Imperial College London

Grantham Institute
Briefing paper No 30

July 2019

Integrating green and blue spaces into our cities: Making it happen

KATHRYN BROWN AND DR ANA MIJIC

Headlines

- Blue-green infrastructure has a host of benefits including those for climate change adaptation, mitigation, health and wellbeing, and biodiversity.
- Despite its importance to people and the environment, blue-green infrastructure is declining rather than increasing in England.
- A systems approach to analysing the role of the blue-green infrastructure in sustainable urban development is important and could support new financial models for their increased uptake.
- Systems approaches to blue-green infrastructure planning includes understanding how their benefits propagate across all urban infrastructure sectors, and more broadly people and environment.

Introduction

Urban blue-green infrastructure (BGI) is a network of nature-based features situated in built-up areas that form part of the urban landscape. These features are either based on vegetation (green), water (blue), or both. Green roofs and walls, grassed areas, rain gardens, swales (shallow channels, or drains), trees, parks, rivers and ponds are all examples of this type of architecture. Blue-green infrastructure is important as a climate change mitigation and adaptation measure, and has a host of wider benefits to people and wildlife.

Contents

Grantham Briefings analyse climate change and environmental research linked to work at Imperial, setting it in the context of national and international policy and the future research agenda. This paper and other publications are available from **www.imperial.ac.uk/grantham/publications**

This briefing note summarises the benefits that blue-green infrastructure brings to people, recent trends in the use of blue or green features in urban settings, and the perceived barriers to greater uptake in the UK and how these might be overcome. This paper also explores how thinking about the way these features fit within a wider system of natural and human factors, so-called systems thinking, can help improve the evaluation of blue-green assets from a range of different perspectives.

The importance of blue-green infrastructure

"There is widespread evidence that communities would be better able to adapt if they were able to work with natural processes and systems[1]."

Blue-green infrastructure provides a host of different benefits to people and wildlife, as shown in Table 1. Its presence can improve air and water quality, and carbon storage; enhance flood and temperature regulation; reduce noise; and improve resource efficiency, biodiversity and amenity value[2]. All of these benefits contribute to enhanced human wellbeing and ecosystems in urban areas. These characteristics, in turn, improve resilience to climate change impacts, especially to higher temperatures and flooding, two of the largest climate risks facing people in the UK[3].

Policy advisers are interested in straightforward guidance stating how much, what and where BGI should be included in new and existing developments[22]. However, coming up with an economically-optimal standard amount of blue-green infrastructure needed, based on a precise assessment of costs and benefits, is not possible. This is because the specific costs and benefits of BGI solutions are dependent on local circumstances.

Instead, it may be useful to define a set of 'win-win' BGI solutions that are likely to have net benefits and very few negative trade-offs in most situations. Figure 1 identifies a selection of such win-win BGI features based on the literature reviewed for this study. Figure 1 also illustrates how the benefits of BGI interventions can be understood through a systems-wide approach.

Table 1: Examples of studies calculating multiple benefits of blue-green infrastructure

Benefit from blue-green infrastructure	Examples from individual studies
Water regulation	• Green sustainable urban drainage solutions (SuDS) such as swales, water gardens and green roofs, increase the infiltration and slow the removal of rainfall into the drainage system, reducing the risk of surface water flooding[4]. • Installing a green roof could absorb up to 100 per cent of incident rainfall, dependent on conditions[5]. • Looking at a regional scale, with only ten per cent of roofs greened, a 2.7 per cent overall reduction in storm water runoff was achieved in one study, with a 54 per cent average reduction in runoff per individual building[6].
Cooling effects	• Trees positioned next to buildings lowered internal summer temperatures by 4°C and raised winter temperatures by 6°C compared to a 'no tree' scenario, with a corresponding decrease in energy consumption of 26 per cent[7]. • Increasing the current area of green infrastructure in Greater Manchester by ten per cent (in areas with little or no green cover) could result in a cooling of up to 2.5°C under a high emissions world compared with a 'no action' scenario[8]. • Green roofs retrofitted to existing buildings reduced surface temperatures on roofs by around 20°C in one study[9]. (Stuttgart is a good example at the city scale). • Green walls in the UK were found to reduce indoor temperatures by 4-6°C in the summer[10].
Improving air quality	• Green infrastructure can improve urban air quality in some situations, but be ineffective or even detrimental to air quality in others[11]. Hedges between roads and pedestrians, green walls in street canyons, and 'green oases' (without internal pollution sources) are all noted as win-win air pollution measures. On the flip side, trees can slow down or prevent dispersion of traffic pollutants and emit compounds that react in the air to form ozone. • The long-term benefits of trees in urban areas – in terms of health benefits from removing air pollutants, cooling, and carbon storage benefits – have been calculated to be more than twice their planting and maintenance costs[12].

