0.6, respectively. Residential sites with new construction must meet a BAF target of 0.6, regardless of the occupancy index. Sites that are either exclusively commercial use, administrative use or residential but with least one floor of commercial use have a lower target (0.3) regardless of site occupancy index. Because such commercial and administrative use buildings tend to be clustered, the spatial autocorrelation of both land use types, and maximum parcel coverage entails at least some spatial differentiation in target scores.

Where the BAF has been used as a regulation, it has been an effective means of increasing green cover and green functionality in the inner parts of Berlin. New developments need to meet the BAF targets in accordance with these areas' Landscape Plans. The BAF provides a simple criterion that can be assessed and interpreted by both developers and authorities without needing additional expertise, thereby reducing information and implementation costs. Flexibility inherent in this simple structure also has advantages. Developers are free to select the permeable and green surfaces they find are most suitable for their sites, providing solutions that are cost-effective and have the greatest benefit for both themselves and the users of the development. Architects, developers, and property owners are reported to praise the BAF system for its ease of use, the immediate visual improvements its implementation generates, and the energy saving benefits that often accompany use of green elements in projects (Keeley, 2011; Nickel et al., 2014). The collaboration between the Berlin departments of landscape planning and land use planning ensured that the two planning instruments central to the implementation of the BAF—Landscape Programs and Landscape Plans—are working in a coordinated way.

3.1.2. Stockholm – Green Area Factor (GYF)

In Sweden, the *Grönytefaktor* (GYF) or Green Area Factor has been used as an instrument to address social values, biodiversity support and climate change mitigation and adaptation in urban development. There is no standardized approach for all Swedish cities, but rather parallel versions of the GYF system that share the same foundation and many of the same objectives. One of GYF's leading themes has been multifunctionality; the system promotes green elements providing functions (and corresponding benefits) across four different domains: social values (health, wellbeing and inclusion), biodiversity, mitigation of negative climate change effects and noise reduction. As with the BAF, GYF scores are calculated as the proportion of 'eco-effective' surfaces relative to the parcel's total area.

The ES approach is a conspicuous component in the conceptual underpinnings and design of the GYF. Due consideration of ES has become a legally binding obligation in Swedish municipal planning and policy setting (Chapter 6. §12 Environmental Code), although 'due consideration' is vaguely defined (Delshammar, 2015). ES terminology features prominently in the GYF supporting documents. However, use of an ES framework and its terminology has been largely restricted local governments and the public realm. Within the private sector, the adoption of ES frameworks and instruments like the GYF remain less common.

Stockholm's GYF was patterned from a system first developed for Malmö in 2001. The Stockholm version of GYF was developed through one of Stockholm's flagship sustainability initiatives, the 'Royal Seaport', and was later adapted to become a more general tool planning and developing housing districts within the city. The GYF system assigns scores to 15 categories of ground and building surfaces within a parcel for two general *sub-factors*: vegetation and water. These categories broadly resemble those used in the original BAF, although the GYF includes additional categories for preserved natural vegetation and open water surfaces, finer differentiation of both ground surface and green roofs' soil depths. Beyond the sub-factor values, GYF also assesses scores for *additional factors* from nearly 50 types of attributes or elements within surfaces that provide contributions to four categories: biodiversity, society (i.e., recreation), climate, and noise (Table S2). Individual elements can contribute additional factor scores in several of these categories, and this emphasis of multifunctionality results in a scoring system where the total scores from additional factors can outweigh general sub-factor scores.

Determining which specific elements and attributes will be included in a development project—and thereby contribute through additional factor values to the overall GYF score—is reasonably flexible and can thus be adapted to suit local conditions. However, projects must also meet a balancing requirement through incorporating at least 60 % of the possible elements or attributes within each of the four factor categories, regardless of whether the points from these additional factors are necessary to meet a GYF target score. This requirement is designed to ensure that design of blue-green elements serve to balance their contributions to generating multiple ES (Stockholms Stad, 2015).

Like the BAF, minimum GYF score targets are determined by parcel occupancy index. Unlike the BAF, GYF minimum scores do not vary according to buildings' intended use. Minimum scores are not differentiated by location. For projects where buildings occupy < 50% of the total parcel area, projects must meet a GYF score = 1.0. Minimum scores for projects on parcels with occupancy indexes between 50-70% and those > 70% are 0.6 and 0.4 respectively. In cases where these standard targets are neither possible nor appropriate (for example for security or cultural heritage considerations), planning and permitting authorities can apply a special (presumably reduced) target or specify which blue green elements must be incorporated into the parcel design. ES framework or its terminology are not used to explain or justify how these minimum targets were set.

Permitting authorities determine whether a parcel is suitable for development and what portion of the parcel buildings can occupy prior to any consideration of GYF criteria. This initial assessment also establishes whether specific natural habitat elements at a site need to be preserved or restored: a consideration which can partially dictate how parcels' development plans will meet GYF targets. The multifunctionality approach involves a degree of complexity that necessitates cooperation between different technical expertise: biology/ecology, building architecture and construction engineering, civil engineering, fire safety, etc. Supporting documents for the GYF stress that dialog about strategies for each parcel needs to be initiated early in the planning process. While preliminary evaluations reported that the GYF was relatively well received by developers (Stockholms Stad, 2014). However there were at least some property owners and developers who were frustrated by the target scores' perceived arbitrariness, and the difficulty of implementing the soil depth over built structures—which both increase load bearing abilities and heighten the risk for leaks—that is needed to achieve GYF target scores (Bajic & Toor, 2018; Samhällsbyggarna, 2019). Landscape architects and others who work with green solutions, on the other hand, generally praised the instrument for giving them a stronger role in the planning and construction process of urban green infrastructure (Naturvårdsverket, 2019).

3.1.3 Oslo - Blue Green Factor (BGF)

The BGF norm originated from the Future Cities project, financed by the Norwegian Ministry of Municipalities and Modernisation, which involved a collaboration between two municipalities (Oslo and Bærum) and landscape architects, engineers and contractors to develop Norway's first green points system: the Blue Green Factor, or BGF(2014). BGF(2014) acknowledged both the Malmö and Berlin GAI systems as its basis, although its level of detail fell in between these two predecessors. The collaborators also chose to modify the German and

Swedish systems' terms by adding the word "blue", to emphasize the central role of water in this norm (Framtidens Byer, 2014). Following two years of testing and feedback, Oslo municipality decided to revise and simplify the BGF criteria. Changes to the criteria addressed the criticism from housing developers that BGF was too complex and that minimum requirement scores were too strict. Property developers have repeatedly stressed the importance of simplifying the BGF scoring system such that property developers themselves can map and calculate blue-green factors for their development proposals with minimal effort. Simplification of building applications provides an incentive for property developers to adopt municipal norms. In the revised version the number of criteria was reduced. Oslo published a revised BGF guidance for developers in 2018, which became a mandatory requirement for all new housing project developments in 2019 (Oslo City Council, 2019).

