Blue-Green Systems

Blue-Green Systems Vol 1 No 1
doi: 10.2166/bgs.2019.922

An SDG-based framework for assessing urban stormwater management systems

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Abstract

Nature-Based Solutions for stormwater management on top of handling water should, ideally, deliver a multitude of other services to society; they are often seen as a lever for transforming cities in a more livable, green, resilient and sustainable direction, and these measures should be acknowledged as part of the services delivered. In this study we assess the services that Nature-Based Solutions for stormwater management deliver with reference to targets and indicators from the United Nations Sustainable Development Goals; we also develop local, project level indicators that inform and are informed by the more broad Sustainable Development Goals indicators. We demonstrate through Danish cases ranging from lot to city scale that the proposed framework can help inform decision-makers about the sustainability of Nature-Based Solutions for stormwater management. Despite difficulties in matching local indicators to SDG indicators, this first attempt at an assessment framework provides insight on which services of a project help to work towards the Sustainable Development Goals and, if used in the planning phase, could facilitate the design of projects that work focused and informed towards achieving the Sustainable Development Goals.

Key words: co-benefits, Nature-Based Solutions, sustainability, United Nationals Sustainable Development Goals, urban stormwater management

INTRODUCTION

The world is facing severe problems and, while international society is sometimes portrayed as struggling to grapple with them, it has not given up. In 2015, the United Nations launched 17 goals for global sustainable development (UN SDGs). Some SDGs address the stewardship needed to maintain our planet's climatic and environmental well-being while others comprise strategies to bridge the gap between rich and poor societies. Overconsumption in some parts of the world, simultaneous with poverty, hunger and early death in other parts is a challenge in the current context because it complicates discussions regarding stewardship, responsibility and justice. While good environmental and climatic stewardship is a global issue, the ways to close the gap between rich and poor, and thus also to enable poor societies to take on the climatic and environmental stewardship responsibility, lies in the hands of political leaders and intergovernmental collaboration, as expressed in SDG 17

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'Partnerships for the goals'. In line with IPPC policy recommendation C.2.4 on pathways toward limiting global warming to 1.5 °C (Masson-Delmotte *et al.* 2018), we ask: to what extent can urban infrastructure projects for stormwater management in affluent Danish municipalities fulfil the claim/promise to promote resilience and sustainability in terms of the SDGs? We further discuss how links between rich and poor societies to achieve resilient and sustainable urban drainage infrastructures worldwide can be strengthened and thus contribute to SDG 17.

Historically, the technological shift from open gutters to piped stormwater solutions enhanced the quality of urban life substantially (Ferriman 2007; De Feo *et al.* 2014). However, city expansion, climate change and other drivers are stretching this technological regime tremendously (Chocat *et al.* 2007). As a substitute – or supplement – solutions implemented on city surfaces that mimic natural hydrological processes were conceived in the 1990s and have gradually developed from vague visions (Larsen & Gujer 1997; Hellström *et al.* 2000) to proof of concept, and finally to frameworks that can generate context-specific solutions via interdisciplinary collaboration (Wong & Brown 2009; Sørup *et al.* 2016; Liu & Jensen 2017). This approach has taken a variety of names (Fletcher *et al.* 2015), e.g. Low Impact Development (USA), Water Sensitive Urban Design (Australia), Sponge City Concept (China) and Nature-Based Solutions (EU). In addition to the appealing nature-mimicking principles, this way of managing stormwater gains attention because it can facilitate the transformation of cities into more liveable, green, and resilient spaces (Belmeziti *et al.* 2015). To the extent these effects can be documented, they should be acknowledged as a valuable part of the services delivered; a part that potentially can push society at large in a more sustainable direction (Madsen *et al.* 2018). This article will describe the approach as Nature-Based Solutions, abbreviated NBS.

In Denmark, NBS for stormwater management has been studied since the 1990s and test sites have increased rapidly over the last decade (see e.g., http://wsud-denmark.com/). Small-scale NBS projects typically based on retention (infiltration and evapotranspiration) and detention (throttled discharge) have been and continue to be implemented, in both Copenhagen and other Danish municipalities. Since 2012, however, the Copenhagen Cloudburst Management Plan has served to coordinate and maximise the efficiency of these projects from a city-wide perspective (City of Copenhagen 2012; Liu & Jensen 2017).

Many barriers continue to hinder the implementation of NBS stormwater management projects. While some are related to the basic hydraulic operation, e.g. the correct parameterization of soil hydraulic conductivity (Bockhorn *et al.* 2017), others are related to the ambition of NBS to be multi-functional and to the governance challenges inherent in NBS projects. A system intended to manage stormwater, mitigate the Urban Heat Island (UHI) effect, and serve as an amenity for local citizens is unlikely to perform any of these single tasks as efficiently as a mono-functional system. However, proponents argue, synergies embedded in these systems enable high levels of success on *all* of these tasks at lower costs, when a project is assessed as a multifunctional whole. The debate centres on whether the levels achieved are politically or technically adequate. Arguably, when viewed in this way, NBS stormwater management is more resilient and more sustainable than mono-functional, discharge-based piped systems (Raymond *et al.* 2017). To assess the extent to which this is true, it makes sense to benchmark against the guiding framework of our time, the UN SDGs. Since all existing cities are facing some degree of transformation in order to reach sustainability, it is of particular interest to assess stormwater management in retrofitting contexts.

Assessing NBS for stormwater management against the SDGs is far from straightforward, since the SDGs operate at the national level in order to enable a global-level assessment. Thus, to downscale the SDGs and make them meaningful at the project level, some translation effort is needed. Tools that make the SDG targets and indicators relevant, specific and measurable at the local project level are starting to emerge (Dickens *et al.* 2019; Grainger-Brown & Malekpour 2019).