Table 1: Examples of studies calculating multiple benefits of blue-green infrastructure

Benefit from blue-green infrastructure	Examples from individual studies
Accessing greenspace and improving health	• Benefits to mental health through increases in physical activity[13]. • Being in a greenspace has been shown to lead to lowered muscle tension, improved attention and emotional state[14]. • In one study, the difference in diastolic blood pressure of people sitting with tree views vs no tree views was 2-8mmHg[15]. • Senior citizens' survival rates were higher if they had a walkable greenspace within easy reach of their residence – the five-year survival rates were 73 per cent for those with access to a walkable greenspace compared to 56 per cent without, and 74 per cent for those with parks and tree-lined streets near their residence compared to 66 per cent without[16].
Cultural value	• High quality (well-maintained) greenspace leads to a greater attachment to community[17] while untidy or poorly kept greenspace is associated with increased anxiety caused by fear of crime[18].
Carbon storage	• A study of four neighbourhoods in Merseyside found that one with 10.7 per cent tree cover stored around 17 tonnes of carbon per hectare, compared to another at 0.3 per cent cover only storing 0.5 tonnes per hectare. Trees were identified to be a particularly important green infrastructure component for carbon storage, even though the storage benefits will be relatively small compared to trees in rural areas[19].
Biodiversity benefits	• The relationship between urbanisation and biodiversity is complex. Increased urbanisation can be detrimental to habitat size, connectivity and condition, which are key components of resilience to climate change[20]. One study has examined a possible greenspace biodiversity indicator based on extent, heterogeneity and connectivity. The indicator results suggested an area with 52 per cent green cover had almost double the biodiversity potential of a site with only 33 per cent cover[21].