Also in 2018, Standards Norway initiated a project to develop a national standard for a blue-green factor that could be applied by any Norwegian municipality. The goal was to provide support particularly to smaller municipalities, many of whom had applied the original Future Cities BGF criteria weighting and targets to much smaller urban areas than the original was designed for. The Standards Norway BGF was submitted for public hearing in 2019, and was adopted in May, 2020. Municipalities can decide individually if and how they wish to implement use of the BGF standard. Substantial changes relative to the Oslo BGF include a substantially higher relative weighting of trees that is more proportional to actual tree canopy size.

The technical experts who participated in creating the first BGF norm cite Oslo municipal strategies that identified which contributions by blue green structures are the most important for valuation (Framtidens Byer, 2014). These included blue-green structures' contributions to natural diversity, climate adaptation, stormwater management, recreation and air quality—although means of stormwater management was the most central criteria used for valuation. The supporting documentation for the 2018 BGF norm states that greatest weight is given to blue-green elements that improve stormwater management, as well as those that contribute to biological diversity and a 'good city life' (Oslo kommune, 2018). The contributions to improving water quality, air quality and reducing noise are evaluated as secondary. Aside from references to other point systems (BAF, GYF and BGF earlier versions), the supporting documents for the 2018 BGF provide no references for quantitatively assessing preference weights.

Unlike BAF and GYF, Oslo's BGF does differentiate the target score required in the inner (BGF > 0.7) outer (BGF > 0.8) portions of the city to reflect variation in building density (i.e., how much of a parcel is not occupied by the buildings themselves). Targets are not differentiated by building use, as BGF assessments are presently limited to residential projects. The intent of this simplicity it to minimize information and implementation costs, by restricting local assessment to the accounting of blue-green surface types and area. Property developers have repeatedly stressed the importance of simplifying the BGF scoring system such that property developers themselves can map and calculate blue-green factors for their development proposals with minimal effort. Simplification of building applications provides an incentive for property developers to adopt municipal norms.

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3.2 Comparison of GAI performance

Six projects met the target scores for the BAF system, and six projects met target scores for the BGF system (Fig 2 and 3). All nine projects effectively met the point target component of the GYF system (Fig 4), although the two developments in Stockholm were the only projects that met GYF system's balance score component. One of these projects (Norra Djurgårdsstaden) did not meet the target score for the BGF system. This made the other (Koppången) the only project to meet all three GAI systems' targets outright. The BAF and BGF systems were largely consistent in terms of which projects met point target minimums, although there were two exceptions. One Oslo project (Christian Kroghs gate) was only 0.01 point short of the BAF target but was further (0.1) from meeting the BGF target. Conversely, Stockholm's Norra Djurgårdsstaden project met the BAF point target, but was 0.23 point short of the BGF target. Appendix B (Supplementary Material) provides further structural explanations for differences in projects' scores. We discuss policy instrument design criteria explaining the differences in project performance in the Discussion.

4. Discussion - policy instrument design

The three performance-based GAIs are quite different in their level of resolution and minimum requirements, despite sharing a conceptual origin. In this section, we summarise the relative performance of the three GAI systems in relation to the development project, their characteristics and discuss policy design characteristics (Table 2).

4.1 Targeting effects of minimum performance requirements

Minimum performance scores are specific to each system. The higher proportion of projects that meet GYF minimum scores could at least partially reflect lower requirements in Stockholm (i.e., relative to maximum attainable score). Stockholm's GYF is an intermediate case where minimum performance score is determined by one criteria, and differentiated by parcel occupancy. Berlin's BAF has a relatively larger number of criteria (4) determining minimum target scores, a complexity that compensates for the relative simplicity of the BAF system criteria. While the simplicity of the weighting system reduces the ability to incentivize specific nature-based solutions, Berlin has a greater ability for municipal planners to target nature-based solutions to specific areas of the city. At the other extreme Oslo's BGF has a remarkably simple inner-outer city targeting criteria which minimises costs for the municipality. The difference could be explained in part by the larger proportion of municipally owned land in Berlin, whereas the city of Oslo owns very little land for residential development. The ability for spatial targeting should therefore be larger in Berlin, leading to a more detailed set of minimum performance requirements.

4.2 Targeting effects of GAI weighting

The three systems all state in principle that urban developments have as their objective to provide a selection of ES and support biodiversity. GAI system performance is a multi-criteria decision problem, in which criteria weighting should be associated with the relative importance of each individual ES the blue and green elements provide (Cortinovis & Geneletti, 2020;

Langemeyer et al., 2020). In the GAI systems we investigated, however, the weights are associated directly with each blue and green surface and structure. The individual, per unit, contribution of these elements to target ES is not directly defined and therefore implicitly valued. Indeed, policy instruments' design often does not explicitly reflect ES valuation research literature—resulting in implicit and indirect valuation of many ES (Chan & Satterfield, 2020; Laurans et al., 2013; Lautenbach et al., 2015)

Not calibrating GAI weights to correspond with demand for ES leads in principle to efficiency losses. For example, the importance of stormwater management—Oslo's primary motivation for the BGF system—is either low or zero on properties near the shoreline. Nevertheless, the BGF prioritizes structures with higher infiltration and water storage potential regardless of location. Similarly, trees have the same score throughout the city, even though their role regarding amenities can vary spatially. In the city center, trees provide green views and improve aesthetics. Elsewhere, however, unobstructed views—for example of the shoreline—may compensate for a lack of green views. Trees located here be a dis-amenity by blocking views of the sea.

GAI weights assigned to surfaces and structures can also promote bundles of ES. For example, trees are more important (have higher relative weights) in the BGF system compared to the GYF, and are not even counted in BAF. The BGF weighting promotes trees' contributions to creating microclimate regulation, recreation and amenity ES beyond what vegetated surfaces without trees can provide—increasing the importance of other ES relative to just stormwater management.

In effect, the weights in the GAI systems provide direct incentives for supply of specific structures, but only indirectly provide incentives to supply the stated ecosystem service objectives of the GAI systems. Structures are implicitly 'priced' by developers through the comparison of importance weights with the cost of supplying the structure in a development design that meets a budget constraint. From the cities' perspective, there may be no need to provide direct weighting of ES in the GAI systems, because they are not mandated to optimise any demand profiles of residents. Local authorities' mandates are usually to ensure a minimum supply of municipal utilities. The private property development sector may seek to meet private residents' demand profiles within the public utility constraints required by regulation and building permitting systems. In such hybrid or mixed instruments, property developers are assumed to be more efficient than municipal planners at designing nature-based solutions that meet residents' private ES demands, while municipal planners are mandated to achieving minimum GAI norms that ensure 'sufficient' ES to the public off-property. The loss of targeting outcome efficiency is compensated by gains in procedural efficiency (Sterner & Coria, 2012; Vatn, 2016) in terms of reduced information costs and flexibility, as we develop below.