We have developed a framework for assessing and documenting the specific contributions of NBS for stormwater management projects to sustainability, as defined by the UN SDGs, and then tested the framework on three projects in and near Copenhagen. Specifically, the societal services NBS can

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doi: 10.2166/bgs.2019.922

deliver were mapped, and these were compared with UN SDG targets and indicators. These findings enabled relevant indicators to be selected and subsequently translated into measures applicable at the project level in a Danish context, with the spirit of the target embedded in the associated measure. To the authors' knowledge, this is the first-ever attempt to make the SDGs operational in the context of urban stormwater management at the project scale. In doing so, this study vitally advances our knowledge of ways to work with sustainable urban water management in practice.

METHODS AND MATERIALS

Assessment framework

The analytical framework used to concretize the UN SDGs at the project level was deduced in four steps, as elaborated below and illustrated in Figure 1.

Identifying relevant services

Relevant services that NBS stormwater management projects may deliver to society were identified from a literature search on stormwater services and NBS, which yielded the papers cited in the introduction as well as recent reviews on best practices (Bach *et al.* 2014; Lerer *et al.* 2015). The services were categorized under four broad domains:

- *Flood resilience*: Flood control is a key service of NBS for stormwater management. Protection against extreme rain events ensures that single severe events do not jeopardize societal functions.
- *Natural resources management*: NBS for stormwater management alters an area's frequent non-extreme urban stormwater flows in ways that can enhance groundwater recharge, improve runoff quality and reduce runoff quantity (Brudler *et al.* 2019). In addition, materials and land are used for the construction of NBS for stormwater management projects, and the resulting effects on the environment are relevant to quantify.
- *Liveability*: NBS for stormwater management at the city-wide level necessarily entail a great physical transformation. Ideally, this transformation process should lead to measurably more liveable urban spaces.
- *Transition and innovation*: The transition towards more sustainable cities has only just begun. NBS for stormwater management projects should ideally add value through innovation and provide insight into how best to continue this transition, beyond the project level.

These four domains hold multiple attributes, and associated services may be relevant to more than one domain (Belmeziti *et al.* 2015).

Matching NBS services with all relevant SDG targets and indicators

For each identified service, all UN SDG targets and associated indicators with some degree of relevance were identified. This was done through a thorough review of the 169 targets (United Nations 2015) and 232 associated indicators (United Nations 2018). Attention was given to the wording of the individual targets and indicators, as well as to the overall intention of the target.

Prioritizing the most relevant SDG targets and indicators

For each service, the most relevant SDG target and indicator pair was selected. Choosing several SDG targets for a service would yield richer results, but at the expense of a more complicated framework structure. If several relevant pairs were available, priority was given to the target-indicator pair that

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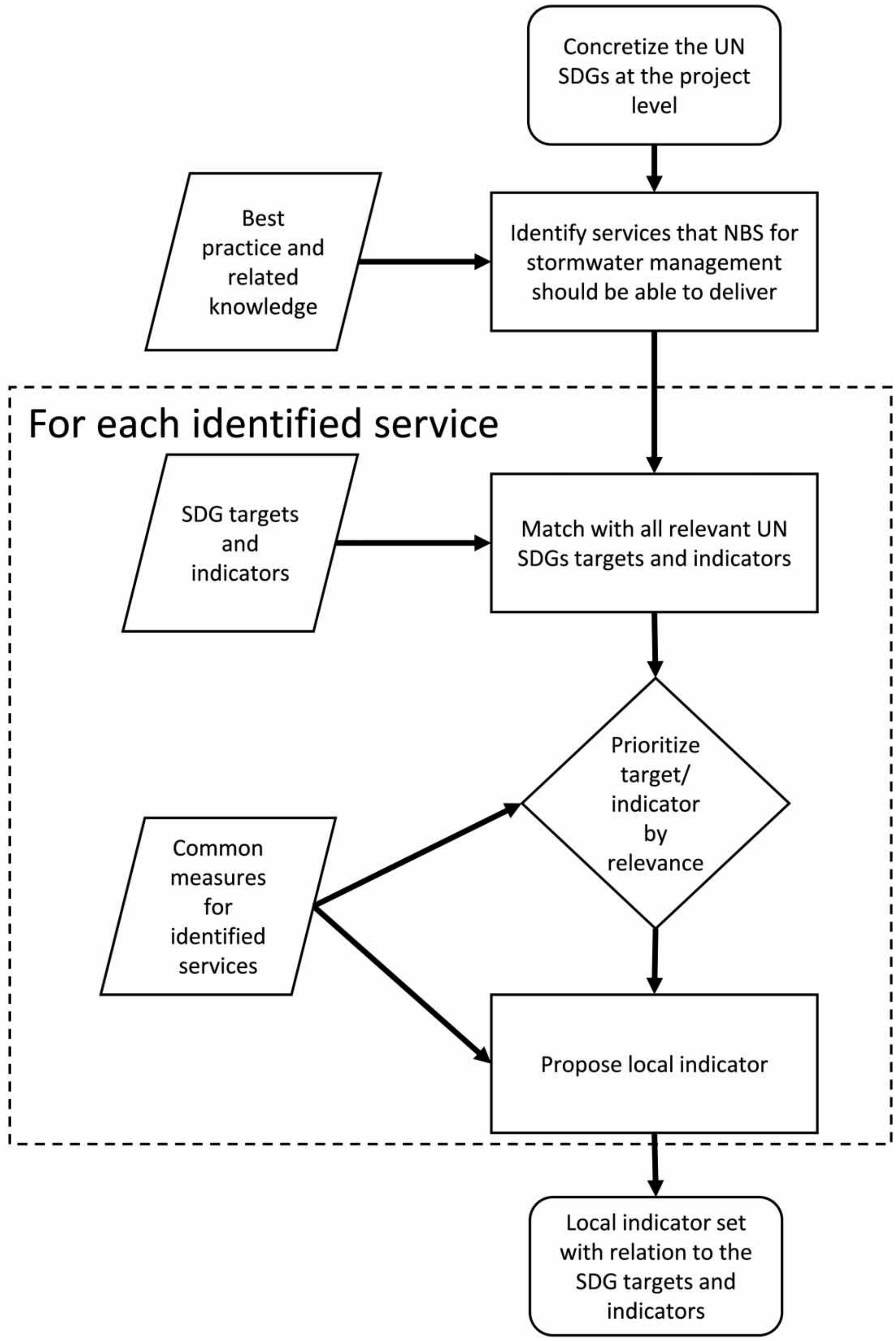