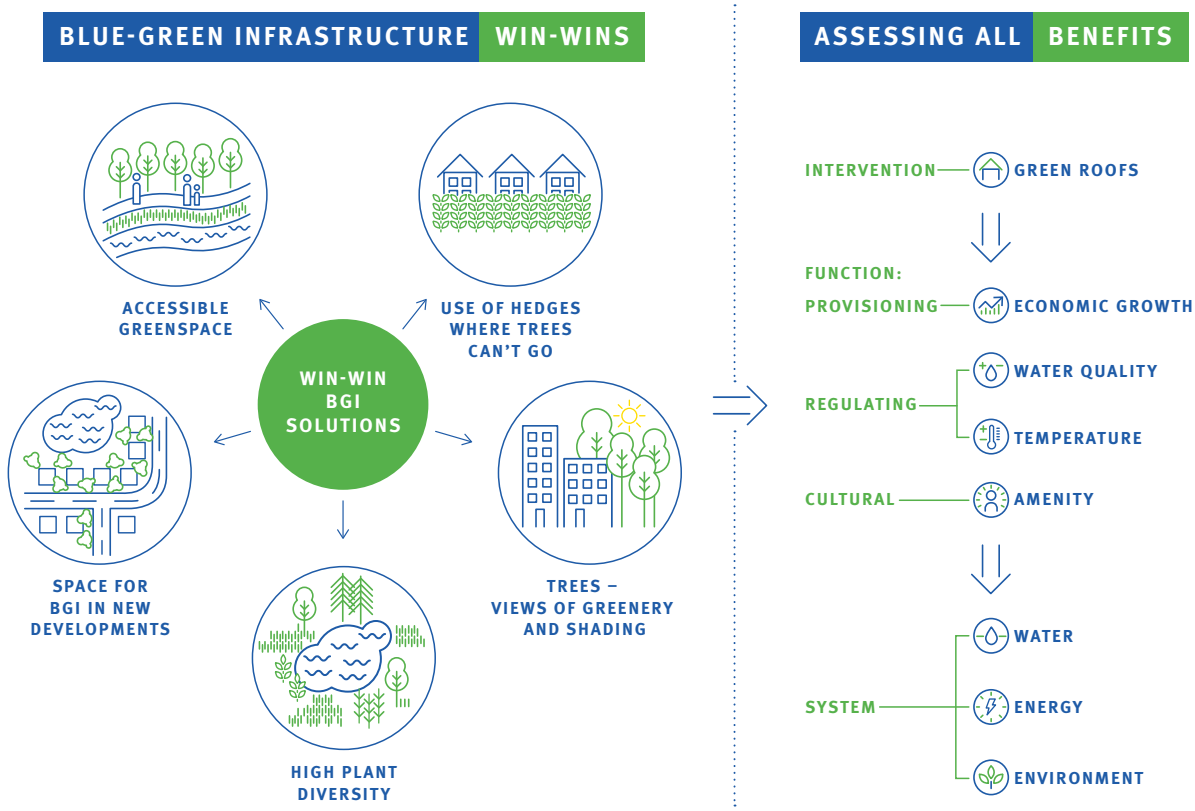

Figure 1: Blue-green infrastructure solutions that are highly likely to deliver net benefits, and a systems-level approach to assessing these benefits

As well as choosing the right features, it is equally important that BGI features are well-maintained to ensure that they provide the full range of mental wellbeing and ecosystems benefits.

Barriers to greater uptake of blue-green infrastructure

Despite its importance to people and the environment, blue-green infrastructure is declining rather than increasing in England. There are two aspects of this problem:

1. **Decline in area.** The proportion of urban areas that are made up of greenspace in England has declined over time. The Adaptation Committee of the Committee on Climate Change measures trends in urban greenspace as part of its suite of indicators for measuring progress in climate change adaptation in England. These data show that the total area has declined from 63 per cent of urban area in 2001 to 55 per cent in 2018[23]. One possible contribution to this reduction is the paving over of gardens[24].

2. **Uneven distribution.** The distribution of urban parks is uneven across England, with deprived communities facing more challenges in accessing high quality green spaces compared to more affluent areas[25]. The Ministry of Housing, Communities and Local Government estimates that the most affluent 20 per cent of wards in England have five times the amount of greenspace compared to the most deprived ten per cent of wards[26].

The quality of urban blue and greenspace is a third aspect, and is also an important determinant of the benefits it provides (table 1). However, there appears to be no national monitoring in place to determine whether quality is increasing or decreasing, which is a notable gap in knowledge[27].

Urban greenspace funders and practitioners were interviewed as part of this study[28]. The interviews identified a number of common factors preventing greater uptake of BGI solutions in urban areas. The barriers mentioned by the most interviewees were:

- **Lack of compulsory standards:** There is a lack of enforceable standards for a minimum amount of blue-green infrastructure in new or existing developments. As a result, BGI measures that are put in at the beginning of a design project are often 'value engineered' out to bring down costs, or areas of green space in existing developments are built upon for similar reasons. Large scale reductions in public spending, and the related reduced resources, capacity and skills in public sector organisations (government agencies and local authorities[29]) means that any issues that are not 'must haves', i.e. statutory requirements, are not routinely taken forward in decision making.
- **Quantity at the expense of quality for new housing:** BGI solutions can be seen as optional extras that get in the way of meeting the need for more housing, and are therefore not treated as an important dimension of plans. Several interviewees noted that the overriding pressure for housing and reductions in local authority budgets meant that any attempts to reduce housing density (which can be required for green SuDS but not necessarily other types of BGI) is met with resistance by developers and some local authorities.
- **Lack of appreciation of the full benefits of blue-green infrastructure:** The interviews highlighted that BGI can be seen purely as a cost by local authorities, with the benefits not being quantified or recorded. In some cases, the benefits of 'green' drainage solutions are too difficult to quantify which can be problematic when measures are required to meet defined standards, though one interviewee noted that "a lot more has been done with a lot less evidence before". Another interviewee noted that "developers say often that they can't afford trees in a new development" because the full benefits of trees are not included on cost sheets.

Box 1: What should I plant in my city?

Better appreciation is needed on how different types of BGI can provide benefits in urban areas. For example, hedges have been replaced with fencing in many areas but are easier to slot into existing developments than trees, mature more quickly, and have a variety of benefits for wildlife as a habitat and food source.

