Greening the Grey:

a framework for integrated green grey infrastructure (IGGI)

University of Glasgow

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NERC SCIENCE OF THE ENVIRONMENT

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1. INTRODUCTION

A quarter of 53 respondents in a recent survey of engineering and environmental practitioners indicated that improved guidance and case studies on the costs and benefits of different forms of green infrastructure would help wider uptake (Naylor et al., 2016). In response to this need, this report identifies the opportunities, economic costs, wider benefits and risks of approaches to construction and development that seek to 'green' elements of 'grey' infrastructure. It collates a range of innovative 'green-grey infrastructure' projects from the UK and elsewhere that showcase opportunities for wider application.

The report is based on a business case model that compares green-grey options with 'business-as-usual' solutions in a range of coastal, urban and historic settings. This approach aims to provide evidence and economic justification that can be used to make a stronger case for implementing green-grey solutions more widely. The report is targeted at a range of practitioners and end-users including developers, infrastructure providers, local authorities, national agencies, public bodies, asset managers and local community groups.

Greening approaches to fluvial engineering are addressed in a separate, complementary report (see HR Wallingford 2017: 'Green approaches in river engineering: Supporting implementation of green infrastructure').

1.1 GREEN INFRASTRUCTURE – A CONTEXT

The concept of Green Infrastructure (GI) has shown strong growth over the last decade. Within flood risk management, focus has been placed on minimising intervention by **working with natural processes** (Environment Agency, 2017) through which some forms of green infrastructure can be achieved. At a European level, the concept of **nature based solutions** is often used as an umbrella term and covers use of GI elements that seek to achieve small-scale local benefits up to tackling larger-scale social issues of flooding, climate change and poverty (European Commission, 2015). Much of the drive to implement GI comes from the recognition that natural elements in cities (and beyond) provide a range of **ecosystem services** (ES) for people, usually grouped into provisioning, cultural and regulating services (DEFRA, 2013). Using GI to maximise provision of these services is a key aim in innovation and application. In urban areas, ecosystem services provided by GI can include reducing flood risk, cleaning air and water, ameliorating extreme weather, and supporting resilience of ecosystems and biodiversity to environmental change.

A large amount of information regarding GI application and benefits (environmental, social and economic) is now available, and GI concepts are increasingly incorporated into national guidance and policy (Table 1.1). These have primarily focused on improving the ecological function, biodiversity value, and social value of existing land and water resources rather than the built environment itself (Naylor et al. 2014). Focus has been placed on the spaces around buildings (parks, urban trees etc.) or to other well-established forms of greening such as green walls and roofs on buildings. In comparison, opportunities for greening other types of hard (i.e., grey) infrastructure assets such as freestanding and boundary walls, transport networks and bridges are not yet widely considered. Where opportunities to green these assets are identified (e.g., EC, 2012) there is little or no guidance on what can be achieved or how to do this effectively. Other types of policy could be

used to integrate green grey infrastructure, examples are listed below in Table 1.2 but this list is not exhaustive.

Table 1.1 Green infrastructure, environment and planning policy which could be extended to include IGGI.

Green Infrastructure	Planning
• Benefits of Green Infrastructure (2010)- Forest Research CIEEM (2016) • Cities, Green Infrastructure (2015)- Landscape Institute • Demystifying Green Infrastructure (2015)- UK Green Building Council • Green Bridges Guide (2015)- Landscape Institute • Green Infrastructure Guidance (2009)- Natural England • Green Infrastructure Guide (2008) – North West Think Tank • Green Infrastructure in Urban Areas (2011)- RICS Green Infrastructure: Connected + Multifunctional landscapes (2009)- Landscape Institute • Multifunctional Green Infrastructure (2012) - Science for the Environment Policy, European Commission • Multifunctional Urban Green Infrastructure (2010)- CIWEM • Trees in Hard Landscapes (2014)- Trees and Design Action Group • Trees in the Townscape (2012)- Trees and Design Action Group • Urban Green Infrastructure (2013)- Houses of Parliament	• Council Directive 2000/60/EC (WFD) (2000)- European Commission • Council Directive 92/43/EEC (Habitats Directive) (1992) - European Commission • Minimum Standards for Open Space (2005)- Scottish Government • Open space strategies Best practice guidance (2009)- CABE • Planning for a healthy environment (2012)- Town and Country Planning Association, Royal Society of Wildlife Trusts • Strategic Scoping Report for marine planning in England (2013)- Marine Management Organisation • The National Pollinator Strategy (2014)- DEFRA • UK Marine Policy Statement (2011)- HM Government

Table 1.2 Other policies that can potentially be used to implement IGGI

Economic	Nature, wildlife and ecosystem services	Social	Climate and flood risk regulation
• Economic Benefits of Greenspace (2012) Forestry Commission (Saraev) • Green Infrastructure Contribution to Economic Growth: A review (2013) - EFTEC, Sheffield Hallam • Microeconomic Evidence for the Benefits of Investment in the Environment (2012)- Natural England • Microeconomic Evidence for the Benefits of Investment in the Environment 2(2014)-	• Council Directive 2000/60/EC (WFD) (2000)- European Commission • Council Directive 92/43/EEC (Habitats Directive) (1992) - European Commission • Ecosystem services in a changing world (2013)- Raffaelli & White • The National Pollinator Strategy	• Community Green: Using local spaces (2010)- CABE • Green space Design for health and wellbeing (2012)- Forestry Commission (Shackwell and Walter) • Health, wellbeing and open space (2003)- OPENSpace • The evidence base for linkages between GI, public health and economic benefit (2015)	• Air temperature regulation (2013)- Forest Research (Doick and Hutchings) • Climate Change (Scotland) Act (2009)- Scottish Government • Estuary Edges Guidance (2008)- Environment Agency • Greater working with natural processes in flood & coastal erosion risk management (2012)-

Natural England • Natural Capital Investing (2015)- GI Task Force • The Green Book: Appraisal and Evaluation in Central Government (2003, 2011 update) - HM Treasury	(2014)- DEFRA	- Bowen & Parry • The Value of Public Space (2004)- CABE Space • Well-being of Future Generations (Wales) Act (2015)- Welsh Government	Environment Agency • Working with Natural Processes- Evidence Directory (2017)- Environment Agency

Full references for these policies are provided in Chapter 5.

1.2 INTEGRATED GREEN-GREY INFRASTRUCTURE (IGGI)

The term 'integrated green-grey infrastructure' (IGGI) is used in this report to refer to greening of hard infrastructure that cannot be replaced with softer green (or blue-green) solutions including transportation infrastructure, boundary walls and public infrastructure such as benches and railings (Naylor et al. 2014, 2017). IGGI therefore sits between entirely 'green' and entirely 'grey' options along a continuum of engineering approaches (Figure 1.1) and in simple terms is 'greening the grey'.

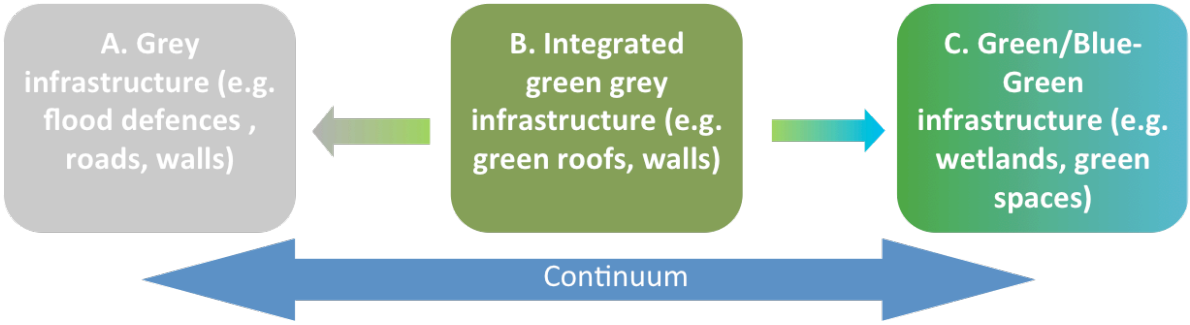


Figure 1.1 A continuum of infrastructure engineering approaches

A good example of where a green-grey approach is required is coastal flood and erosion alleviation infrastructure. Although there is a growing trend towards greener, nature-based approaches to flood and erosion risk alleviation (Environment Agency, 2017), in many urbanised locations traditional hard engineering approaches are adopted as nature-based approaches are often not socially, technically or economically feasible. In these cases, alternative approaches to 'green the grey' can be used to improve the multifunctionality and ecological value of hard coastal and estuarine infrastructure. The IGGI measures in this report can be used to help greening those grey assets that must remain primarily grey including flood alleviation and erosion control structures (including seawalls) as well as transport infrastructure, boundary walls and street furniture (Figure 1.2).