4.3. Information costs

Anecdotal evidence from Stockholm suggest developers regard the GYF system as costly to implement. The BGF system in Oslo was also criticized by developers for adding an additional design constraint to already existing regulations on open space requirements in residential projects[1]. Ecosystem service assessments rarely consider costs of acquiring information (Barton et al., 2018), which can be an important impediment to their implementation. ES assessments that

[1] OBOS uttalelse til Kommuneplan "Oslo mot 2030- Smart, trygg og grønn", dated 30.05.2014

involve modelling or attributing structures to ecosystem function require expertise that is not generally available with entrepreneurs or municipal planners. All three GAI systems provide low information-cost ES assessments. The greater criteria detail in Stockholm's green points system (GYF) articulates ES and biodiversity benefits of blue-green infrastructure more explicitly than the other two systems. However, information costs generally increase with the complexity of the criteria that need to be documented. In Stockholm, developers primarily bear these information costs as part of obtaining a building permit. The BAF system has the lowest compliance costs for developers because it both contains a smaller number of performance criteria and shifts some of the information cost to the municipality, which must provide more detailed classification of areas and their minimum requirements.

4.4 Flexibility

Based on GAI scores alone, the case studies indicate that minimum performance standards are harder to attain in the simpler Oslo BGF and Berlin BAF systems, than in the more complex Stockholm GYF system. The greater complexity of the GYF system initially provides developers with opportunities to incorporate blue and green elements that can achieve minimum performance requirements with many more design combinations. The balancing requirement reduces this flexibility somewhat, but it is still greater than in both BGF and BAF.

When the balancing criteria are included, none the projects from outside Stockholm meets the minimum criteria for the GYF. This demonstrates the obvious intention of a performance-based system: it provides incentives for project designers to make choices that are adapted to the local minimum requirements. The level of planning detail and the projects' design reflect the complexity of their city's respective GAI system. The two Stockholm projects were the only projects to attain the balancing requirement of the GYF system, and it was clear from their site plans that the properties were designed with the GYF criteria in mind. Both Stockholm projects included many of the elements that simultaneously fulfil several balancing requirements (fountains, pergolas), but are not incentivized in the other systems.

The reports of metric development and studies upon which the BAF is based cite no specific scientific studies to support either the selection of ecosystem service criteria or GAI weighting (Becker & Mohren, 1990a; Boetticher & Fisch, 1988). Moreover, the BAF concept remained entirely unchanged for nearly 30 years, in terms of the number and detail of the criteria used. The minor changes initiated in 2019 do not reflect evidence of using research results to update criteria or weighting. This is clearly a shortcoming of the Berlin application, which could be relatively easily addressed, given the increasing availability of green infrastructure performance data and remote sensing data. A drawback of direct weighting of blue and green elements is this approach lacks flexibility to adapt GAI systems to municipalities with different ES priorities than these capital cities. Smaller, less densely populated municipalities may have other needs, but it difficult to adjust weights systematically without a clear weighting methodology. For this reason, many smaller municipalities around Oslo have adopted the BGF system 'wholesale,' with identical criteria and weights, even though their stormwater runoff issues are less severe than they are in Oslo.

4.5 Uniformly diverse or tailored to site

Our results highlight the remaining gaps and discrepancies in the cross-scale implementation of NBS and ES mainstreaming: Much of the broader ES discussion has focused on specific green elements, larger green spaces or green infrastructure, overlooking the potential complementary and non-additive outcomes of working with different types of green elements (see e.g., Andersson, Haase, Scheuer, & Wellmann, 2020; Colding, 2007; Dunning, Danielson, & Pulliam, 1992). The potential contributions, assumed by the three GAIs, of the built environment to the overall supply of urban ES are still tentative and very likely context dependent (Andersson et al., 2019; Andersson et al., 2015). None of the GAI systems reviewed in this study explicitly includes or account for the character or quality of the area surrounding a site. Reconceptualizing all urban spaces as potential sources of ES (across the full range of services and not just specific regulatory functions or aesthetic values), enabled or constrained by their surroundings, would be an important step towards a less polarized positioning of grey against green (e.g., Prevedello & Vieira, 2010). This mind-shift would also offer new opportunities to connect policies and standards for built environments more solidly to green and green-blue infrastructures strategies.

5. Conclusions

We find that performance-based GAI in Berlin, Stockholm and Oslo have been implemented without the explicit use of an ES assessment framework to determine preference weighting or relative valuation of green and blue elements, which results in lost outcome efficiency with regards to meeting municipalities' ES objectives. However, the efficiency losses that may occur in some parts of the city from not differentiating relative valuation by ES are (at least partially) compensated at the city-wide level through greater process efficiency in implementation of a simpler system. Direct weighting of elements, rather than the ES they provide, reduces the information costs of attributing the ecological functions of different types of blue green elements to specific ES. We also see a hard trade-off between the increased flexibility that a GAI system gives developers and information costs which developers must be bear. Some of these information costs can be reduced without losing targeted outcome efficiency by decreasing GAI criteria complexity and increasing differentiation—spatially or by intended use—of the minimum performance criteria set by the municipality. This would shift some of the information costs from the developer to the municipality, as is exemplified in the contrast between the Berlin BAF and the Stockholm GYF. The lack of direct weighting of individual ES we found in all three GAI systems also resonates with studies of urban planning that have found the ES framework to be at odds with a rights-based planning (Rinne and Primmer, 2016). GAI systems are hybrid instruments aimed at guaranteeing a minimum (rights-based) access to public ES, while allowing for market-based adaptation to meet private demand. We speculate that rights-based planning approaches are also more prevalent in case study countries we have chosen.

Future research can contribute to development of more effective implementation and utilization of GAI systems by exploring how to increase system flexibility through adaptive scoring. This work should address how variation in the spatial context of a development may influence the importance (or value) of blue-green elements (Andersson et al., 2021; Andersson et al., 2019). GAI systems need regular updating in terms of the criteria they use. An appropriate assessment of projects' spatial context will also involve expanding GAI systems to include more land cover than just privately-owned parcels. Stockholm recently introduced a companion system for public land cover like parks, forests and boulevards: the GYF for public (Stockholms Stad, 2019). Similarly, Oslo is developing its BGF to consider minimum requirements for design of public spaces. Future work should explore how GAI systems can achieve greater targeting efficiency through spatial differentiation, while still limiting the information costs that come with greater criteria complexity. Exploration of GAI designs with public-private sector sharing of information and transaction costs looks promising. More generally, we see a need for research on how GAI systems can be designed to complement existing policy mixes (Ring and Barton 2015) that promote conservation and restoration of urban nature by both the private and public sector.