Trees are critically important for urban areas because of their cooling, carbon storage, and biodiversity benefits as well as potential benefits for reducing air pollution in some circumstances. More thought is needed into which species have the best co-benefits in specific places, for example, pollution capture is more effective in trees that are evergreen, rough, have hairy leaves or stems, and are densely planted. Thought is also needed about which species will thrive most in certain areas as the climate changes, given their long lifetimes. Some guidance on species suitability for urban areas is beginning to emerge (http://www.tdag.org.uk/species-selection-for-green-infrastructure.html)[30].

Diversity is also an underexplored part of urban greening. Species-rich planting has known benefits for biodiversity, but also allows for better water infiltration due to a more diverse root network, for example.

(Based on an interview with the Royal Horticultural Society)

The role of finance in supporting blue-green infrastructure projects

"Everyone wants to do more collaborative working, but paying for it is hard to do.[31]"

"It happens on every project; we have lots of different objectives, different programme lines, different agendas and timescales, we need a joint pot. There needs to be some sort of commitment to do BGI with funding. What are the ways of achieving this?[32]"

Better green financing for multi-benefit projects is a key enabler that could unlock more innovation in the uptake of BGI in the absence of regulation. Specifically, these should be funding pots that multiple partners can bid for together to finance schemes that deliver a range of benefits. To enable this approach:

- finance that will pay for these multi-partner projects needs to be made available to the right parties, and
- applicants need to be able to assess the wider benefits of their projects to put robust cases together.

Innovation in the green finance sector can help with providing access to finance. The New Markets for Land and Nature report[33] is a significant step forward in thinking about land management and finance. In addition, the 'natural capital' approach that is promoted by the Government's 25 Year Environment Plan[34] provides a basis that can enable the evaluation of wider benefits of BGI. The greater challenge lies in how to associate BGI benefits with private values, rather than public goods, that can repay those who contribute to the funding schemes[35]. In that context, systems thinking can support understanding the role of individual sectors in the urban sustainability agenda, and how they can be linked with the BGI benefits.

Using systems approaches to understand the benefits of blue-green infrastructure

Urban infrastructure systems are comprised of multiple sectors, including water, transport and housing. These interact with each other, with other infrastructures and with the environment. Each of these sectors puts different pressures on the environment and human wellbeing, from resources extraction to pollution and waste. Systems thinking provides a structured approach to link the components of a system together. This can help decision makers take a shared view of the system and make decisions that achieve the objectives of the whole[36]. This approach can also help stakeholders understand their activities from a sustainable development perspective, accounting for environmental, social and economic factors. As a result, they will be able to assess the role of BGI in offsetting their impacts and contributing to cutting operational costs.

Systems mapping for urban infrastructure sectors

The value of BGI can be assessed through the urban ecosystem services they provide[37], which include benefits listed in table 1. Here we propose a mapping framework (figure 2) that assigns a value to these services based on the interactions between water, transport and housing sectors, and the spread of BGI benefits across the system.

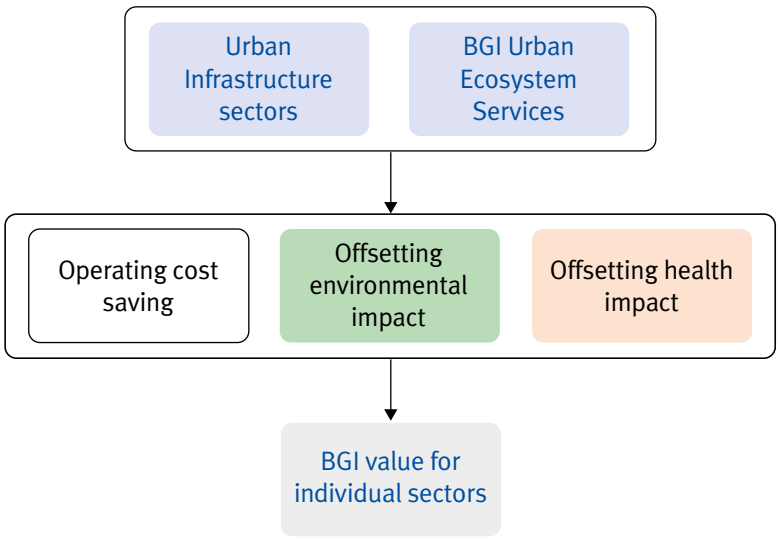

Figure 2: A framework for analysis of the value of BGI at the systems level for individual urban sectors.