Figure 1 | The four-step analytical framework used to concretize each UN SDG.

was most formulated in a way that facilitated the generation of a meaningful and informative project-level indicator, thus looking into possible local indicators and using these to find the best match between the SDG and local level indicators (Raymond *et al.* 2017).

Proposing local indicators

Indicators that are applicable and can be measured at the local project level even as they inform the global/national level UN SDG indicators were thus formulated for each identified service. Existing

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literature on how identified services are currently measured in practice informed our process (Merz *et al.* 2014; Raymond *et al.* 2017).

CASE PROJECTS FOR TESTING OF THE ASSESSMENT FRAMEWORK

Three Danish projects using NBS for stormwater management were selected to test the new assessment framework. Their spatial scales range from a single parcel, over a neighbourhood, to a full city. Table 1 presents properties of the three case studies and Figure 2 illustrates the physical measures installed for retrofitting stormwater management systems with an NBS approach.

Case A, Holmegaardsparken

This private retirement home in Gentofte Municipality, approximately 12 km from Copenhagen, was completely renovated in 2014 with new dwelling units and landscaping. Stormwater management based on NBS was opted by the developer since it was estimated to be cheaper than conventional discharge to the public sewer. Stormwater is today managed by infiltration and evapotranspiration in lawns between raised paths, with overflow to a central pond with bank infiltration and evaporation. It is designed for an event return period of 20 years; runoff from more severe rainfall is to be diverted towards a public street.

Case B, Kokkedal Climate Change Adaptation Project

A residential neighbourhood dominated by social housing in Fredensborg Municipality, some 30 km from Copenhagen, regularly experienced fluvial flooding from Usseroed Creek. In addition to conventional measures to reduce the flood risk, including a dike and widening of the creek profile, the neighbourhood's detention capacity was enhanced by equipping the existing stormwater pipe system with a number of dry detention basins, each designed for a return period of either five or 20 years and all designed to accommodate socio-cultural activities. This NBS enhancement has been praised for both its successful flood protection and its approach combatting socio-economic deprivation, preventing crime through passive surveillance and promoting spatial cohesion and sense of place through urban design. The philanthropic trust Realdania supported the planning process and NBS planning and construction were financed jointly by the water utility company and the municipality.

Case C, Copenhagen Cloudburst Management Plan

In response to an extreme rainfall event on July 2, 2011, the city councillors of Copenhagen Municipality approved the plan, with the goal of ensuring that, no streets, buildings or other valuable assets will be flooded to depths exceeding ten centimeters more frequently than once in a hundred years,

Table 1 | Basic description of the three case studies

PROJECT	A: HOLMEGAARDSPARKEN	B: CLIMATE CHANGE ADAPTATION KOKKEDAL	C: COPENHAGEN CLOUDBURST MANAGEMENT PLAN
AREA [HA]	2.2	69	8600
STATUS	Built	Built	Planned, under construction
LAND OWNER	Private	Municipal/private	Municipal
MAIN DRIVER FOR PROJECT	Cost savings	Urban renewal Climate change adaptation	Flood protection Urban renewal economy