This report does not cover types of urban greening that are already well established or are covered extensively elsewhere, including GI in open blue and green spaces, Sustainable Urban Drainage Systems (SuDS), and green walls and green roofs on buildings.

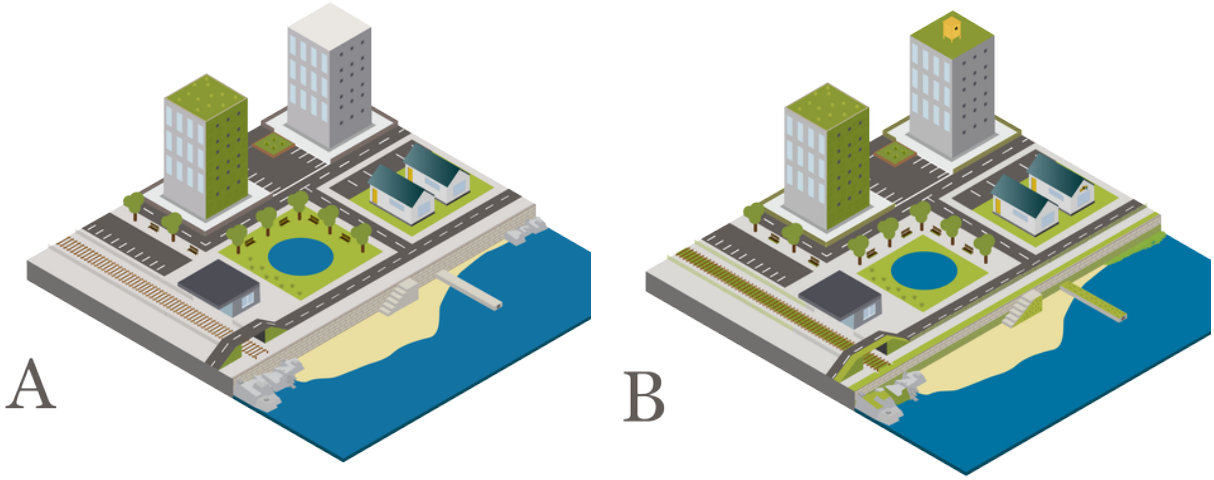


Figure 1.2 Examples of opportunities for 'greening the grey' where A: shows the types of GI currently covered in GI policy and practice and B: shows the potential additional greening that IGGI measures and solutions can provide.

1.3 THE BENEFITS OF IGGI

The social and environmental benefits of GI are increasingly well known (see sources in Tables 1.1 and 1.2). Equally, the examples described in this report show that IGGI solutions can provide ecosystem services in a range of settings, including ameliorating impacts of short-term flooding, urban heat and air pollution, and supporting biodiversity conservation. This aligns with many large organisations seeking to put biodiversity at the forefront of environmental commitments, including Highways England, National Rail and some local authorities. 'Good practice principles' for achieving biodiversity 'net gain' have also been developed for the wider construction industry (CIEEM, 2016), which IGGI can support. Greening of grey assets further provides opportunities to complement related targets and policies set out in, among others, Biodiversity Action Plans, Green Infrastructure Plans, Living Landscape plans, and Strategic Nature Areas.

Application of IGGI ideas has been facilitated by policy such as environmental impact assessment, the Habitats Directive, and corporate social responsibility. In doing so, IGGI approaches reported here have been successful in securing planning approval, winning public support and levering federal/national funding. Incorporating green elements into a greater range of built assets also offers opportunities for tackling social problems of health and well-being in urban areas. For example, IGGI can support local and national plans which regularly identify a need to achieve increased access open spaces, greenspaces, and green-blue spaces.

Despite these opportunities, the biggest barrier to wider uptake of greening of grey assets is uncertainty over (1) economic cost and (2) impacts on engineering performance, inspection and maintenance. By providing detailed information on costs, benefits and risks of already implemented IGGI examples, this report demonstrates that greening can not only provide a range of social and

environmental gains, but that this can be achieved relatively cheaply with, very often, negligible impact on asset function. This report provides the tools and examples needed to support a business case for applying GI principles to those hard, non-building infrastructure assets that have typically been overlooked.

By broadening the range of assets for which greening is considered, more opportunities to achieve a range of economic, social and environmental benefits will be created. By drawing together examples of IGGI innovation and by providing a comprehensive economic assessment of different options, this report provides the evidence-based framework needed to enable wider uptake of greening.

1.4 REPORT STRUCTURE

Chapter 1 (this chapter) gives a broad context of GI and IGGI and illustrates some of the key issues and opportunities for implementation. It outlines the structure of the report and introduces some key terminology.

Chapter 2 outlines the IGGI measures and solutions that are included in each bundle.

Chapter 3 outlines the decision-making process. It presents a tool that can be used at a strategic level to identify wider implications of any IGGI solution applied as part of new schemes, on-going maintenance or retrofit activities. Importantly, it demonstrates how costs and benefits were calculated for IGGI options compared to business-as-usual options.

Chapter 4 introduces the factors felt to be critical to IGGI projects and an increased uptake. The chapter details how these critical success factors were identified and how they can be assessed for individual schemes and strategic assessments of historic, urban, coastal and historic environments, or at landscape, national or international scales.

Chapter 5 contains the Bundles – collated suites describing the business cases for each classification – a consideration of why IGGI measures may be of value in that field, with respect to relative drivers, cost benefits and possible outcomes. The bundles collate case studies and examples across four themes - Historic, Urban, Mowing and Coastal. Detailed case studies are based on existing examples of the IGGI technology in the field, drawing on evidence gathered as part of a relevant study, PhD work or similar. Less detailed examples can be found in the 'Art of the Possible' vignettes – these show similar examples of IGGI measures in alternative settings, and illustrate how these innovations can be implemented elsewhere.

2 IGGI MEASURES AND SOLUTIONS COVERED IN THIS REPORT

This report presents IGGI measures from four different environments found in peri-urban to urban areas (Figure 2.1). These environments were selected in close discussion with the project partners and were designed to draw in examples from fields such as coastal ecology, biogeomorphology and heritage conservation that can usefully enrich green infrastructure policy and practice. Importantly it covers urbanised parts of our built environment such as coastal and historic assets that are typically overlooked in GI policy.

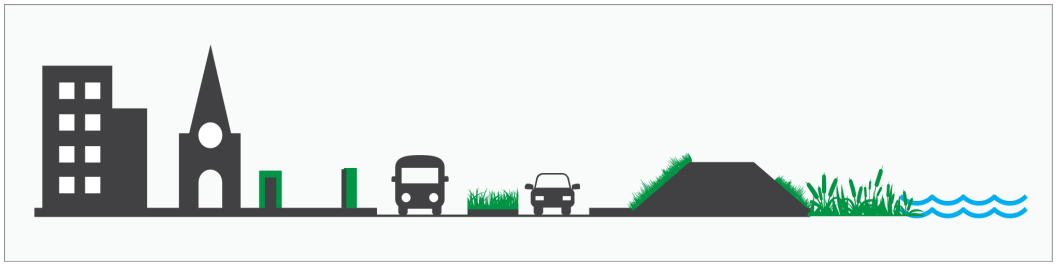


Figure 2.1. Illustration the range of environments covered by the report.