A representation of the system can be created to explicitly account for economic (e.g. operational costs), environmental (e.g. impact of water pollution) and social (e.g. impact on health) concerns of relevant stakeholders, which are linked with physical elements (infrastructures), and related resources use (e.g. energy use for water and housing infrastructure) that affect the state of the system as a whole. Box 2 gives an example of a systems mapping that links BGI benefits with water, housing and transport sectors.

The links between sectors mean that the influence of BGI is spread through the system and influenced by the decisions that individual sectors make. At the same time, multiple benefits that BGI provides through so-called urban ecosystem services (e.g. urban heat mitigation, storm water and wastewater management, etc.) can have a positive impact for multiple sectors by either reducing the operational costs (for example, reduction of the energy use for heating/cooling) or offsetting their negative impact on environment and health (for example, reduction of road runoff pollution). These interactions are the basis for systems level assessments of the overall value of BGI implementation for a range of relevant stakeholders. This information can provide a framework for discussing the funding mechanisms that could support wider uptake of BGI.

This systems approach can be used for several applications:

- to map the impacts across the system with respect to economic, social and environmental concerns from a single stakeholder perspective,
- to link all relevant stakeholders based on their operational, causal and/or impact management,
- to gain a full understanding of the impact of developments and land use change on urban sustainability,
- to provide justifications for statutory requirements of mitigation measures responsibilities with respect to the urban sustainable development agenda, and
- to help local authorities reassess how the planning application process is used for mitigating environmental impacts.

Box 2: Systems mapping of the blue-green infrastructure role in the urban system

Links provide an example of systems thinking with respect to the role of BGI for providing benefits for water, housing and transport sectors. Note that this example does not measure the size or importance of the linkages and therefore the value of the BGI, but this could be done as a follow-on step.

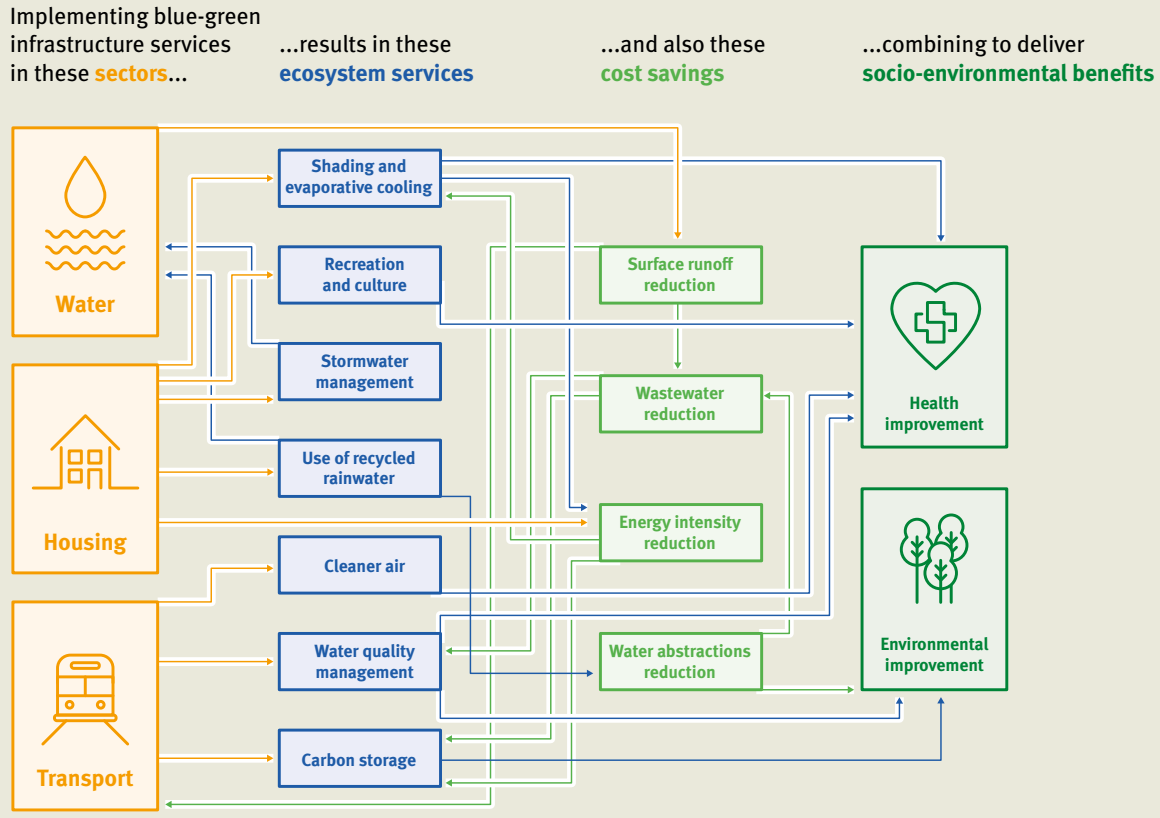

Table 2: Selected examples of how the benefits of BGI can be used to define the value for housing, water and transport sectors based on the interactions mapped in box 2.