Despite the recent focus in the literature on estimating demand for urban ES and benefits, municipal performance-based systems for nature-based solutions do not value ES directly. By focusing on information cost-minimisation and dynamic flexibility, they are examples of ‘satisficing’ policy instruments that balance outcome and process efficiency. Paraphrasing Vatn and Bromley (1994), performance-based green area indices make it possible for municipal planners and property developers to *choose nature-based solutions*, *without prices*, *without apologies*.

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Table 1. Simplified graphical overview of the relative articulation of the green area indicator systems in Stockholm, Oslo and Berlin. See Table S1 (Supplementary information) for the complete table with criteria categories and weights.

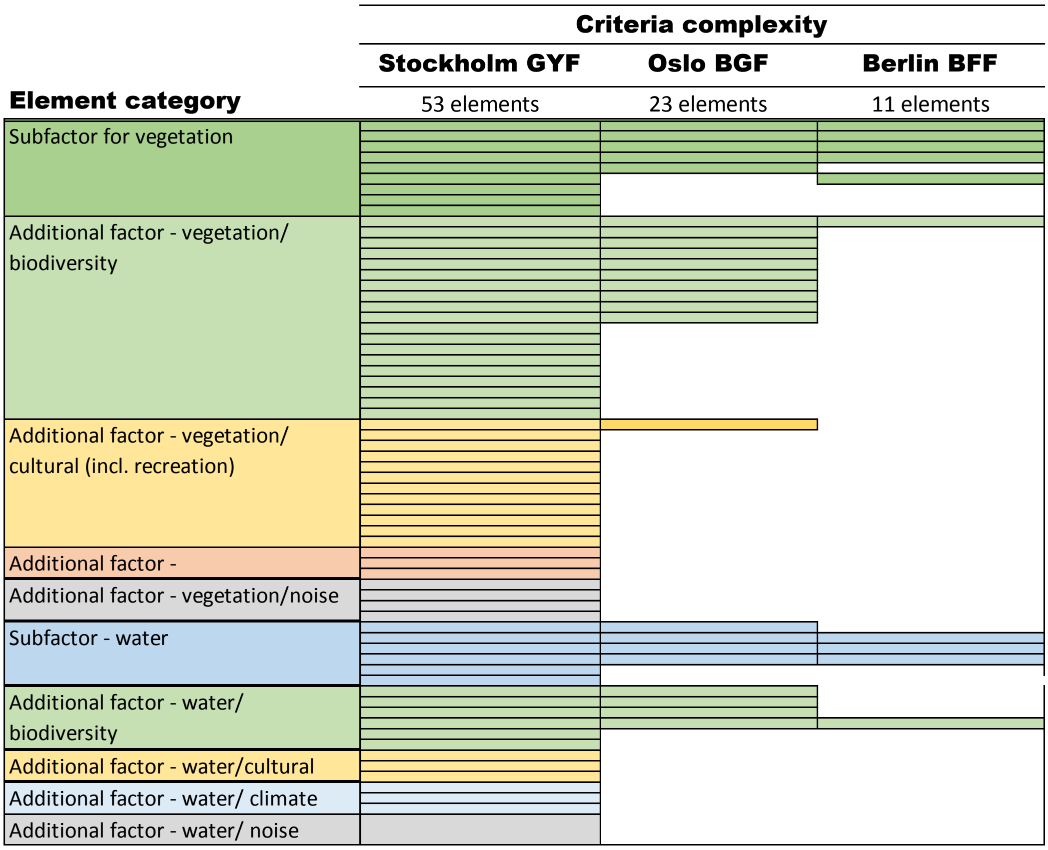

Table 2. Comparison of green area indicator (GAI) systems.

	Berlin (BAF)	Stockholm (GYF)	Oslo (BGF)
Case project developments that meet minimum performance target.	5	2 (9)	5 (6)
ES concept explicit identified in municipal planning?	Yes	Yes. Legally binding planning concept	No
Established	End of 1980s	2011	• 2014 Pilot Oslo-Bærum • 2018 Voluntary in Oslo • 2019 Norm in Oslo • 2020 Norwegian standard
Legal status	Mandatory & voluntary depending on planning area	Mandatory	Mandatory
Scope	Private property	Private property and public spaces	Private property
Performance focus	• evapotranspiration • air pollution mitigation • natural soil function • stormwater control • habitat	• social values (health, wellbeing and inclusion) • biodiversity • climate change mitigation • noise reduction	Primary: • stormwater management • biological diversity • good city life Secondary: • water quality • air quality • noise reduction
Assessment criteria	11	53	23
Weighting justification documentation	none	none	none
Design constraints	none	60% of structures and surfaces in each category in design	Manage 20 year rain on property
Minimum performance differentiation	Land use Occupancy index Building use New/established	Occupancy index	Spatial differentiation inner / outer city.
Policy instrument design			
Targeting effects	Indirect Lower	Indirect Higher	Indirect
Information costs for developer	Lowest	Highest	Medium
Information costs for municipality	Highest	Medium	Lowest
Flexibility	Lowest	Highest	Medium

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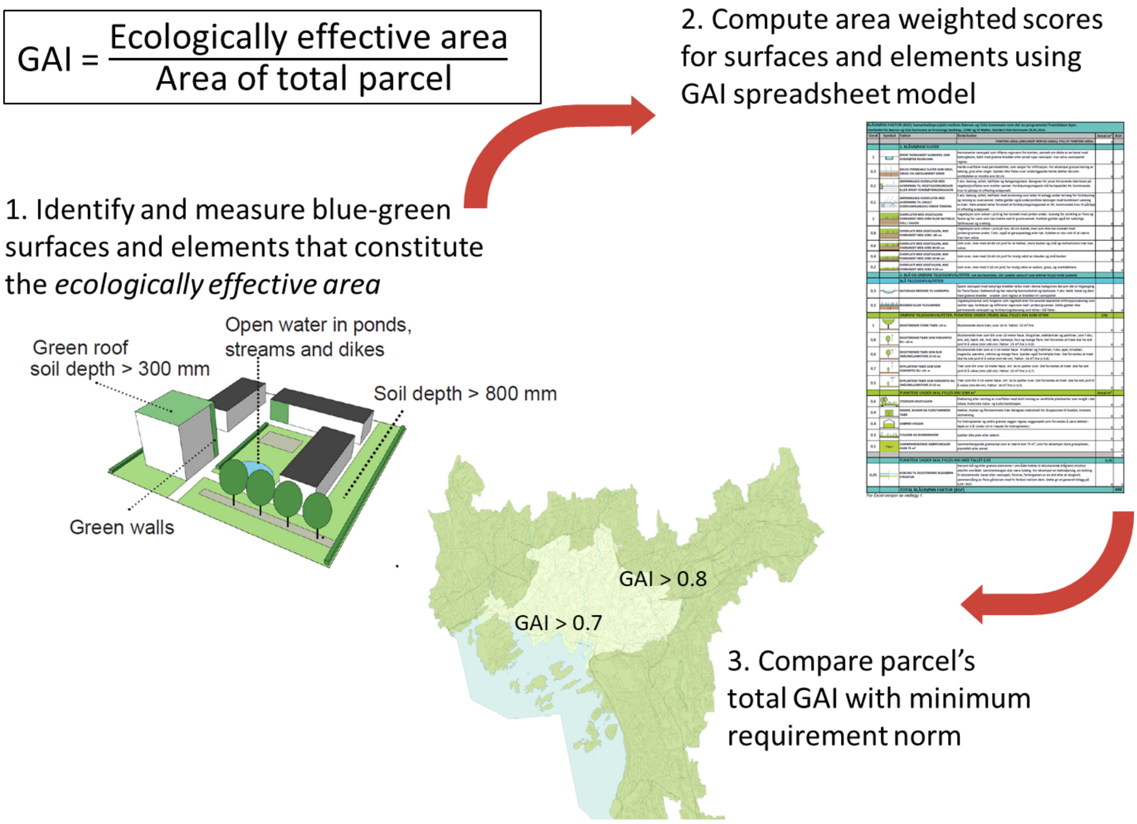