The integrated green grey infrastructure (IGGI) examples are the primary outcome of this project and are packaged into four main **topic bundles** (Appendices 1-4). The 'bundle' format was developed by project partners and practitioners who wanted to have the majority of suitable examples for each environment covered in a single document, along with the reasoning behind implementing these types of measures. For those working for local authorities, developers, statutory bodies, and other larger scale landowners, the bundles provide a one-stop shop to support measures on a landscape scale – and provide evidence-based support to aid wider implementation of a range of integrated green grey infrastructure alternatives to traditional, hard engineered solutions. The bundles are as follows:

Historic bundle: examples of greening of either historic grey assets or grey assets within historic conservation areas. This including old boundary walls, historic buildings, monuments and ruined sites.

Urban bundle: examples of greening of urban grey assets including temporary planting in urban spaces and construction sites, boundary walls and railings.

Mowing bundle: examples of managing grassed assets (earth embankments) for improved biodiversity and social amenity that can be applied in urban, historic and coastal settings (Figure 2.2).

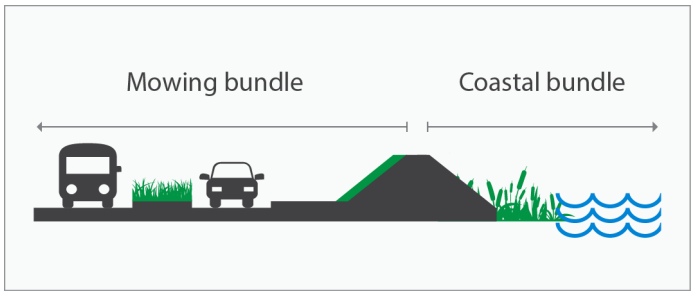


Figure 2.2 Diagram showing which environments the mowing bundle covers

Coastal bundle: examples of greening of coastal and estuarine grey assets including seawalls, breakwaters, jetties and walkways, revetments and outfalls.

Each bundle consists of a **Business Case** (BC) supported by several **Case Studies** (CS) and '**Art of the Possible**' (AP) examples (Figure 2.3):

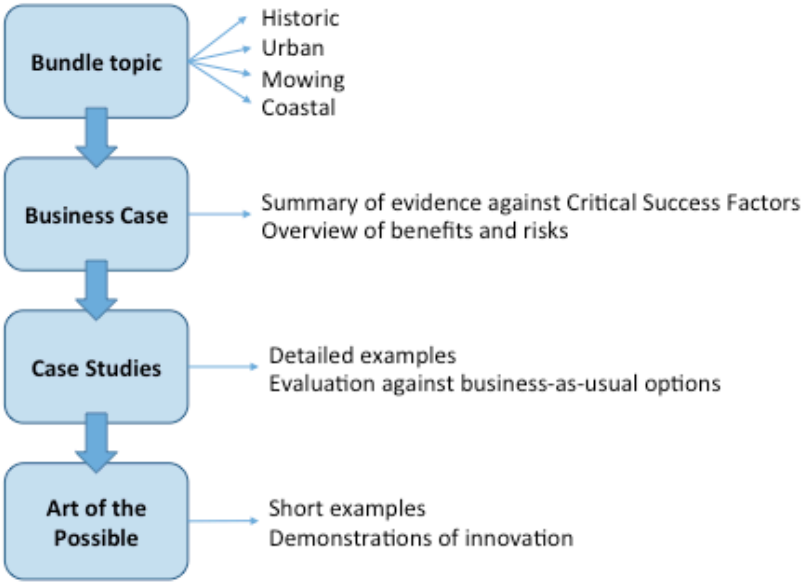


Figure 2.3 Overview of the structure of each 'bundle' used in this report

Business case: Describes the type and scope of the innovations in each environment, how they have been applied, where and when. It sets out a summary of all the evidence complied for each topic bundle. It provides an overview of the different IGGI measures showcased as case studies and 'Art of the Possible' examples (see below). This is based on eight **Critical Success Factors**: economic costs, ecosystem services, engineering, policy, data quality, social, reputation and asset resilience (see Chapter 5 for a full explanation of Critical Success Factors). Each Business Case considers: where IGGI measures have been applied so far; the contexts in which they may be applied elsewhere including physical, engineering and ecological context, and; the limitations and risks involved in their application.

Case studies: Detailed examples provided by a range of project partners (including academics, national agencies and private firms) that have sufficient data to enable assessment against each of the Critical Success Factors. Each case study is compared to grey ('business-as-usual') options. This approach is designed to help decision-makers budget more effectively, and to determine where cost-saving or cost-neutral IGGI options may be possible. Detailed accounts of the potential additional benefits to the environment, the local community and to businesses are provided to help to strengthen a case for application in other situations.

Each case study contains a data quality table that indicates the robustness of the supporting evidence, and sources of further information and key contacts.

Art of the Possible: Shorter examples that do not have sufficient supporting data for full evaluation (e.g., those at early stages of development or which have not yet been tested in practice) but which demonstrate innovation that could be considered in other situations. In the urban bundle only, there are also bite-sized art of the possible examples providing short summaries of IGGI measures that have been built but for which no or very limited data were available.

2.1 EXAMPLE IGGI MEASURES

For each bundle, IGGI measures were grouped into broad types to help cluster examples provided based on the types of infrastructure that IGGI has been deployed on and/or the environmental context of the IGGI measure. Each measure represents a specific type or installation of an IGGI approach which have been applied individually. These are summarised for each topic in Figure 2.4 below. Each case study (CS) and art of the possible (AP) included in the report is labelled by environment, e.g. Historic Case Study 1 is labelled as CS-H1 and Historic Art of the Possible 1 is labelled as AP-H1. The number of case studies and art of the possible measures included in this report varies between environment, this is based on the data that was provided through various requests for data from project partners, key practitioner and academic networks, as well as generated from webinars and events attended during the project.