BGI Urban Ecosystem Service	Housing sector	Water sector	Transport sectors
Water reuse	Reduces impacts of water shortages	Reduces operational costs of abstractions, pressure on the wastewater system and impact on the environment	
Storm water management and water quality	Reduces costs for flood risk management from surface water runoff	Reduces operational costs of the wastewater system and impact on the environment and health	Reduces costs for flood risk management from surface water runoff and offsets impact of road runoff pollution on environment and health
Carbon storage	Offsets impact of energy use in households on CO_2 emissions	Offsets impact of energy use for water processes on CO_2 emissions	Offsets impact of transport use on CO_2 emissions
Heat mitigation	Reduces the energy use for heating/cooling and related costs, and CO_2 emissions		
Air quality			Offsets impact of transport use on air pollution
Recreation and cultural value	Offsets impact of urbanisation on physical activities and mental health and increases the price of the property		Offsets impact of transport on the physical activities and level of noise

Table 2 describes how the BGI ecosystem services deliver multiple benefits across these three urban sectors.
Two significant messages emerge for BGI uptake:

- The benefits of BGI implementation for the water sector go significantly beyond the surface water management and the SuDS concept, and they could play a significant role in an integrated approach to urban water management, in particular from the economic and environmental perspectives.
- BGI urban ecosystem services can play a particularly significant role in offsetting the impacts of the system, in particular the impacts of housing and transport systems such as urban creep, climate change, pollution and urban heat island effects. This observation confirms that developers and transport providers, as well as local and transport authorities, have a role in delivering sustainable development, which will be key for successful adaptation to future change.

It is important to emphasise that the number and, in particular, the strength of the interactions presented in box 2 will depend on the selected BGI intervention, its location and the scale of implementation. To provide evidence for large-scale implementation of a specific BGI, for example a green roof, the next step would be to systematically map all benefits and allow them to spread through the system using a computational tool. The model should be spatially explicit with a capacity to simulate the interactions between all factors and benefits. By quantifying the value of all BGI benefits, we can help stakeholders deliver BGI interventions that achieve the maximum impact across the entire system.

Summary and conclusions

This briefing note summarises only some of an extensive literature available on determining and quantifying the multiple benefits of blue-green infrastructure. It highlights that current policy levers for increasing the amount of greenspace in England are not working; the proportion of greenspace in urban areas has dropped by 8% since 2001. There is a misalignment between the private and social benefits associated with increasing BGI; a lack of proper accounting of co-benefits in plans for new housing developments; and a lack of appropriate finance to support projects.

While the list of benefits presented in this document is far from comprehensive, a simple mapping framework provides a tool for analysing the benefits of BGI for multiple sectors and stakeholders. The proposed approach can be useful for engagement and open discussions during the pre-planning phase of new developments. In particular, this approach could support better understanding of the impact of new housing developments on the provision of water services[38]. Individual sectors, such as transport, could use this approach to maximise the benefits of BGI for their system. The framework can also be used to assess the impact of new housing plans on urban sustainability as a whole, providing a basis for environmental net gain assessments, which have the potential to fundamentally change how we build in the future[39].

The systems framework presented here opens the question of shared responsibility for sustainable development[40] and proposes a possible way to add environmental and social perspectives to planning decisions. Once we account for the full value of blue-green infrastructure – reduction of operational costs and, more importantly, offsetting negative impacts on the environment and health – we can devise funding schemes based on the full level of benefits that BGI provides.

Ultimately, the value of the work presented is in uncovering interactions and feedback across sectors and highlighting the role of BGI in improving the overall quality of life in cities. Tools such as these can help funders and stakeholders identify the benefits of shared projects and funding streams, think about who they need to work with, and consider how to target green finance in the best way to maximise the natural capital benefits of any development.