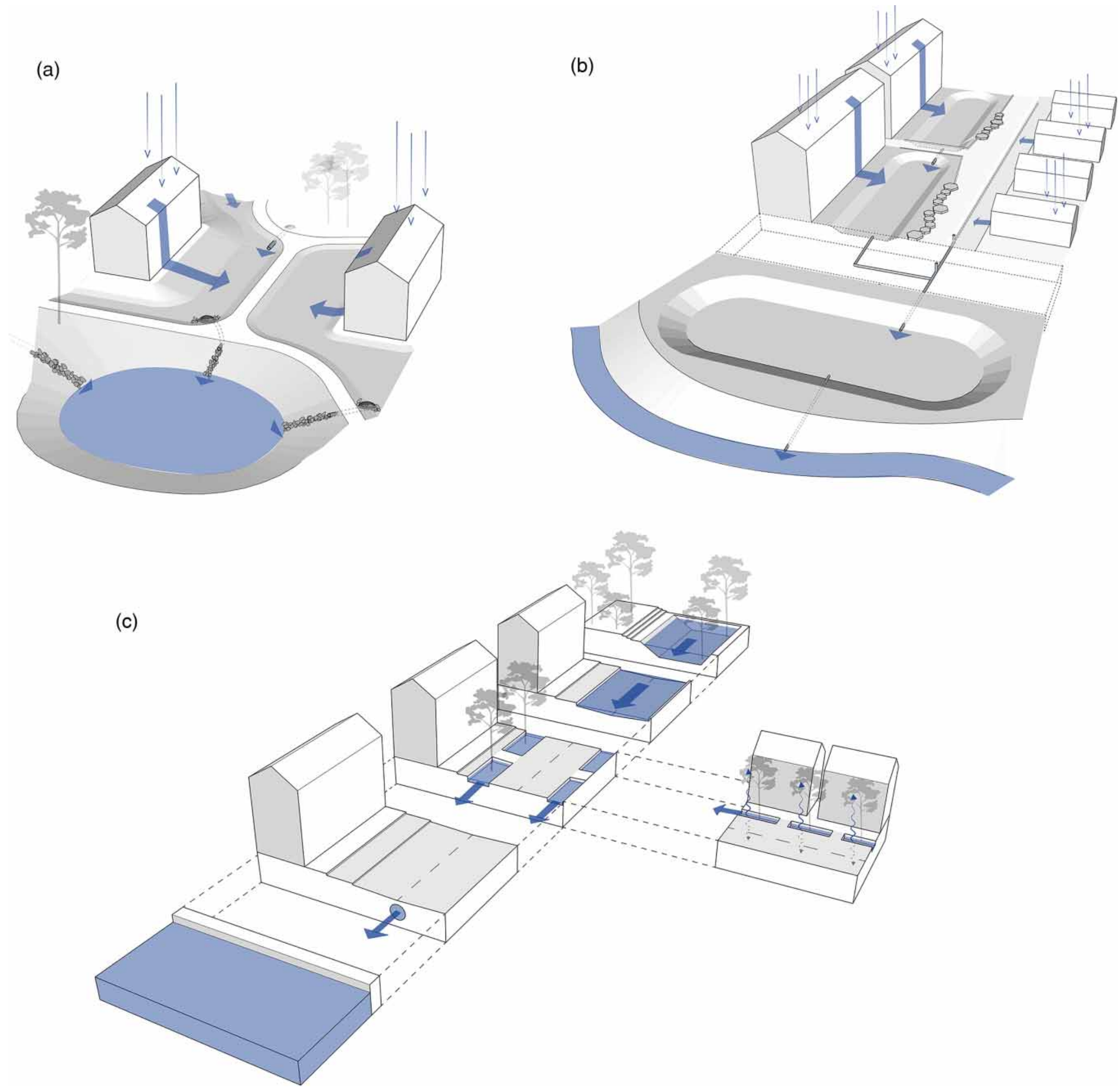

Figure 2 | Illustration of the hydraulic and hydrologic measures used in the three Danish cases. (a) Holmegaardsparken: retention in lawns between raised paths, (b) Kokkedal: Detention in basins and throttled discharge to stream, and (c) Copenhagen Cloudburst Management Plan: Detention in streets, plazas and parks, and discharge to harbour through re-profiled streets and new cloudburst pipes and tunnels. In addition, a number of smaller side streets are to be disconnected permanently from the sewage pipe (illustration to the right, connected with dotted lines to the detention street).

except for areas designated for flooding. This service level is more rigorous than the designed service level of existing sewer systems: no sewer surcharge up to a ten-year rain event. The current system is 90% combined and 10% separate, so a substantial fraction of stormwater goes to the sewer. For rainfall events beyond 10-year events and up to 100-year events, stormwater will be managed in the new cloudburst system, while events exceeding a 100-year event will be uncontrolled. The new system consists of 60 cloudburst branches (sub-catchments) distributed over seven catchments. Each branch is positioned to capture runoff primarily on urban surfaces and divert it to the harbour, via selected cloudburst discharge streets. Along these discharge routes, dry detention basins are inserted in hydraulically connected streets, plazas and parks. Pipes and tunnels are used to avoid problems posed by difficult terrains and structures, like railways. The re-profiled streets and detention areas are designed to enhance socio-cultural values and biodiversity. In addition, many side streets that slope towards the cloudburst discharge streets, dubbed Green Streets, will be disconnected from

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the sewer. Their stormwater will be managed either by on-site retention or discharge to the cloudburst system. The Cloudburst Management Plan, which currently is being implemented, is co-financed by the water utility company through raised water fee (for all conventional elements and the NBS hydraulic functions), the city through tax money (for the part of the system that concerns liveability rather than hydraulic functions), and private landowners investments (for security of houses with non-return valves or disconnection of the plot from the conventional stormwater system).

RESULTS

Identified relevant services

Within the four domains, 11 services related to urban stormwater management based on NBS were deduced from the scientific literature (Table 2). While the first domain is the management of stormwater per se, i.e. urban drainage and flood risk management, the remaining three concern the multi-functional elements of NBS services (Belmeziti *et al.* 2015; Raymond *et al.* 2017).

The first service is the main target of stormwater management, which this study defines as the management of the risk associated with pluvial flooding to a project's specific standard, as expressed in terms of an event return period (Zhou *et al.* 2013; Brudler *et al.* 2016; Löwe *et al.* 2018).

In the domain related to natural resources, stormwater management may link to water quantity through the option of using stormwater for water supply either directly through stormwater harvesting, or indirectly through groundwater recharge. Likewise, it links to water quality since stormwater runoff is contaminated to various degrees. Also, by applying lifecycle thinking, materials, construction, operation and decommissioning of the stormwater management solution should have the smallest possible environmental impact and greenhouse gas emissions (De Sousa *et al.* 2012; Brudler *et al.* 2016). Carbon footprints can act as a simple proxy for a full life cycle assessment. The design of infiltration and evaporation elements may enhance habitat quality (Monberg *et al.* n.d.), and thus strengthen the condition of urban nature as it is. Further, since water is a prerequisite for all life, NBS can support enhanced biodiversity. However, the extent to which existing and anticipated efforts can have a substantial effect on the goal of retaining or expanding biological variation is uncertain.