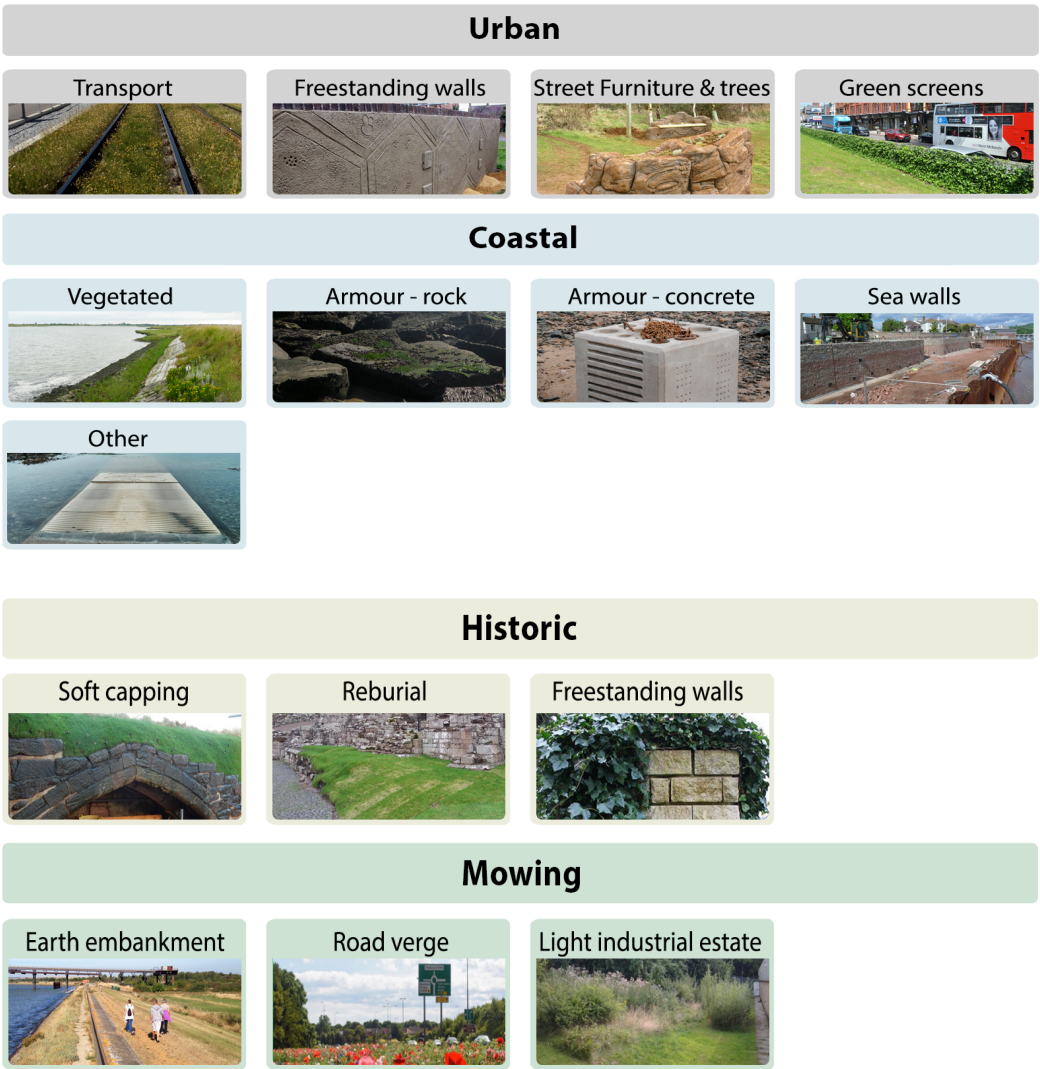


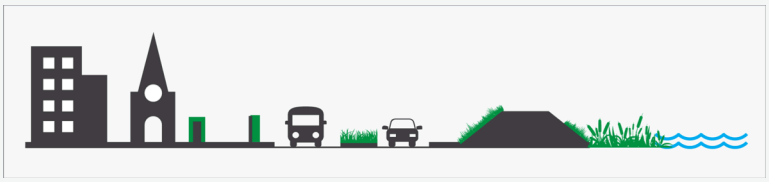
Figure 2.4 Summary of the different groups of IGGI measures which are included in each of the four environments covered in this report. Photo credits are listed in Appendices 1-4.

2.2 IGGI SOLUTIONS

Individual IGGI measures can be grouped as IGGI 'solutions' where individual IGGI measures can be combined, or used in combination with other more nature-based forms of greening such as GI and working with natural processes approaches to reducing flood risk. Each topic bundle contains a full list of IGGI measures and identifies potential IGGI solutions. For example, the IGGI solutions can be used, in combination with more conventional GI approaches, across the landscape as part of strategic GI planning by landowners or government agencies. Some possible combinations of IGGI interventions, referred to as 'solutions' are illustrated here:

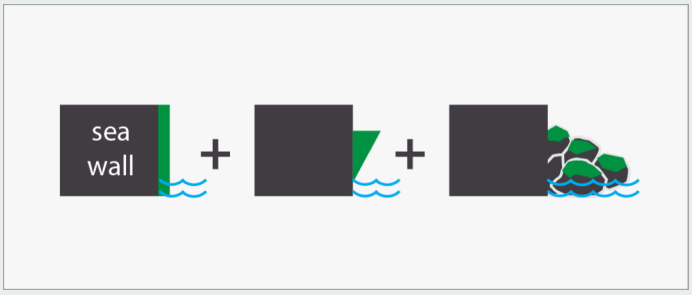
Example 1. An estuarine town with some architectural heritage might develop a strategy to ameliorate traffic-generated pollution while improving resilience *and* aesthetic appeal to tourists and locals - a 'solution' or collection of IGGI measures might include:

- Soft capping of historic walls to reduce the degradation of the stonework.
- Green screening of urban railings or street furniture to help trap and remove pollution.
- Altering mowing regime on verges and sea defences to improve the look of the town.
- Coastal salt marsh generation to improve flood resilience.



Example 2. Coastal: Multiple IGGI measures combined at a single location, e.g. sea wall – a traditionally flat, uniformly grey, poor substitute for a natural rocky shore. By combing;

- Textured sea wall (cast in a textured form liner).
- Retrofitted pocket rock pools, e.g. Vertipools.
- Textured rock placed to create maximum habitat and water retention.



The above examples illustrate how a traditional grey engineering solution can be enhanced to provide variety of complex habitats and support a broader diversity of species helping support urban ecosystem service provision.

3 INCLUDING IGGI IN DECISION-MAKING PROCESSES

Most engineered or manufactured environments could be adapted to include habitat, to some degree. The limiting factor in including it is, perhaps, not the lack of an IGGI option, but the drive to do it and the potential returns. Anecdotal evidence suggests sometimes IGGI measures can be scoped out when they are considered an additional asset that requires maintenance but there is no capacity in the budget to cover this.

IGGI measures have been used in every stage of a project; in early planning processes (as mitigation to offset potential impacts) or integrated at the construction phase, or as alternative maintenance or repair practices. Other measures provide opportunities for retrofitting into existing schemes and the examples in the Historic Bundle show how well certain IGGI measures can perform as retrofits on historic monuments and ruins.

The case studies and 'Art of the Possible' examples in this guidance (see Chapter 7) highlight a variety of opportunities for including IGGI in the decision-making process. Importantly, these examples illustrate how different measures can be used across an asset's timeline from pre-planning, commissioning and design, through to construction and completion right and then through its working life, including maintenance and repair events to decommissioning and beyond.

3.1 STRATEGIC LEVEL (SCALE)

Including IGGI at a strategic level can provide the framework that supports the inclusion of individual measures at a local scale. Like traditional GI, IGGI can be 'designed-in' as part of strategic planning and policy (e.g. Metro Vancouver, 2015). This can be particularly valuable in strategic attempts to meet specific targets, with combinations of measures, referred to here as 'IGGI Solutions' collectively helping address problems of air pollution across an urban borough, for example, or address flood risk across a watershed.

Potentially IGGI measures can be adapted for inclusion within a wide range of schemes, as illustrated by the 'Art of the Possible' examples. Some approaches will better suit large-scale projects or be more relevant across a landscape scale than more local measures; key considerations include:

- IGGI can be designed in as part of strategic planning and policy
- IGGI solutions (i.e. suites of measures) can be identified to help meet particular targets for GI, air quality, working with natural processes (the flood risk example) or ecosystem services (e.g. London Ecology Masterplan).
- The strategic scale can provide the framework that supports inclusion of individual IGGI measures at the local scale.

A good example of a strategic approach to urban greening that includes elements of IGGI is the London Ecology Masterplan developed by Arup and the Crown Estate, as described in Box 3.1 below. IGGI measures can also be usefully included as part of strategic estuarine and coastal flood risk strategies such as those being developed for the Thames and Humber estuaries. These strategic approaches to flood risk allow opportunities to identify IGGI measures and solutions, and to include key performance indicators to include them as part of strategic planning. For example, these strategic plans can recommend working with natural processes and use of IGGI measures wherever possible when meeting cost, engineering, policy and/or ecological requirements.