Figure 1. Conceptual design of Green Area Indicator (GAI) systems. Redrawn from Framtidens Byer (2014) and Stockholms Stad (2015).

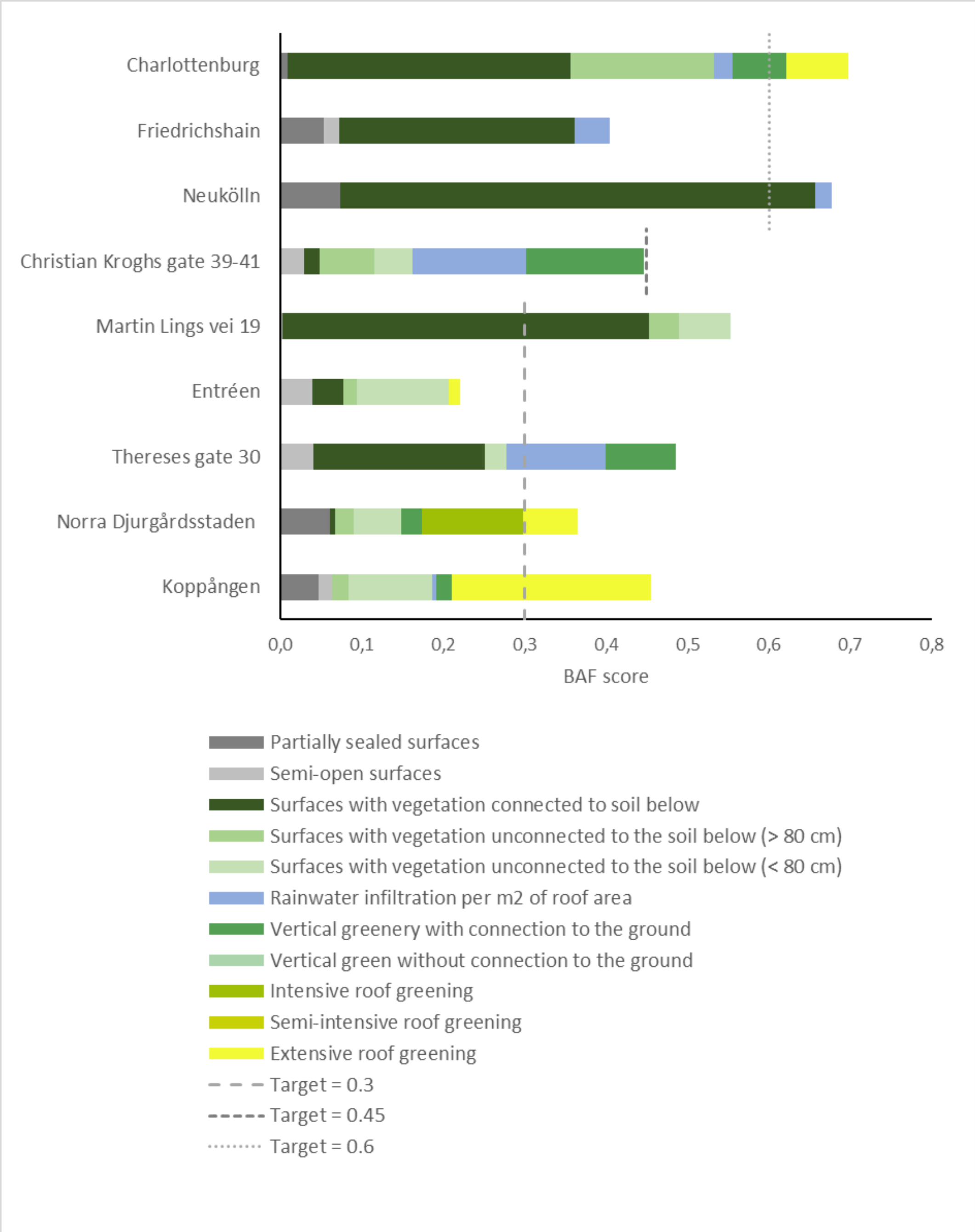

Figure 3. Parcel-scale point scores for 9 development projects according to Berlin's BAF performance-based green area indicator system. Colors within bars represent the contributions different surface types made to the overall score. Projects are grouped according to the minimum target scores, which are defined by parcel occupancy and intended use.