The third group of services targets the people living in the neighbourhoods where stormwater solutions are implemented. These solutions may offer improved human health and well-being, and therefore belong under the concept of liveability (Alcock *et al.* 2014; Andersen *et al.* 2017). Socio-cultural services include a range of benefits that urban greening and attractive public open spaces may provide, e.g. increase walking and cycling, improve mental health, increase residents' sense of place and pride, provide options for social interactions, and renew historical constructions

Table 2 | Identified services that NBS for stormwater management can provide, within four domains, when implemented in a catchment as part of retrofitting stormwater practices

DOMAINS			
Flood resilience	**Natural resources management**	**Liveability for people**	**Transition and innovation**
Reduce flood risk	Protect quantity of water resources	Mitigate urban heat island effect	Strengthen stakeholder participation
	Protect quality of water resources	Enhance socio-cultural values	Build knowledge through documentation and monitoring
	Minimize material use and carbon footprint		Improve economy
	Support biodiversity		Facilitate knowledge sharing

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(Backhaus & Fryd 2013; Brooks & Rich 2016). Similarly, mitigation of daytime surface UHI effect by means of evaporative cooling and shadowing is a well-documented green infrastructure service (Backhaus & Fryd 2013; Gunawardena *et al.* 2017).

The final group of services targets the ability of society to ensure sustainable development in the future (Wong & Brown 2009). Knowledge building and sharing among all members of society and across disciplines, institutions and land ownerships – therein monitoring and documenting the successes and failures – are essential in order to inform future stormwater management projects and help avoid replicating sub-optimal solutions (United Nations Environment Programme 2006). Finally the economic investment has to be reasonable in terms of the services provided. This is a question of efficiency in the way resilience and sustainability are reached, also considering trade-offs between economic development, climate change adaptation and climate change mitigation (Chambwera *et al.* 2014). It concerns both the actual costs of obtaining a specific service at the local level, but also the efficiency in the transfer of good solutions, from one community to another or from one society to another.

Matching selected services to relevant SDG targets

The 11 services were matched to relevant targets and associated indicators, searched among all 169 SDG targets. Table 3 lists relevant targets identified for the first service regarding flood risk management. As seen, the targets belong to four different SDGs, highlighting the necessity of reading through all targets for the matchmaking and not limit oneself to the one intuitively relevant SDG, SDG6, on water.

Similar tables for each of the additional ten services are reported in the Supplementary material.

Prioritization and definition of local indicators

For each of the 11 services, the most relevant SDG target-indicator pair was selected, along with a proposed complementary local indicator (Table 4). Here, the line of thinking was to aim for local indicators that are either common already or where data should be somewhat readily available.

Flood resilience

As a local indicator to measure the reduction in flood risk, the return period of the design storm is chosen because it is commonly used as a measure to balance benefits and costs of flood risk management (Löwe *et al.* 2018).

Natural resources management

Water quantity is related to the hydrological cycle, and onsite stormwater management has an impact on the overall water balance through infiltration, evaporation, runoff and supply (Henrichs *et al.* 2016; Jia *et al.* 2017). Water quality in relation to stormwater management is primarily related to discharges that may prevent water bodies from reaching good ambient quality (Ingvertsen *et al.* 2012). Future NBS for stormwater management systems should have a lighter material footprint than conventional infrastructures, which rely heavily on concrete, steel and plastic (Brudler *et al.* 2016). Urbanization has a detrimental impact on biodiversity and, as such, 15.1.2 does not apply at all. However, with reference to reconciliation ecology (Rosenzweig 2003) it may still be relevant to include a focus on biodiversity. The Biotope Area Factor (Becker *et al.* 1990) is a general urban ecology indicator that matches the scale aimed for here.

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Table 3 | SDG targets and indicators relevant to the domain Flood Resilience

TARGET	TARGET TEXT	RELEVANT SDG INDICATORS
1.5	By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters	1.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population 1.5.2 Direct economic loss attributed to disasters in relation to global gross domestic product (GDP)
9.1	Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all	None
9.4	By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities	9.4.1 CO_2 emission per unit of value added
11.4	Strengthen efforts to protect and safeguard the world's cultural and natural heritage	11.4.1 Total expenditure (public and private) per capita spent on the preservation, protection and conservation of all cultural and natural heritage, by type of heritage (cultural, natural, mixed and World Heritage Centre designation), level of government (national, regional and local/municipal), type of expenditure (operating expenditure/investment) and type of private funding (donations in kind, private non-profit sector and sponsorship)
11.5	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	11.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population 11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters
11.B	By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels	11.b.2 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies
15.3	By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation-neutral world	15.3.1 Proportion of land that is degraded over total land area

Liveability for people

Mitigation of the UHI effect is the only service seemingly not covered at all in the SDGs. The suggested local indicator points to the ability of stormwater management systems to lower ambient temperatures through the conversion of sensible heat to latent heat and by providing shadow (Gunawardena *et al.* 2017). SDG indicator 11.7.1 concerns access to public space for all. In affluent societies, liveability may also include the support of recreational and social experiences, including good options for biking and walking.