LONDON ECOLOGY MASTERPLAN

'Through a holistic estate-wide approach, the Masterplan provides a long-term, flexible strategy for enhancing landscape and ecological value through the delivery of multi-functional green infrastructure features that provide a range of ecosystem services. It links green spaces with new features to create a green corridor through the site'

London Ecology Masterplan Case study (Landscape Institute, 2017)

The Masterplan is underpinned by the innovative inclusion of ecology within the buildings environmental performance assessment method - UK BREEAM (Building Research Establishment Environmental Assessment Method). The London Ecology Masterplan was developed to enable the crown estate to more efficiently and effectively deliver their BREEAM requirements. This led to the development of a Strategic Ecology Framework (SEF) to evaluate and improve the ecological performance of buildings and other infrastructure assets in the Crown Estate's holdings. The SEF is used instead of annual BREEAM assessments for the assets within the Masterplan and aims to support decision makers/ project teams to:

- understand the existing ecology of a site to identify the best approach,
- identify, protect and enhance key ecological features,
- remove or limit existing features that are negatively affecting the site's ecology,
- mitigate unavoidable impacts and compensate against residual impacts,
- enhance the ecological value of the site and surrounding areas by encouraging ecological features.

The Masterplan targets planting of UK native species, where possible, to maximise biodiversity gains. Non-native species are selected where they provide a known ecological benefit e.g. a foraging resource.

One of the first project's arising from the Masterplan is to green the Crown Estate's St James Palace and Regents Street portfolios. By selecting those species of trees, shrubs and flowers with known ecological benefits, the rooftops, walls and the streets of the portfolios will encourage a range of wildlife species into the centre of London. This has been named, 'Wild West End' and many other property owners are now joining in the project to green one of the greyest parts of central London. IGGI measures in this report can be used to support this award-winning endeavour.

Box 3.1 Strategic scale GI including IGGI elements in central London.

3.2 SCHEME SCALE

At a scheme scale, there are three categories of intervention that can be adopted: 1) new or replacement build, 2) on-going maintenance activities and/or 3) retrofit. Many of the examples presented in this report have been tested or implemented in one form – such as during maintenance, but could be readily applied in all three intervention stages.

3.2.1 NEW BUILD

Though the client brief, site characteristics, and subsequent design and budget limitations will influence what is ultimately possible, new build projects can offer the widest possible opportunities to include IGGI. Strong business cases that address the risks, costs, benefits and opportunities can aid approval of IGGI approaches. Reference to successful examples, such as the case studies presented in this report, can help in supporting IGGI inclusion.

3.2.2 ON-GOING MAINTENANCE

The inclusion of IGGI can positively influence maintenance regimes, such as via cost savings. Initial use of IGGI measures has been driven by some organisations' attempts to reduce maintenance costs (e.g. reduced mowing budget necessitating a move from mowed grass to wildflower meadow). Even where IGGI measures are more costly than the business-as-usual model, IGGI measures merit consideration in decision making where they can provide enhanced resilience and/or reduce the need for interventions in the medium and longer–terms. Many of the examples presented involve simple changes in maintenance procedures that are cost neutral.

3.2.3 RETROFIT

Sometimes the driver to add IGGI measures may be a local, corporate or national policy change, and/or efforts to ameliorate a problem or potential problem. In these instances, retrofitting of IGGI measures has been used to improve social cohesion and/or improve ecological outcomes.

3.3 THE DECISION SUPPORT TOOL

3.3.1 OVERVIEW

This project has developed a decision support framework that is designed to help guide practitioners through the process of considering IGGI measures as part of an engineering or development scheme. This framework has been developed in coordination with the project partners and with HR Wallingford, who developed a similar framework. It is designed to sit within the five point business model context used by central government and aims to support decision makers in evaluating if IGGI measures can be applied within their new build, replacement or large-scale maintenance projects.

The process is circular and iterative where decisions made, and measures implemented are monitored and modified if needed using an adaptive management approach (Figure 3.1). The essential wider decision-making remains the same at each iteration of the process, including determining a need to take action and in assessing the strengths, weaknesses, opportunities, risks and losses of any alternatives. Initial consideration of the most environmentally beneficial option is

needed at each stage and iteration of the adaptive management cycle. This report does not cover projects where the initial options appraisal (during the drivers of change phase) recommends no intervention, working with natural processes or where entirely hard engineering options are the most suitable. It is instead used to identify where it is possible to use an IGGI solution instead of or alongside a grey engineering option.

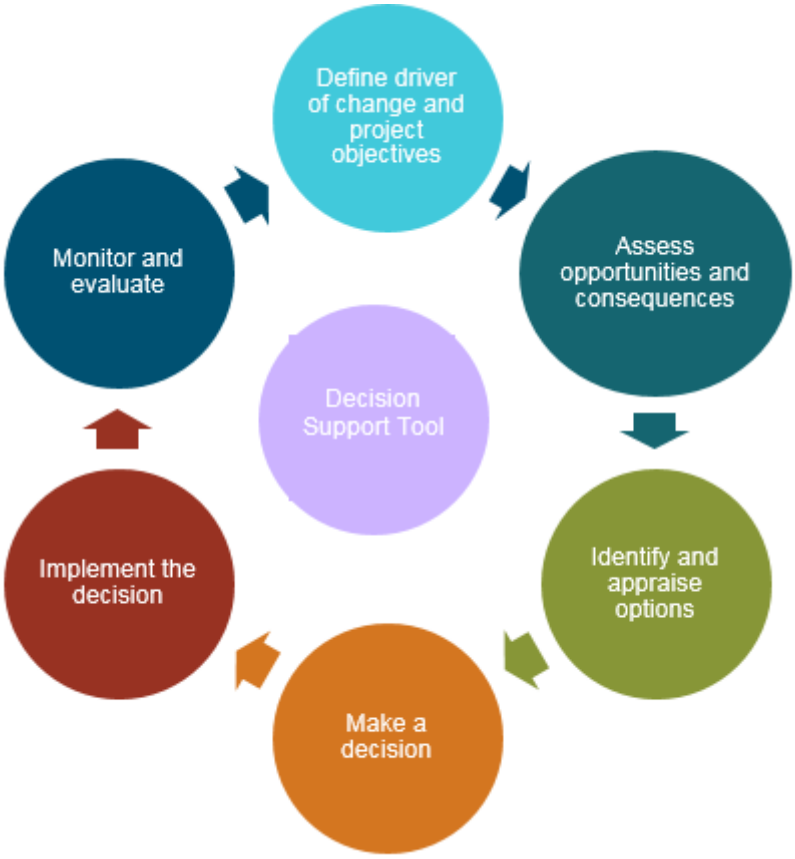


Figure 3.1 General decision-making process

Figure 3.2 Continuum of scheme scale decisions from no intervention through to a grey engineering solution, commonly used in flood risk management (after Roca et al., 2017).

3.3.2 DEFINE DRIVERS OF CHANGE AND PROJECT OBJECTIVES

In any project, it is important to define the key objectives explicitly; however, with IGGI projects this can add a layer of uncertainty as objectives can often be less familiar or more challenging to measure against expected outcomes. Improving biodiversity, habitat value and ecosystem 'enhancement' are complex and often subjective issues. Prioritising and quantifying what is possible,

preferred, essential or sufficient, and issues of scale and timeframes can also be hugely important, often affecting the success of IGGI measures. Where an IGGI measure is part of a project that requires mitigation then these parameters will be more clearly defined; where the scheme is a general attempt to improve the environmental appeal or ecological value of an area, then the judgement of experts will be required to help determine what the key goals for habitat(s), assemblages and species are. The Critical Success Factors framework outlined in Chapter 4 enables practitioners to make more informed judgements on the relative value of IGGI approaches compared with traditional grey engineering options.

3.3.3 ASSESS STRATEGIC OPPORTUNITIES AND CONSEQUENCES

Before any option or a number of options have been identified, it is important to determine to what extent any potential benefits and consequences can be managed. Lawton's principles (Defra, 2010), and similar guidance at the landscape scale illustrate the need to look strategically when installing infrastructure, i.e. can any additional enhancements be created within the design? For example, can links be made to neighbouring habitats, can green networks be enhanced or barriers removed, allowing improved access? Can local groups be involved and to what extent can additional internal or third party funding be employed? If habitat is being removed, can it be offset elsewhere, of equal or additional value? Asset managers may have opportunities to combine multiple IGGI intervention types, across a single site, a linear asset, a network or at the landscape scale as part of strategic planning initiatives.