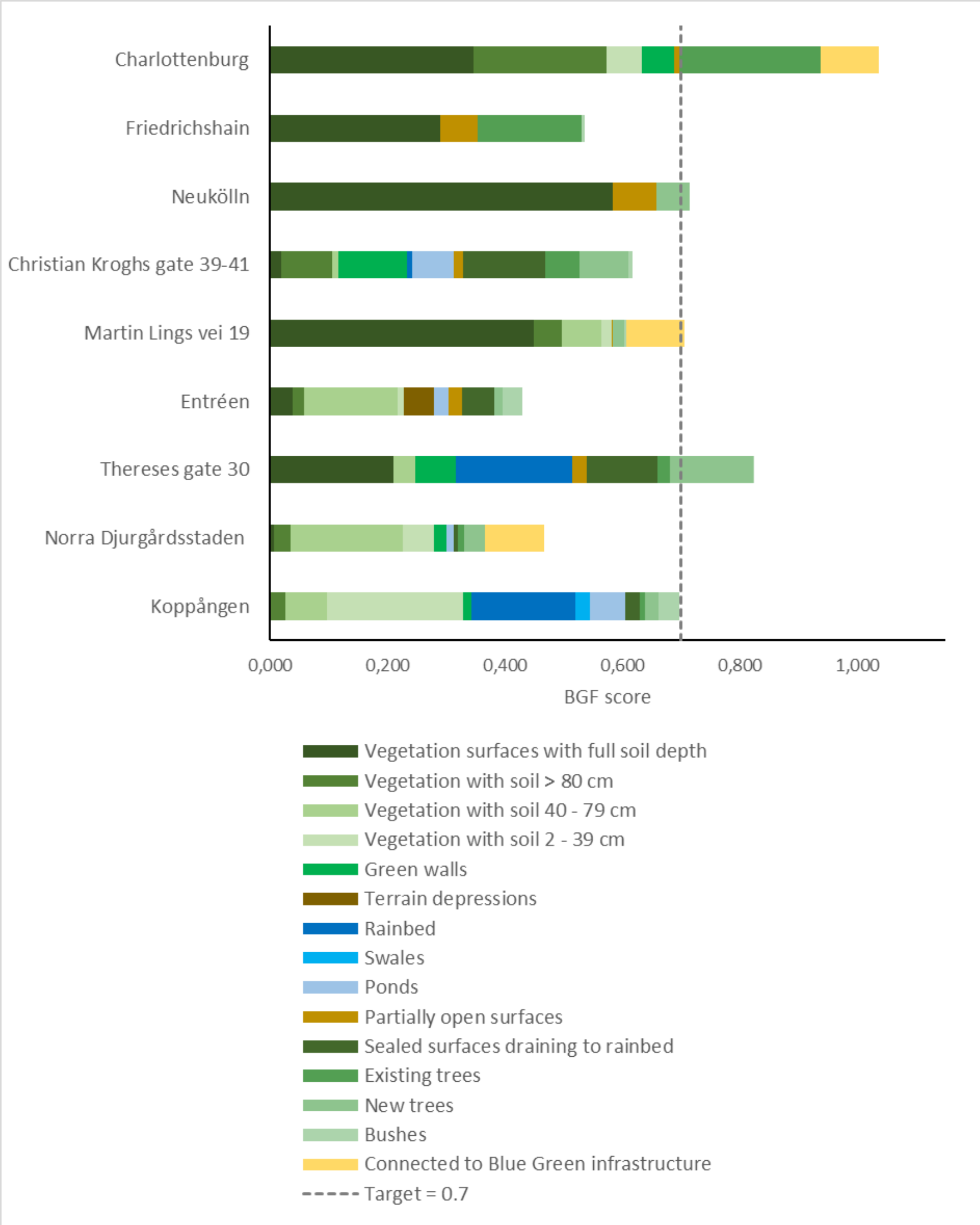

Figure 4. Parcel-scale point scores for 9 development projects according to Oslo's BGF performance-based green area indicator system. Colors within bars represent the contributions different surface types made to the overall score. The dashed line represents the minimum target score we applied to all projects (0.7), which corresponds with the target for projects located within the more densely built city center.

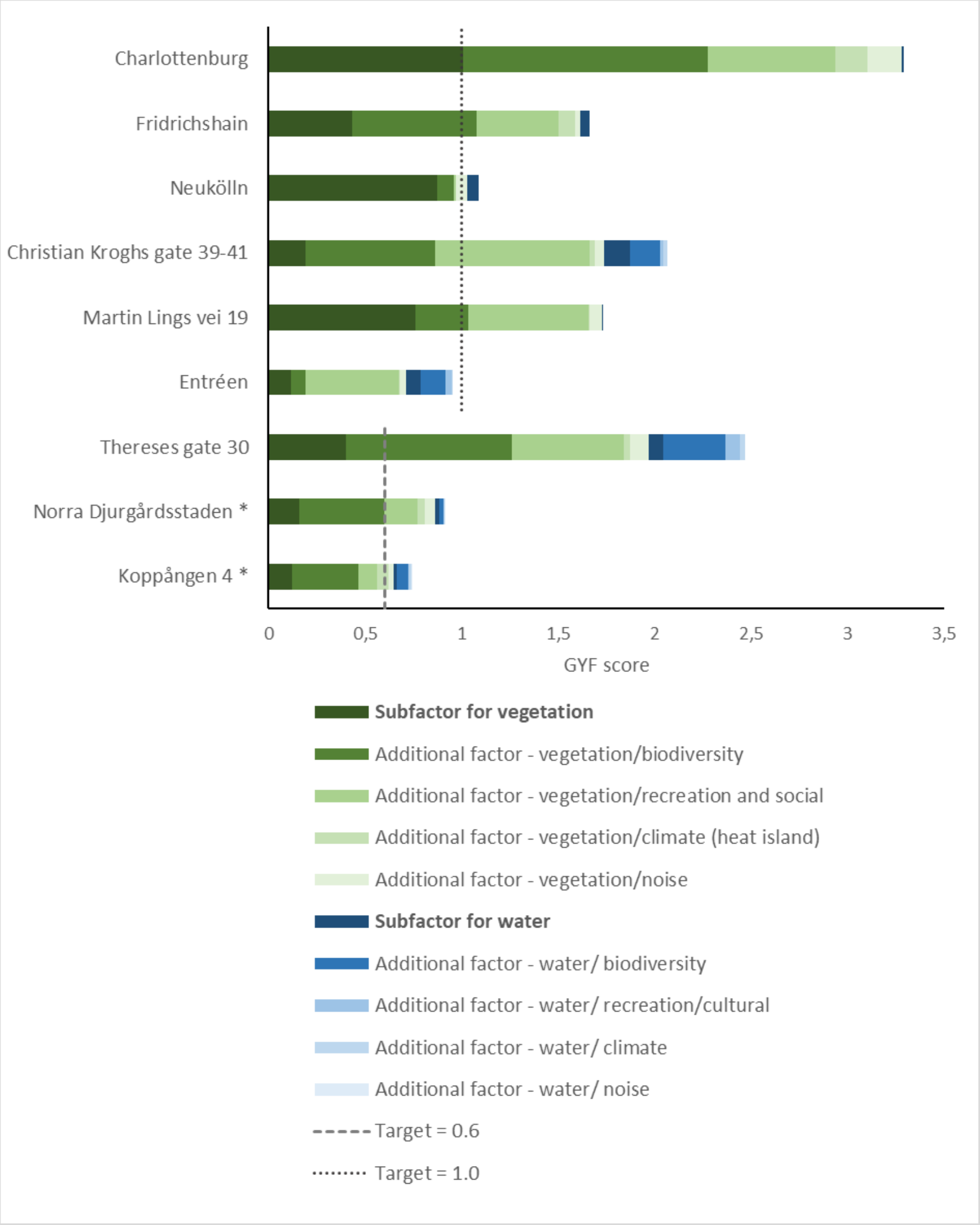

Figure 5. Parcel-scale point scores for 9 development projects according to Stockholm's GYF performance-based green area indicator system. Colors within bars represent the contributions different surface types made to the overall score. . Projects are grouped according to the minimum target scores, which are defined by parcel occupancy. Project names followed by asterisks also met a balance requirement by having at least 60% of the possible elements pertaining for each of four areas: biodiversity, social, climate and noise.