Table 4 | Prioritized SDG target and indicators for each service, and proposed local indicator

SERVICE	SDG TARGET	SDG INDICATORS	LOCAL PROJECT LEVEL INDICATORS
I. FLOOD RESILIENCE			
REDUCE FLOOD RISK	11.5	11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters	1. Return period of design storm (unit: year)
II. NATURAL RESOURCES MANAGEMENT			
PROTECT QUANTITY OF WATER RESOURCES	6.5	6.5.1 Degree of integrated water resources management implementation (0–100)	2. Proportion of annual runoff managed on-site (unit: %)
PROTECT QUALITY OF WATER RESOURCES	6.3	6.3.2 Proportion of bodies of water with good ambient water quality	3. Proportion of annual stormwater runoff where the quality of runoff is managed with consideration for the receiving water bodies (unit: %)
MINIMIZE MATERIAL USE AND CARBON FOOTPRINT	12.2	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP	4. Carbon footprint of materials and processes used in construction, operation and decommissioning per person served (unit: CO_2e/person)
SUPPORT BIODIVER-SITY	15.1	15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	5. Biotope Area Factor (BAF) measuring the abundance and quality of inhabitable surfaces at the project site (unit: 0–1)
III. LIVEABILITY FOR PEOPLE			
MITIGATE URBAN HEAT ISLAND EFFECT		None	6. Reduction in peak ambient air temperature onsite, compared to surrounding urban environment (unit: °C)
ENHANCE SOCIO-CULTURAL VALUES	11.7	11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities	7. Proportion of project area that is designed to enhance the quality, safety and public use of urban open space (unit: %)
IV. TRANSITION AND INNOVATION			
STRENGTHEN STAKEHOLDER PARTICIPATION	6.B	6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management	8. Degree of participation by the local community as well as engineers and landscape architects in the design and maintenance of the project (unit: 1–8)
BUILD KNOWLEDGE THROUGH DOCUMENTATION AND MONITORING	9.5	9.5.1 Research and development expenditure as a proportion of GDP	9. Proportion of budget spent on documentation and monitoring (unit: %)
IMPROVE ECONOMY	11.4	11.4.1 Total expenditure (public and private) per capita spent on the preservation, protection and conservation of all cultural and natural heritage, by type of heritage (cultural, natural, mixed and World Heritage Centre designation), level of government (national, regional and local/municipal), type of expenditure (operating expenditure/investment) and type of private funding (donations in kind, private non-profit sector and sponsorship)	10. Direct cost per hectare served by the stormwater solution (unit: USD) and type of funding
FACILITATE KNOWLEDGE SHARING	17.6	17.6.1 Number of science and/or technology cooperation agreements and programmes between countries, by type of cooperation	11. Number of visits by national and international delegations

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Transition and innovation

SDG indicator 6.b.1 can be seen as a way to strengthen local transition capacity. Referring to Arnstein (1969), local community involvement can take various forms (hence the unit 1–8). Further, interdisciplinary collaboration increases the chance of identifying integrated solutions (Fryd *et al.* 2012). Weight: citizen participation (50%), engineering expertise (25%), landscape architecture expertise (25%). Documentation and knowledge sharing is often under-prioritised, so the chosen local indicator stresses the need for allocating resources to develop future systems and is a prerequisite for international transfer of knowledge. Regarding economy, 11.4.1 is chosen although it concerns heritage protection and conservation. The suggested local indicator is helpful to inform cost effectiveness and funding scheme. The final indicator reflects the role of precedents as a means for knowledge diffusion, technology transfer and upscaling.

Applying the framework with local indicators to cases

To test their relevance and feasibility, the selected local indicators were applied to the assessment of three specific cases located in Greater Copenhagen. Table 1 lists the basic data for the three cases, and all results can be found in the Supplementary material. We summarize the findings here.

Flood resilience

All three cases were designed to manage storms up to a specific return period, thus making data easily available and easily comparable. The two smaller-scale projects, Cases A and B, were designed for a return period of 20 years and the Copenhagen Cloudburst Management Plan for a return period of 100 years.

Natural resources management

While all three projects consider and manage stormwater quality in relation to the receiving water body, the proportion of annual runoff managed differs greatly between the projects. Case A is designed to handle all water onsite (100%) whereas the two other projects are mainly based on detention and only handle up to an estimated maximum of 25% of the annual runoff from the site.

Data for estimating the carbon footprint could not be obtained. However, a full Life Cycle Assessment for one sub-catchment of the Copenhagen Cloudburst Management Plan shows that green infrastructure in general generates fewer environmental impacts than the more traditional concrete, steel and plastic-based systems (Brudler *et al.* 2016). With this in mind, Case B is expected to have a rather high carbon footprint, and also Case C which involves new tunnels, connection pipes and a number of curb-elements for street re-profiling. In contrast, the solution in Case A relies almost exclusively on (considerable) soil work, as well as gravel and vegetation. The Biotope Area Factor was estimated to increase from 0.42 to 0.56 for Case A; while the infrastructure created in the other projects also promises BAF benefits, data is not yet available.

Liveability for people

Data regarding UHI mitigation could not be obtained, but a significant impact is expected in Case A, where all water is kept onsite and thus is available for cooling through evapotranspiration. Effects for the two other projects are expected to be small, as they quickly discharge accumulated stormwater runoff and heat mitigation is thus generally dependent on the ability of vegetation to provide shadow. The quality of public open spaces is considered to be greatly improved for Cases A and B,

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where the designs actively sought these effects (Fryd & Jensen 2018; Marling & Kiib 2019). Improvement of urban space quality is a relatively high priority for Case C, too, but since only some of the elements operate in the urban space, i.e. green streets, detention plazas and some detention streets, the improvement is not expected to be as spectacular as witnessed in the other two projects. The suggested local indicator is proved to be relevant and feasible in terms of data collection and assessment in all three cases.