3.3.4 IDENTIFY AND APPRAISE POSSIBLE OPTIONS

The topic bundles (coastal, historic, mowing and urban) presented in Appendices 1- 4 are designed to help support practitioners in identifying possible IGGI measures and solutions that could be adopted or adapted for their particular schemes. Each case study includes a table expressing data quality based on its sources and quantity. This data quality table can be used to assess scheme specific, expert judgement and wider supporting evidence that underpins the data quality reported, helping assess the rigour of each case studies (see Chapter 4).

It is worth noting that many of these innovations have only been applied to particular contexts to date, but can potentially be applied much more widely in the future. For example, Vertipools (Case study CS-C5, Appendix 4) are pocket rock pools designed to be applied to vertical sea defences to create water retentive habitat features. These can be manufactured in an almost endless number of shapes and sizes, incorporate a range of textures inside and out, and can be placed at a variety of sites at the coast, at different heights within the tidal frame.

As many IGGI options are innovative and often location specific, the merits of scheme specific designs compared to business-as-usual options may need to be assessed. The Critical Success Factors framework (Chapter 4) was created as a tool to help appraise possible IGGI measures and solutions (Naylor et al. 2017). It has been designed and tested using the case studies presented in Appendices 1- 4 and can be used to evaluate other IGGI measures against a business-as-usual grey solution.

Issues of scale are key to the anticipated returns of many of the IGGI elements included here, and while this may be heavily influenced or solely determined by the budget of an individual scheme, it is important to establish how well IGGI is able to meet the aims of the scheme or help a scheme meet regulatory requirements or aid policy implementation. The case studies in each Bundle and the policies that can support IGGI implementation in section 1.2 can aid practitioners in identifying the most suitable IGGI measures and solutions for their scheme.

3.3.5 MAKE AND IMPLEMENT DECISION

As in any scheme, a decision will be made based on cost benefits, levels of risk and ability to provide returns for specific goals or achieve results under any particular drivers. The Critical Success Factors framework (Chapter 4) and the topic bundles (Appendices 1-4) presented in this report are designed to help demonstrate the cost benefits and risks to allow more informed decision-making when considering IGGI options.

Where the IGGI measure is part of installing a grey-engineered project then it is important to determine to what extent including it alters the installations process, for example, is it seasonal? Is it dependent on additional expertise or suppliers? Can the process begin immediately or are there preliminary works to be carried out?

3.3.6 MONITOR AND EVALUATE

Where green elements are installed, such as a freestanding green screen (Figure 2.4), it is important to monitor how well they establish after construction to measure their success in meeting policy or scheme targets. This can also boost the evidence of how well IGGI measures work in a range of settings. Often the long-term efficacy of ecological enhancement schemes is poorly monitored, even where it is part of mitigation for a development. Exceptions are those schemes where the IGGI innovation becomes part of third party research work, such as through collaboration with Universities.

4. INTRODUCTION TO THE CRTICAL SUCCESS FACTORS

Once a decision has been made to undertake a project, and the type and general design features are agreed, there are a number of scheme specific factors (e.g. cost, engineering, policy, ecosystem services etc.) that can be considered. These are the **Critical Success Factors** (CSF) and although they may not all apply to every scheme, they provide a framework to compare alternatives and establish useful metrics, which is essential for setting goals and determining if a scheme can be judged a success. The Critical Success Factors comprise a range of drivers, motivators, constraints, opportunities, costs and benefits that can be compared to business-as-usual.

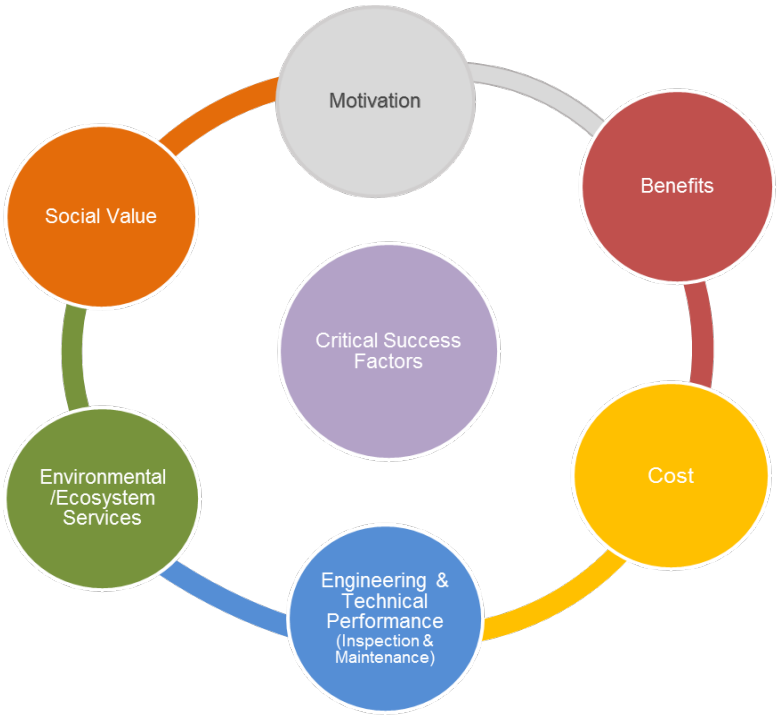


Figure 4.1. Critical Success Factors underpinning the decision support framework.

The CSF framework is designed to consider the range of policy, engineering, ecological and social parameters that have been, or could be, used to support, measure and/or improve the green credentials provided by greening hard infrastructure. The framework was developed through an iterative, co-production approach (Reyers et al. 2015) with the project partners (and HR Wallingford's work (Roca et al. 2017) on riverine green and green-grey infrastructure). The framework includes both engineering and ecosystem services elements identified through a series of meetings, teleconferences and workshops with project partners (Naylor et al. 2017). This aims to ensure the outputs are of direct value to engineers, environmental practitioners and a wide variety of users.

Aimed at building on the Benefits of Sustainable Drainage Tool (BeST) from CIRIA, the Construction Industry Research and Information Association (BeST, CIRIA, 2015), the CSF framework assesses the wider multifunctional benefits that IGGI can provide. The framework is designed to support existing ecosystem services documents and appraisal guidance documents, such as the Flood and Coastal Erosion Risk Management Appraisal Guidance (Environment Agency, 2010).

4.1 USING THE CRITICAL SUCCESS FACTORS

This section explains how the different IGGI measures presented in the bundles have been evaluated. In each case the same set of Critical Success Factors (CSF) are considered, as outlined in Table 4.1. Wherever possible, this has been done relative to a 'business-as-usual' (i.e. 'grey') baseline. This approach can help overcome barriers that may limit the uptake of these measures elsewhere. The information provided can help make a more reasoned assessment of the suitability of IGGI measures and provide mechanisms to support the approval process.

The CSF approach can help evaluate the benefits of adopting an IGGI measure compared to a grey engineering solution; this will be the case where the options appraisal has determined that alternative 'soft' solutions (e.g. Working with Natural Processes) are not suitable.

Table 4.1 Critical Success Factors - what are they?