List of appendices

Table S1. Graphical overview of the relative articulation of the green area indicator systems in Stockholm, Oslo and Berlin

Appendix A. Project descriptions

Appendix B. Explanations of projects' blue-green elements and corresponding GAI scores

Stockholm GYF				**Oslo BGF**			**Berlin BFF**		
Element category	*Element name*	*Unit*	*Score*	*Element name*	*Unit*	*Score*	*Element name*	*Unit*	*Score*
Subfactor for vegetation	Preserved natural area	area	1.5						
	Ground vegetation connected to soil	area	1.5	Surfaces with vegetation associated with soil or bedrock	area	1	Surfaces with vegetation, connected to soil below	area	1
	Plant bed >800 mm deep	area	1.5	Surfaces with vegetation, not associated with soil > 60 cm	area	0,8	Surfaces with vegetation, unconnected to soil below (>60 cm)	area	0.7
	Plant bed 600-800 mm deep	area	0.4	Surfaces with vegetation, not associated with soil 40 - 80 cm	area	0.6	Surfaces with vegetation, unconnected to soil below (<60 cm)	area	0.5
	Plant bed 200-600 mm deep	area	0.1	Surfaces with vegetation, not associated with soil 20 - 40 cm	area	0.4	Surfaces with vegetation, unconnected to soil below (<60 cm)	area	0.5
				Surfaces with vegetation, not associated with soil 5 -20 cm	area	0.2			
	Green roof with >300 mm deep soil	area	0.3				Green roof	area	0.7
	Green roof with 110-300 mm deep soil	area	0.1						
	Green roof with 50-110 mm deep soil	area	0.05						
Additional factor - vegetation/ biodiversity	Vegetation on walls	area	0.4	Green walls	area	0.4	Vertical greenery up to a maximum of	area	0.5
	Vegetation on balconies	area	0.3						
	Diverse field layer vegetaion	area	0.05	Perennials and other ground cover	area	0.3			
	Natural species community	area	0.5	Native vegetation	area	0.6			
	Diversity on green sedum roofs	area	0.1						
	Flowerbed with butterfly-friendly growth	area	1						
	General bushes	area*	0.2	Hedges, bushes and multi-stemmed trees	area	0.4			
	Bushes producing berries	area*	0.4						
	Trees of special character	converted	3	Existing large trees > 10 m	converted	1			
	Existing trees	converted	3	Existing trees that can be expected to grow to over > 10 m	converted	0.8			
				Existing trees that can be expected to grow to be small to medium, 5 - 10 m	converted	0.6			
	New large trees (>30 cm dbh)	converted	2.4	Newly planted trees that are expected to be	converted	0.7			
	New medium trees (20-30 cm dbh)	converted	1.5	Newly planted trees that are expected to be	converted	0.5			
	New small trees (12-20 cm dbh)	converted	1						
	Berry producing trees (rowan, cherry,	converted	0.4						
	Nest boxes, bee cubes, etc.	converted	0.5						
	Beetle boxes (habitat for wood-dwelling	converted	2						
	"Faunadepot"	converted	2						
	Biological design elements/habitat-strengthening measures	converted	2						
Additional factor - vegetation/ recreation and social	Areas for social activity	area	1.2	Contiguous green areas over 75 m2	area	0.1			
	"cultural areas"	area	0.5						
	Rooftops, terraces, and greenhouses for cultural activities	area	0.5						
	Accessible roof terraces	area	0.5						
	Visible green roofs	area	0.05						
	Flower-dominated field layer vegetation	area	0.2						
	Experiential value of bushes	area	0.1						
	Bushes with edible berries and fruits	area	0.2						
	Experiential value of trees	converted	0.4						
	Fruit trees and flowering trees	converted	0.2						
	Pergolas and other constructions	area*	0.3						
	Habitat-strengthening design,	area	0.2						
Additional factor - vegetation/climate	Shade trees	converted	0.4						
	Pergolas and other constructions that	area	0.5						
	Green roof or multi-layers vegetation	area	0.05						
Additional factor - vegetation/noise	Vegetation covered ground	area	0.1						
	Vegetation on walls or sound barriers,	area	0.3						
	Vegeation on walls or sound barriers, climbing plants	area	0.1						
	Green roofs	area	0.05						
Subfactor - water	Water in ponds, streams and ditches	area	1	Open permanent water surface	area	1			
	Open permeable surfaces (crushed gravel, natural stone), reinforced grass	area	0.3	Partially permeable surface like gravel, crushed stone, and reinforced grass	area	0.3	Semi-open surfaces		0.5
	Half-open semi-permeable surfaces	area	0.2	Impermeable surfaces with drainage to vegetated areas or an open magazine	area	0.2	Partially sealed surfaces		0.3
	Impermeable surfaces with seams	area	0.05						
	Impermeable surfaces	area	0	Impermeable surfaces	area	0	Sealed surfaces		0
Additional factor - water/ biodiversity	Biologically available water in ponds, stremas and ditches within the property	area	4	Natural edges to water surfaces	area	0.3			
				Connection til existing Blue-green	unit	0.05			
	Ephemeral ponds, rain gardens	area	2	Rain bed or equivalent	area	0.3			
				Collection of stormwater for irrigation	unit	0,05	Rainwater infiltration per m² of roof area		0.2
	Draining stormwater from impermeable	area	0.2						
	Surface water storage magazine	area	0.05						
Additional factor - water/ recreation/ cultural	Open water surfaces	area	0.5						
	Biologically available water in ponds, streams and ditches (experiential value)	area	1						
	Fountains	converted	0.3						
Additional factor - water/ climate	Ponds and wetareas that hold water during summer's dry periods	area	0.5						
	Collection of water that can be used for irrigation	area	0.1						
	Fountains	converted	0.3						
Additional factor - water/ noise	Fountains	converted	0.3						

Appendix A. Project descriptions

We provide simple descriptions of the for these projects here:

Koppången 4 (Stockholm) development includes a multi-floor apartment building and its courtyard within a 2830 m^2 property. The courtyard's landscaping utilizes small trees, perennials plantings designed to improve stormwater infiltration. A common patio under the pergola serves as a common social space, as well as a sandbox and a sculpture. The yard also has several places to sit, partly on the central grass area and on the various wooden decks. The project developer provided the data for this site.