References

1. Kovats, R.S., and Osborn, D., (2016) UK Climate Change Risk Assessment Evidence Report: Chapter 5, People and the Built Environment. Contributing authors: Humphrey, K., Thompson, D., Johns. D., Ayres, J., Bates, P., Baylis, M., Bell, S., Church, A., Curtis, S., Davies, M., Depledge, M., Houston, D., Vardoulakis, S., Reynard, N., Watson, J., Mavrogianni, A., Shrubsole, C., Taylor, J., and Whitman, G. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
2. Maksimovic, C; Mijic, A; Suter, I; Van Reeuwijk, M (2017) Blue-green solutions. *A systems approach to sustainable, resilient and cost-effective urban development*. Imperial College London.
3. Committee on Climate Change (2016) UK Climate Change Risk Assessment Evidence Report.
4. Ossa-Moreno, J; Smith, KM; Mijic, A (2017) *Economic analysis of wider benefits to facilitate SuDS uptake in London, UK*. Sustainable Cities and Society 28, 411-419
5. Mentens, J., Raes, D. & Hermy, M. (2006) *Green roofs as a tool for solving the rainwater runoff problem in the urbanised 21st Century.* Landscape Urban Plan., 77, 217–226.
6. ADAS (2019) for the Committee on Climate Change: Research to provide updated indicators of climate change risk and adaptation in England
7. Bozovic, Ranko & Maksimovic, Čedo & Mijic, Ana & Smith, K.M. & Suter, Ivo & Van Reeuwijk, Maarten. (2017). *Blue Green Solutions. A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development*. 10.13140/RG.2.2.30628.07046.
8. Gill, S. E., Handley, J. F., Ennos, A. R. and Pauleit, S. (2007) *Adapting cities for climate change: the role of the green infrastructure*. Built Environment, 33(1), 115-133
9. Charlesworth, S.M. (2010) *A review of the adaptation and mitigation of global climate change using sustainable drainage in cities*. Journal of Water and Climate Change, volume 1 (3): 165-180.
10. Ip, K., Lam, M. & Miller, A. (2010) *Shading performance of a vertical deciduous climbing plant canopy.* Build. Environ., 45(1), 81–88.
11. Hewitt, C.N., Ashworth, K. and MacKenzie, A.R., (2019). Using green infrastructure to improve urban air quality (GI4AQ). *AMBIO: A Journal of the Human Environment*.
12. McPherson, E.G., Nowak, D.J. & Rowntree, R.A. (eds.) 1994 *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project,* Gen. Tech. Rep. NE-186. US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Radnor, Pennsylvania.

13. Lee, A. C. K. and Maheswaran, R. (2011) *The health benefits of urban green spaces: a review of the evidence.* Journal of Public Health, 33, 212-222.

14. Tzoulas, K; Korpela, K; Venn, S; Yli-Pelkonen, V; Ka´zmierczak, A; Niemela, J; James, P (2007) *Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review.* Landscape and Urban Planning 81 (2007) 167–178

15. Hartig, T; Evans, GW; Jamner, LD; Davis, DS; Garling, T (2003) *Tracking restoration in natural and urban field settings.* Journal of Environmental Psychology 23, 109–123

16. Takano, T., Nakamura, K.,Watanabe, M., (2002) *Urban residential environments and senior citizens' longevity in mega-city areas: the importance of walkable green space.* Journal of Epidemiological and Community Health 56 (12), 913–916.

17. Kim, J., Kaplan, R., (2004) *Physical and psychological factors in sense of community.* New Urbanist Kentlands and Nearby Orchard Village. Environ. Behav.36, 313–340.

18. Kuo, F.E., Bacaicoa, M., Sullivan, W.C., 1998. *Transforming inner city landscapes: trees, sense of place and preference.* Environmental Behaviour 42, 462–483.

19. Whitford, V., Ennos, A.R. and Handley, J.F (2001) *"City form and natural processes" – indicators for the ecological performance of urban areas and their application to Merseyside, UK.* Landscape and Urban Planning 57 (2001) 91–103

20. Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., & Wynne, G.R. (2010) *Making Space for Nature: a review of England's wildlife sites and ecological network.* Report to Defra.