Critical Success Factors	Description
Motivation	The strength of motivation (e.g. policy, biodiversity, reputation etc.) that led to an IGGI measure being adopted.
Benefits	The overall reason/positive outcome of including the IGGI measure.
Cost	Monetary costs associated with including an IGGI measure (relative to business-as-usual).
Engineering performance maintenance and inspection	Assessment of how/to what extent the IGGI measure influences asset function, maintenance and inspection. This includes an evaluation of whether the IGGI element has negative, neutral or positive effects on asset resilience.
Ecosystem Services (ES)	Evaluation of the environmental (primarily ecological) gains of a measure, and the evidence supporting this.
Social Value	Specific assessment of both tangible and intangible benefits to people and communities.
Case Study Criteria	Case studies were required to be data-rich against more than one critical success factor and operationally applied. Those carried out as part of research trials, or where only one CSF was measured in detail were included as art of the possible rather than case studies.
Data Quality	Assessment of the quality/robustness of economic, technical and environmental data available. This was a key determinant to distinguish between case studies and art of the possible.

The CSF framework was developed through an iterative process in close collaboration with the project partners. Potential case studies evaluated using each CSF were solicited from national

agencies and were filtered based on the evidence available; good data on costs (that could be compared to business-as-usual) and ecological impacts (that could be compared with suitable control sites) were the primary selection criteria for case studies. In cases where such data were not available or limited, and therefore the CSF framework could not be fully applied, 'Art of the Possible' (AP) examples were instead used to showcase innovation. Where site-specific data were lacking, supporting information was gathered using expert judgement or wider evidence consistent with the EA appraisal tools (Environment Agency, 2016).

Each CSF is outlined in the following sections, including an indication of how they can be evaluated for planned works, allowing readers of this report to apply the CSF framework to their own schemes:

4.1.1 BENEFIT

This is the overall benefit of the scheme. This will either be a summation of the assessments for each critical success factor (in Figure 4.1 and outlined below) or a key benefit that significantly increases the viability of an IGGI measure, e.g. to meet a policy requirement. A visual representation of the cumulative benefits is given for each case study in the bundles at the end of this report using a 'benefits wheel'. This is designed to show the relative benefits/strengths of each CSF succinctly in a single diagram. This can help quickly identify what the key drivers and benefits were for each case study.

4.1.2 COSTS

Economic cost comparisons are crucial in making a strong business case. All costs should be calculated using the best available data (advice on this is available from the Green Book (HM Treasury 2003, 2011 update). Where specific costs are not available, assumptions may be made based on similar scheme/measure costs. In the bundles at the end of this report, a range of measures are presented which have been implemented across the last 5 years. Costs have therefore not been standardised across years. However, to maximise comparability, costs in the case studies were calculated as 'per meter' where applicable and where applicable, made use of standardised costs for specific infrastructure types such as coastal and estuarine flood alleviation (EA, 2010).

Adopting an IGGI measure may simply involve an additional cost on top of the business-as-usual price (e.g. 'an additional £100 per metre of defence'). In other cases, including an IGGI measure in a scheme may require changes to the design of a particular element, materials and equipment used in construction, and/or the maintenance regime of an asset. These additional costs should be included in assessments using existing examples and published documents wherever possible. Guidance may be sought from relevant experts and/or standard industry reference materials such as the Environment Agency (EA) flood risk management estimating guide/cost unit database (Environment Agency, 2010).

For each measure being evaluated, cost elements can be assessed as:

1. **Net cost –** where data permitted this was the per unit (e.g. cost per linear metre) cost of the IGGI measure. Often these data were not available or difficult to disentangle from the total project costs, in these instances the cost of the entire project is reported for as much as the design life that data were available.

2. **Direct (construction) cost –** the estimated or known capital expenditure (capex) cost of construction including the proposed IGGI measure in a scheme and/or adopting it instead of a grey measure. This can be estimated at the business case stage using case studies, standard industry information (possibly from contractors, suppliers and installers). This may consider things like additional 3rd party funding availability, insurances and research, requirements for environmental assessments, etc. Where possible the IGGI component of the construction costs were separated from the overall construction costs.
3. **Cost compared to business-as-usual –** the cost of undertaking the innovation/IGGI measure relative to that of standard practice/ grey solutions. This can be based on existing data on project costs (e.g. EA/DEFRA cost estimates for fluvial and coastal protection works (EA 2015a; 2015b)), estimates and actual figures based on completed projects, cumulative costs of individual elements, and expert judgement. Comparison with business-as-usual is needed in order to determine a cost–benefit value for the IGGI measure. It is especially useful for making a business case where additional benefits assessed elsewhere in the CSF framework are considered greater than any additional costs. This cost can be effective for identifying 'quick wins' where an IGGI measure represents a savings on the business-as-usual *and* provides wider benefits.
4. **Long-term cost –** an estimate of overall financial impact across design-life of the project (often referred to as Totex – a term used to represent the total or whole life costs of infrastructure) and/or the anticipated future maintenance costs where whole life (or Totex) costs were not available. This includes any self-sustaining elements and what any required long-term maintenance of the measure might cost in various scenarios including consideration of climate change. These impacts on costs can be negative (e.g. an IGGI element having a shorter design life and therefore requiring repair/replacement sooner compared to business-as-usual) or positive (e.g. increased asset resilience to on-going decay afforded by the greened element).

4.1.3 ENGINEERING PERFORMANCE, INSPECTION AND MAINTENANCE

Limited information about how the engineering performance (the primary requirement for any scheme) and maintenance needs of an asset might be changed by incorporating greening measures is a major barrier for wider uptake. Addressing these uncertainties is crucial for assuring engineers, funders and other stakeholders that the project can be successful. Much of this assessment will involve expert judgement and/or information from similar schemes. Using case studies (such as those included in the bundles in Appendices 1-4 of this report) can be extremely helpful in overcoming some of these uncertainties. Key aspects to consider are:

Performance

Incorporating GI into grey infrastructure can improve or limit engineering performance, asset resilience and design life across short, medium and long timescales. It is important that this is understood and well communicated from the outset to manage expectations, maintain buy-in and to ensure that risks or unknowns are clear and understood during the options appraisal phase of a project. IGGI measures will influence grey infrastructure to varying degrees, from having a negative impact on long-term performance (they may not last as long as grey solutions) to having a neutral influence (no effect on performance) to a positive impact (by increasing asset resilience). Where the IGGI measure can have a significant influence on engineering performance this should be reflected in planning how

and where it should be implemented, e.g. seeking additional expert judgement, determining more detailed site-specific prediction and modelling, or reducing risk by applying the measure in low risk environments, or incrementally.

Inspection

Extensive vegetation cover and/or presence of protected species can make visual inspection of grey assets more challenging (e.g. plants covering walls). In some cases this may easily be mitigated against, but it is worth considering any necessary changes to inspection regimes. In some instances the IGGI measure may aid inspection. For example, where vegetated terraces accrete material and develop salt marsh habitat at the toe of block wall sea defences, then signs of marsh erosion may be indicative of deterioration of the wall.

Maintenance

Projects that include working with natural processes tend to benefit from the self-regenerative capacity of plants, but this can still involve maintenance work such as maintaining ecosystems and/or removing undesirable species. These positive and negative elements need to be factored in to any business plan.

Asset Resilience

The effects of the IGGI measure on the resilience of the assets they are built within, inhabit or grow in front of was assessed using data (where available such as in the Historic and Coastal bundles) or via expert judgement. This was used to evaluate whether the effect of the IGGI measure was negative, neutral or positive on the resilience of the asset to deteriorative agents. No IGGI measures were found to negatively influence asset resilience, many were neutral and some had positive effects on asset resilience.

4.1.4 ECOSYSTEM SERVICES

Most IGGI measures are environmental enhancements; they can provide habitat where there was little or none and can support individual species or wider biodiversity. They are not designed to restore or recreate natural habitats completely but instead to improve the ecological function of grey infrastructure.