Norra Djurgårdsstaden (Stockholm) is a 6766 m^2 property with 4115 m^2 of new residential and mixed-use buildings. The landscaping plan includes passages lined with trees, and the large areas of the roofs are covered with both extensive and intensive green roofs and roof terrace areas for social activities. The data for this site were provided within the guidance materials for the GYF system

Entréen (Oslo) is another apartment development with a central courtyard just east of the city center. We used data for the portion of the project within a 6760 m^2 lot, although later stages of the development will approximately double this project's size. The landscaping's vegetation is characterized by 18 new trees, and extensive use of bushes. The courtyard also features a combination of terraces and a pergola in its common courtyard, as well as accessible roof terraces and with green roof elements. The project developer provided the data for this site.

Christian Kroghs gate 39-41 (Oslo) is an apartment development in inner Oslo on a 1213 m^2 property. The landscaping emphasizes storm water management. It has few green surfaces, but all impermeable surfaces drain into basins intended for the gradual release of storm water. Two existing trees stand together with nearly 20 small and medium new trees, and the project includes nearly 380 m^2 of green wall vegetation.

Thereses gate 30 (Oslo) is an apartment and adjacent courtyard designed for stormwater management. Its ground floor is used as commercial space. Approximately 25% of the 1173 m2 property is covered with vegetation, and virtually all of this is on soils of natural depth. Impermeable surfaces drain into basins designed to gradually release stormwater.

Martin Lings vei 19 (Oslo) is a large (72000m^2) property housing the regional offices for Statoil in a suburb west of the city and the largest site in our analysis. The data we used includes both the landscaping immediately adjacent to the office building and the park areas that also define the property. Stormwater from the both building and impermeable areas (35 % of the lot's area) drain into municipal sewers. A small patch of green roof has a thin substrate and contributes little to slowing storm water flows. We used data from Fremtidens Byer for this and the two previous Oslo projects (Ardilla & De Caprona, 2014)

The **Charlottenburg (Berlin)** project was a conversion of a business park into a general residence area with new multi-story housing and mixed-use buildings and an underground car park on a 10400 m^2 property located along the banks of the Spree river. In addition to the vegetation over the underground parking facility, four new residential buildings will also have green roofs. The remaining areas are covered either by meadow or existing trees, and are deemed “park / green space."

The **Neukölln (Berlin)** project involved construction of 23 detached single-family houses with parking spaces and a private parking area on a 39135 m^2 lot. These new homes covered 10 % of the lot's total area. A large number of new trees were planted (31), in addition to retaining many of the existing smaller trees along the perimeter of the lot (12 trees), for a total canopy area = 2249 m^2. However the bulk of the surface area cover surface (58%) was projected to be full depth soil covered by turf grasses.

The **Friedrichshein (Berlin)** project involved approximately quadrupling the density of terraced apartment buildings on a 11655 m^2 property (an increase from 670 to 2521 m^2). Although this development also involved increasing the area used for car parking, the lot retained 3200 m^2 of park-like green space along its south-eastern edge, approximately 2000 m^2 of which was covered by the canopy of existing trees. Liana Liebmann digitized several Berlin development project plans for her masters' thesis (Liebmann, 2017) including the three examples we used here.

Appendix B. Explanations of projects' blue-green elements and corresponding GAI scores

Koppången met the BAF target due primarily to its extensive areas of green roofs, which cover the equivalent of half the lot's total area. The project has no areas where soil is its full (undisturbed) depth and only a modest amount of ground where soil is > 80 cm deep. The project's use of rain beds also contributed importantly to meeting the BGF target score. The two Swedish projects had the lowest GYF point scores component of all projects, with both earning approximately half of the necessary points through elements from the vegetation/biodiversity additional factor. The connection between the site plan and the point system it was designed for was unmistakable for the Koppången and Norra Djurgårdsstaden projects. Both included several elements that matched criteria specified in the GYF system—flowering plants, oak trees, animal depots and nest boxes—that are necessary for meeting the system's balancing requirement.

The Martin Lings vei, Charlottenburg and Neukölln projects all met the BAF, BGF and GYF point-component target scores, but did not achieve the GYF balance criteria. The Martin Lings vei office location earned enough points to meet all three systems' target solely from the lot's substantial portion of land with full soil depth, although its location would most likely correspond to a higher minimum target score that it would not meet. As an office complex, the Martin Lings vei project is considered commercial space and therefore only needs to meet a BAF score of 0.30.

The Charlottenburg project had the highest score for both the BAF and BGF systems. This project scored well in the BAF system due to its extensive areas of full-depth soil (30% of the total area) and the deep soil that covered the underground parking (22% of the total area). The green roofs on all new buildings, and green walls also contributed to the BAF score. For the BGF score, this project received enough to meet the target score from the soil-depth based elements (0.71). The project earned another 0.24 points from its large trees. Neukölln also earned most of its points towards the BAF target from its full depth soil (58% of the total area), while partially sealed surfaces (24% of total area) contributed marginally (0,07 points). Neukölln received nearly all of its BGF points from its full depth soil. The new and existing trees contributed 0.06 points to its total, and allowed it to meet its target.

Thereses gate easily met both the BAF and BGF targets. Commercial use of the ground floor lowered the BAF target to 0.30, but it would have met the BAF target even if it had been an exclusively residential building (a 0.45 target). This project earned substantial points towards the BGF target score by incorporating a rain bed, retaining an existing large tree and planting a relatively large number of new smaller trees for a lot of its size. However, these elements are not included in BAF scoring. The project earned BAF points from the full depth soil covered 21 % of the total area, the green wall, and the rainwater infiltration of its roof area to the surrounding soil.

Entréen and Friedrichshain both failed to meet both BAF and BGF target scores. Entréen had the lowest point totals of all the projects for both BAF and BGF point systems. Buildings and other sealed surfaces covered 61% of the project's total area, and the vast majority of areas with vegetation had soil depth that was < 80 cm. Meeting either of the two system's targets would require considerable changes to the site's design. Friedrichshain fell 0.19 points short of meeting the BAF target for sites with a site occupancy index < 0.37 (0.60), and 0.16 points shy of meeting the BGF target. Meeting either target would require substantial changes in the site plan (i.e., converting the all roof surface to green roofs would not have been enough). The project at Christian Kroghs gate effectively met the BAF target and was quite close to meeting the BGF target. Small modifications, such as including green roof surfaces, would have been enough to meet both targets. Norra Djurgårdsstaden was the sole example of a project that met the BAF target but not the BGF project. Buildings here occupied over 60% of the total parcel area, and most areas with vegetation had soil < 80 cm.

CRediT author statement

Erik E. Stange: Conceptualization, Methodology, Investigation, Visualization, Writing (original draft, review and editing). **David N. Barton:** Conceptualization, Methodology, Validation, Writing (original draft, review and editing). **Erik Andersson:** Writing (review and editing), Funding acquisition, Investigation. **Dagmar Haase:** Investigation, Writing (review and editing).