21. Ibid.

22. There are many guides and information sources available on how to design and maintain urban spaces so that they make the most of green and blue infrastructure. Many of these resources are available through the Green Infrastructure Partnership Resource Library. https://www.tcpa.org.uk/green-infrastructure-research-database

23. Committee on Climate Change (2019) *UK Housing: Fit for the Future?.*

24. Committee on Climate Change (2015) *Progress in preparing for climate change: 2015 Report to Parliament.*

25. Commission for Architecture and the Built Environment (2010) *Urban Green Nation: Building the Evidence Base.*

26. House of Commons Communities and Local Government Committee (2017) *Public Parks. Seventh Report of Session* 2016-17.

27. CABE (2010)

28. Fifteen in-depth interviews were carried out with a range of people representing different bodies involved in decision making on blue-green infrastructure. The organisations represented included central government, local government, government agencies, water companies, consultants, property developers and the charity sector.

29. Committee on Climate Change (2017) *Progress in preparing for climate change: 2017 Report to Parliament.*

30. http://www.tdag.org.uk/species-selection-for-green-infrastructure.html

31. Quotes from the interviews conducted as part of this study

32. Ibid.

33. Green Alliance (2016) *New markets for land and nature. How Natural Infrastructure Schemes could pay for a better environment.*

34. HM Government (2018). *A green future: our 25 year plan to improve the environment.*

35. Natural Capital Solutions (2018) *Natural Capital Assessment in Northern Ireland: Urban Study.*

36. Pandit, A., Minné, E.A., Li, F., Brown, H., Jeong, H., James, J.A.C., Newell, J.P., Weissburg, M., Chang, M.E., Xu, M. and Yang, P., (2017). *Infrastructure ecology: an evolving paradigm for sustainable urban development. Journal of Cleaner Production, 163,* pp.S19-S27.

37. Keeler, B.L., Hamel, P., McPhearson, T., Hamann, M.H., Donahue, M.L., Prado, K.A.M., Arkema, K.K., Bratman, G.N., Brauman, K.A., Finlay, J.C. and Guerry, A.D.,(2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability,* 2(1), p.29.

38. Policy Connect (2018) *Bricks & Water: A plan of action for building homes and managing water in England.*

39. Adaptation Sub-Committee, Committee on Climate Change (2019)

40. Lenzen, M., Murray, J., Sack, F. and Wiedmann, T., (2007). Shared producer and consumer responsibility—Theory and practice. *Ecological economics,* 61(1), pp.27-42.

Acknowledgements

We would like to thank Dr. Alex Collins and Peter Massini for reviewing this paper and making many constructive suggestions.

A range of people interviewed anonymously from central government, local government, government agencies, water companies, consultancy, property developers and the charity sector to provide the insights summarised in this paper. Several of those people also attended a workshop on blue green infrastructure in September that helped contribute further to our thinking.

About the authors

Dr Ana Mijic is a Senior Lecturer in Systems Water Management at Imperial College London, with expertise in advanced modelling and analysis of processes, planning, resilience and economics of water systems.

Kathryn Brown leads the secretariat that supports the Adaptation Committee of the Committee on Climate Change (CCC). Kathryn has worked at the CCC for seven years, during which she has led the production of the UK's Climate Change Risk Assessment, as well the Committee's analysis on water, health, biodiversity, emergency planning, agriculture and forestry. Prior to 2012, Kathryn worked in Defra's climate change team for ten years, covering international negotiations, carbon budgets and adaptation evidence. She holds degrees in natural sciences and international development.

About the Grantham Institute and Imperial College London

In 2007, the Grantham Foundation for the Protection of the Environment made the visionary decision to support an Institute at Imperial College London to provide a vital global centre of excellence for research and education on climate change. Ten years on, the Grantham Institute is established as an authority on climate and environmental science.

The Grantham Institute is Imperial's hub for climate change and the environment, and one of six Global Institutes established to promote inter-disciplinary working and to meet some of the greatest challenges faced by society. We drive forward discovery, convert innovations into applications, train future leaders and communicate academic knowledge to businesses, industry and policymakers to help shape their decisions.

Imperial College London is a global university with a world-class reputation in science, engineering, business and medicine, and excellence in teaching and research. Consistently rated amongst the world's best universities, Imperial is committed to developing the next generation of researchers, innovators and leaders through collaboration across disciplines.

www.imperial.ac.uk/grantham

Contact us

For more information about this subject, to discuss how the issues covered affect you and your work, or to contact the authors, please email us at: **grantham@imperial.ac.uk**