To evaluate these ecological services, it is useful to consider whether ecological goals form part of the motivation for adopting a particular IGGI measure. To evaluate success, comparisons can be made against these original aims, business-as-usual options and/or experimental 'control' sites within the same scheme, nearby or at other locations with comparable environmental conditions. In the case studies included in the bundles, the most useful data were derived from ecological monitoring after asset construction – ideally in comparison to a baseline collected before construction began. Simple ecological metrics (e.g. number of species, number of target individuals etc.) can provide useful evidence on environmental performance. In the majority of cases these data were used to provide qualitative assessments of the ecosystem services value provided by the habitat created. Limited data on provisioning services or on the tangible benefits of increased regulating services such as air pollutant trapping meant that quantitative metrics were limited. More robust data across multiple ecosystem services is required to fully evaluate and quantify the

ecosystem service benefits in future. This would allow a more realistic comparison of the financial benefits of IGGI measures compared to business as usual grey engineering.

4.1.5 SOCIAL VALUE

As well as ecological services, IGGI measures can have benefits for people that should be included in a business case. Some of these benefits can be long-term and relatively low cost, particularly when assessed against chronic and intractable socio-economic and health issues. This is increasingly reflected in wider policy and guidance (see Section 1.2). Clearly defined aims, metrics and monitoring regimes should be established at an early stage, as helping to deliver benefits for local communities can provide valuable impetus for choosing an IGGI option. This can include meeting regulatory requirements, e.g. planning. As well as any site-specific information, tools may be available to help evaluate social value, including Building Information Management system files, greenspace maps, social and health data and similar databases.

In addition to improving the wellbeing of 'users', the externalities from including GI in developments can include increased commerciality, improved aesthetics, raising the desirability of an area (e.g. higher rental returns and property prices), reduced employers staff sickness costs and improved staff retention rates. Greening can also offer corporate social responsibility opportunities and chances for businesses to improve public relations.

Social data are often difficult to obtain. In the case studies in the bundles, expert judgement has been used, often involving qualitative inferences from other geographically or economically similar schemes.

4.2 DATA QUALITY

An important issue when building a business case is the existing evidence base, as this can provide important leverage in getting new greening measures approved. To help with this, 'data quality' has been assessed and shown in a simple table at the end of each case study. In each instance, the type of data (economic, engineering and environmental) is evaluated using a combination of expert judgement, availability of scheme-specific information and wider supporting evidence.

For example, the highest quality data would represent a measure that has been tested/implemented in multiple locations, where pre- and post-installation monitoring data are available, where multiple supporting sources are available from other similar projects, and where several experts agree on its relative benefits/impacts.

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7. BUNDLES

The design and contents of each bundle were developed iteratively in close coordination with project partners, advisors and/or contributors. Specific design features were agreed to ensure that the contents of the bundle were useful for readers from a diverse range of backgrounds (e.g. engineers, project managers, ecologists and policy makers). Icons and a colour scheme were developed to ensure quick, clear and simple access to the contents of the bundles. The materials, along with this report, were reviewed and for the coastal bundles, an independent engineering expert judgement review was also undertaken to assess the risks of IGGI to engineering performance. The limitations, risks and opportunities associated with each topic are presented in the business case in each bundle.

7.1 CASE STUDIES

Several case studies are included for each of the coastal, historic, urban and mowing bundles. These case studies are examples of IGGI measures for which the best data were available. In each case, the assessment of key Critical Success Factors are summarised in a diagram (at the start of the case study), as explained in Table 6.1. Case studies provide an overview of the measure (e.g. what it involves, how it works and the motivation for its use) and outlines its assessment against each of the Critical Success Factors (benefits, cost, engineering performance inspection and maintenance, ecosystem services and social value).

Table 6.1 'Sliders' showing overall values of key parameters

Parameter	Score		
	Negative	Neutral	Positive
Benefit	Increase in cost relative to other benefits/Critical Success Factors	No change	Overall improvement against Critical Success Factors
Ecosystem services (ES)	Overall reduction in habitat quality / ecosystem service provision	No change	Increased ecosystem service provision/ Measureable improvement in environment
Engineering, performance, inspection, maintenance and asset resilience	Increased need, cost and/or complexity or reduced design life	Neutral / No impact	Improved asset resilience or reduced need, cost or complexity of maintenance
Cost (capital or whole life where possible)	Overall increase in cost	No change	Benefits outweigh any increase in cost

In addition to the CSF, the possible application of each measure in other locations/on other grey assets is broadly evaluated. This is done by considering which organisations/asset owners and asset types the case study might also be applicable. Similarly, opportunities for 'scaling up the benefits' of the case studies are evaluated, often involving simple but informative extrapolation of costs and ecosystem services.

The quality of the supporting data is assessed in a simple table at the end of each case study (see Chapter 4). Sources and contacts for further specific information about each case study are also provided.

7.2 ART OF THE POSSIBLE

These provide shorter examples of innovative research ideas that have not yet been tested operationally, are at the early stages of development and/or are lacking control sites to compare against. In many cases, they have a very high quality of data (e.g. biodiversity value), but only this Critical Success Factor was measured rather than having data for a range of metrics. As such, these examples require more supporting data for further evaluation to be able to compare with business-as-usual ('grey') options. Although these examples are less data rich than the full case studies, they demonstrate a range of ideas for enhancing hard infrastructure. They often represent a 'proof of concept', showing that a broader range of habitat enhancements and associated benefits are possible than those covered by the case studies.

APPENDICES - BUNDLES

All of the outputs for each environment topic covered in this report have been bundled by topic (Historic, Urban, Mowing, Coastal). These are contained in Appendices 1-4 and are available to download as an entire project report (this report + all four appendices) or as individual units (Appendices 1-4). Together the content of the bundles can be used to extend the range of urban greening beyond that which is covered as part of most GI policies (Figure 7.1A-B).

APPENDIX 1 - HISTORIC

APPENDIX 2 - URBAN

APPENDIX 3 - MOWING

APPENDIX 4 - COASTAL

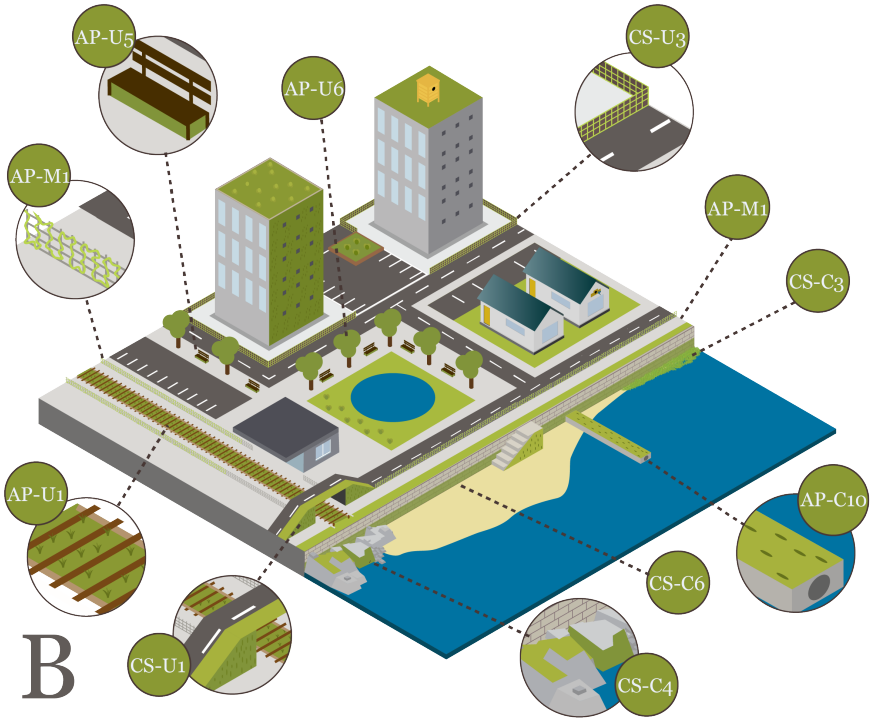

Figure 7.1 A-B. A: Urban greening that is part of GI policy. B: Illustrating the benefits of adding IGGI to the range of urban GI measures used where each label refers to a specific example found within the topic bundles in Appendices 1-4.