Transition and innovation

All three projects have been top–down-driven with the initiative coming from a private developer, a municipality together with a private trust, and a municipality for Cases A, B and C, respectively. In Case B, local community involvement was extensive and planned for throughout all phases, while in Cases A and C the public was mainly involved through legally required public hearings. No budget has been allocated for monitoring of any of the projects, and only the two larger projects make documentation of the basic design and implementation publicly available. The direct costs of the projects vary greatly from approximately US$ 0.3 mil. per hectare to approximately one million dollars per hectare, with no apparent correlation to project size or funding source. A substantial number of guided tours have been arranged for all three projects for both national and international audiences. The suggested local indicators are proved to be relevant, but more insightful knowledge of the projects' processes and attention to documentation is required for a fair assessment.

DISCUSSION

When choosing SDG targets and indicators for assessing urban stormwater management systems at the project level, we experienced almost no challenges in ascertaining relevant SDG targets, except regarding UHI, but many of the SDG indicators provided by UN were difficult to apply directly. As the SDG indicator framework is meant to measure progress on a national scale this is not surprising and, as it is meant to be general and cover all urgent challenges for sustainable development at the global level, it is also not surprising that the relevant targets are easy to identify. However, this experience highlights the need to amend the SDG framework to include project-specific indicators, in order to make the goals and targets relevant in practice.

The chosen SDG indicators presented in Table 4 have strong connections to SDGs 6 and 11 on water and cities, with several services well matched to both; this was expected, as these SDGs should be relevant for stormwater management in cities. SDGs 9, 12, 15, and 17 are also represented among the indicators exemplifying the necessity to formulate services that NBS systems deliver beyond stormwater management. These targets illustrate that the SDGs' holistic nature makes all targets plausibly relevant to the measurement of a given project's sustainability. The matching step illustrated in Table 3 and the Supplementary material further illustrate this, as all defined services are matched to targets and indicators from a range of SDGs.

Although we have focused on finding a single SDG target-indicator pair per service, among several possible, it has proved difficult to define relevant indicators for all services provided at the project level, and also to find the data needed to assess existing projects. In consequence, the framework may rather serve as a steering tool for future projects by mapping out the four categories and pointing to the eleven specific services (Table 2), with the local indicators providing concrete measures for the degree of service delivered.

Our assessment of the three NBS projects revealed that they place substantial focus on flood control, which more generally has been the main driver of climate change adaptation projects in Denmark. The clearly communicated return period targets of 20 to 100 years (local indicator 1) reflect

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that Denmark has a fully developed stormwater management system and that the loss of human lives as a result of pluvial flooding are not an issue, but only economic losses as expressed in SDG-target 11.5.2. Here we see a direct match between SDG-target 11 (disasters), the corresponding SDG-indicator and the suggested local indicator. Of the natural resources management services, there has been practically no consideration of water supply through harvesting or aquifer recharging (local indicator 2), which indicates that water supply currently is not recognised as a concern for the Copenhagen region, despite a severe drought in 2018. In contrast, the contaminant profile of stormwater runoff and environmental protection of receiving water bodies (local indicator 3) received much attention in all three cases, reflecting pre-existing concerns regarding groundwater contamination as well as implementation of the EU Water Framework Directive. Materials used and carbon footprint (local indicator 4) were not specifically addressed in any case, whereas biodiversity (local indicator 5) received some attention in all three cases but still played a role inferior to liveability and stormwater management. So for category II (natural resources management) we see that some of the possible services are not at all addressed in the three Danish cases (water supply, material use and carbon footprint), or only addressed to some extent (biodiversity). Further, the suggested local indicators present a poor match with the relevant SDG-indicators of SDG targets 6 (water), 12 (sustainable consumption and production) and 15 (biodiversity), where stormwater management is not even mentioned.

Despite the UHI problem being directly targeted in the Copenhagen Climate Adaptation Plan approved in 2011 (City of Copenhagen 2011), one year prior to the Copenhagen Cloudburst Management Plan, none of the three cases addresses UHI, and UHI-mitigation is not mentioned in any of the SDGs, making this category III service and local indicator 6 somewhat isolated, possibly caused by a lack of successful NBS demonstration sites to refer to. However, there have been strong efforts to design stormwater management projects that also provide high-quality, eminently liveable public spaces, so as to buttress both the Danish reality and its branding effort to present urban public spaces in general as being of high quality. Although local indicator 7 and the SDG-indicator relating to SDG-target 11.7 (access to green urban space for all) present a good match because the quality of Danish urban spaces is already high, and issues regarding accessibility for children, women and disabled people rarely arise, all of which render this indicator less urgent in a Danish context.

As for category IV services, project-level public involvement in various forms (local indicator 8) has been practiced, but only at the later stages in the form of public hearings, and these tended to focus on liveability parameters beyond SDG target 6b (participation of local communities in water and sanitation management). Despite a high score (see Supplementary material), the local indicator may not capture whether these measures of knowledge transfer have developed the anticipated water-related skills at the community level. Further, since local indicator 8 merges public participation with interdisciplinary cooperation among professionals and the two cannot be distinguished, the positive tendency observed for inter-disciplinarity is blurred. Our assessment reveals that there have been only limited efforts on documentation and knowledge sharing, and no effort on monitoring (local indicator 9), which also explains the challenge in gathering data for a quantitative post assessment. The match of the local indicator with SDG-target 9 (sustainable development knowledge platform) is good, and the low score in all three cases documents its relevance in the Danish context. Local indicator 10 was supposed to reflect the project's economic efficiency, yet despite the availability of data, the numbers were difficult to relate to. Further, the local indicator has a poor match with the SDG-indicator for target 11.4.1 (preservation, protection and conservation of all cultural and natural heritage) and its relevance may be questioned. The final local indicator 11 is a simple but rather imprecise count of national and international delegations that have visited a project, and all three cases are performing well here. If the precision could be improved, this local indicator could be a good proxy for the targeted SDG 17.6 (technology facilitation). Thus, merging with local indicator 9 on documentation could be considered.

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The extent to which the three selected cases can be said to truly represent NBS for stormwater management can surely be open to scrutiny and debate. Since two of the three cases rely on detention and discharge, with only a fraction of the annual runoff coming into contact with onsite soil and vegetation, it is clear that the adopted stormwater management scheme is not mimicking the natural water cycle in these two cases. Only in Case A does the hydraulic solution rely on natural infiltration and evapotranspiration mechanisms, which provide resilience towards not only flooding but also drought. This difference between the three cases is well captured in local indicator 2, the proportion of annual runoff managed on site. As such, local indicator 2 may be seen as intimately linked to NBS. While this may also be the case for the remaining category II indicators, i.e. 3, 4 and 5, only local indicator 2 can be easily quantified. Local indicator 4, on carbon footprint with units in CO_2-equivalents per person, is especially cumbersome to calculate, and not doable in the three cases. This is unfortunate since this indicator, like indicator 2, can help distinguish among NBS. A simple yes/no indicator may be a better choice, e.g. 'is steel, concrete or plastic used in the solution?'. Interestingly, in the Chinese Sponge City construction guidelines published in 2014, the cumulative annual control volume (i.e. volume not discharged) is used to set targets for sponge cities, and the corresponding volume capture ratio of annual rainfall (VCRa) is used to size elements. In Beijing, for example, a VCRa of 80%, that is, on average 80% of the annual rainfall is captured for local control, corresponds to 27.3 mm (Randall *et al.* 2019). This approach corresponds to our suggested indicator 2.

The application of the assessment framework to the three projects has revealed that NBS for stormwater management projects have to be assessed in a holistic way: the assessment results as measured by various indicators should be understood only in relation to each other, and should be seen within the context of each project. A major insight generated by this study is that instead of posing the question: 'is this project sustainable?' one should rather ask: 'how is this project sustainable?', in order to assess whether the sustainability of a project is satisfactory. Almost all projects will be sustainable in some respects and to some extent due to the general nature of the SDGs, but the local assessment framework provides a set of indicators that can provide the foundation for a meaningful discussion on whether the desired outcomes are prioritized.

The test of the selected local indicators with reference to the three case projects has been carried out primarily by the authors. The assessment process indicated that some of the quantitative indicators require demanding work for data collection, which may distract the overall focus of the assessment. Therefore, local indicators for projects need to be feasible in terms of data availability and resources required for assessment. The assessment process also indicated the necessity of insightful knowledge of the projects in terms of both technical solutions and project processes. Therefore, future application of this framework could involve other data collection methods, including direct data collection through interviewing project managers, in order to improve the quality of the assessment results.

We experienced that the SDG framework provides useful direction for future development and encourages reflection on how multi-functional NBSs for stormwater management and their implementation should be carried out. However, we also noticed that the SDG framework does not necessarily cover all important services and targets that affluent societies like Denmark strive for, such as liveability aspects that can be associated with this type of project. With this in mind, one may wonder about the extent to which the SDGs represent a relevant assessment framework, and whether they point to the absolute gap between rich and poor societies that the global partnership described in SDG 17 is supposed to address. Taking this further, it may be argued that only SDG 17 and NBSs that feed into improved conditions for closing the gap should be considered. All in all, the approach applied by the study, including its process for assessing local NBS stormwater management projects, has proved to be a fruitful learning process, and worth practicing by local city administrations as a further stride towards sustainability.

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CONCLUSIONS

To secure the overarching ambitions of globally sustainable development, the UN SDGs must be made relevant everywhere and to everybody. From emerging practices in Denmark and elsewhere on urban stormwater management, we derived eleven services often advocated to be achievable with NBS. By reading the eleven services against the 169 UN SDG indicators, and translating the most suitable pair of SDG-target and SDG-indicator into an appropriate local indicator for each service, we developed a targeted framework considered to support practice. From testing the framework on three Danish cases from lot to city scale, we find that the proposed framework can help inform decision-makers about the sustainability of existing and especially planned NBS for stormwater management. The best matches between local indicators and UN SDGs were found for services related to flood protection (SDG 11 on disasters), minimized material use and carbon footprint (SDG 12 on consumption and production), and documentation of solutions and knowledge sharing (SDG 9 on industry, innovation and infrastructure). Poor matches were found regarding linking of stormwater to water supply, protection of receiving water bodies from contaminants in stormwater runoff, and stormwater management NBS that supports biodiversity. No match was found for mitigation of UHI effect. Although a match to social-cultural liveability aspects was easily found, it was obvious that the relevant UN SDG (on safe access to green urban spaces) did not make much sense in a Danish context where this goal is already met. For the category of services related to transition and innovation, some matches were found, but the discussion seems to make clear that the most important target is UN SDG 17 on global partnerships, where Danish NBSs can contribute if well documented and shared internationally. Linking services provided by NBS for stormwater management to the UN SDG targets and indicators has proved a difficult task. Even so, this first attempt at developing an assessment framework provides insight as to which services of a project may help work towards the UN SDGs and, if used in the planning phase, could help design projects that are more informed and focused on achieving those goals.

ACKNOWLEDGEMENTS

This study has been economically supported by the philanthropic foundation Realdania (https://www.realdania.org/), the Danish Innovation Network for Water in Urban Areas (http://www.vandibyer.dk/english/) and the Horizon 2020 project RECONECT (http://www.reconect.eu/, grant agreement No. 776866).

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First received 23 May 2019; accepted in revised form 27 September 2019. Available online 18 October 2019