PROMOTING SINO-UK COLLABORATION ON DEVELOPING LOW CARBON AND SUSTAINABLE METHODOLOGIES FOR BROWNFIELDS AND MARGINAL LAND RE-USE IN CHINA

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The purpose of this report is to provide information on how adaption of existing innovative methodologies can be used for integrating sustainable remediation with urban planning and public realm design.

EXECUTIVE SUMMARY

Rapid urbanisation and changes in land use resulting from industrial change has left a legacy of vast polluted industrial and commercial areas (also called brownfields) and marginal land areas. Recent evidence from the UK, EU and USA indicate that these land areas may have considerable potential for renewables production, for example from solar, wind or biomass. In parallel there are opportunities for carbon storage in rehabilitated soil, as well as substitution by the production of renewables. The UK is also leading the understanding in the wider parallel benefits that can be achieved from ecosystem services and public health benefits from improved provision of green space. These multiple services can be provided together, in synergy, from soft re-uses of post-industrial sites, and in this way the post-industrial regeneration areas in China should be seen as a major opportunity for new enterprise, society and the wider environment. The improving bankability of renewable energy projects, and the possibility of creating a voluntary carbon offset business, means that revenue streams may be sufficient to pay for ongoing land management over time as a profit generating activity. In terms of fastest benefit to UK PLC and China, the likelihood is that combination of renewable energies with “dual use” for habitat will provide both more readily commercial brownfield re-use opportunities for cities in China in the short term, and also create better carbon management opportunities, as well as a variety of wider sustainability benefits. Thus this type of re-uses will create a platform for rapid commercial exchange and development between Chinese and UK companies. Considering that China is preparing an action plan for managing soil pollution and remediation across the country estimated to be RMB 7tn which is equivalent to one-third of the national exchange reserves, this report on developing low carbon and sustainable methodologies for brownfields and marginal land re-use in China provides timely information that will support the decision making for sustainable remediation opportunities in China.

The report is intended to serve as a tool and resource guide to stakeholders involved in land remediation willing to engage in sustainable remediation implementation for renewable energy and carbon management applications. It is intended to inform remediation stakeholders unfamiliar with sustainable remediation about the concept, practices, and available resources. The report capitalises on UK leadership positions on the sustainable rehabilitation of brownfields land (SURF-UK), the soft re-use of brownfields (e.g. for energy or amenity rather than buildings); effective end-use directed risk management for contaminated land, and sustainable remediation.

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1 Overview

1.1 BROWNFIELDS REGENERATION CONTEXT IN CHINA

In 2015, the estimated market size in China for environmental technology and services was 40 billion RMB, with an estimated market growth from 2015 -2020 to be 665.9 billion RMB. With a global market worth $5.4trillion, China is well on its way to becoming the biggest country market, with $473billion committed to environmental protection over the next four years.

The reuse and regeneration of industrialized sites has become a national priority in China, with a '10 point Action Plan' for soils management now enshrined in its current 5 year plan. With this in place China's environmental legislation is actively developing in this sector and planned legislation will shortly introduce a risk-based regulation system for contaminated land similar to the UK system.

The Chinese authorities have also committed 30 billion RMB within the twelfth Five-Year Plan to address soil pollution, along with a specific plan of action for the prevention and control of soil pollution coming into force during the period of the 13th Five-Year Plan (2016-20). This along with the development of the nation's first specific national law on the control and prevention of soil pollution being drafted by China's Ministry of Environmental Protection demonstrates the commitment for long term soil management and regeneration of industrialized sites.

China has set very ambitious targets for a high percentage of contaminated sites to be used by 2020, the establishment of soil quality standards systems by 2017; the promotion of onsite remediation; as well as opening up of the monitoring services market. This project is at the perfect time to show case and share real case studies that all can learn from rapid urbanisation and changes in land use resulting from industrial change has left a legacy of vast polluted industrial and commercials areas (also called brownfields) and marginal land areas. Recent evidences from the UK, EU and USA indicate that these land areas may have considerable potential for renewables production, for example from solar, wind or biomass. In parallel there are opportunities for carbon storage in rehabilitated soil, as well as substitution by the production of renewables. The UK is also leading understanding in the wider parallel benefits that can be achieved from ecosystem services and public health benefits from improved provision of green space. These multiple services can be provided together, in synergy, from soft re-uses of post-industrial sites, and in this way the post-industrial regeneration areas in China should be seen as a major opportunity for new enterprise, society and the wider environment. The improving bankability of renewable energy projects, and the possibility of creating a voluntary carbon offset business, means that revenue streams may be sufficient to pay for ongoing land management over time as a profit generating activity. In terms of fastest benefit to UK PLC and China, the likelihood is that combination of renewable energies with "dual use" for habitat will provide both more readily commercial brownfield re-use opportunities for cities in China in the short term, and also create better carbon management opportunities, as well as a variety of wider sustainability benefits. Thus this type of re-uses will create a platform for rapid commercial exchange and development between Chinese and UK companies. Now that China is preparing an action plan for managing soil pollution and remediation across the country estimated to be RMB 7tn which is equivalent to one-third of the national exchange reserves, information that will support the decision making for sustainable remediation opportunities in China is very important and timely.

1.2 PROJECT OVERVIEW

The UK Prosperity Fund project "Promoting Sino-UK collaboration on developing low carbon and sustainable methodologies for Brownfields and marginal land re-use in China" capitalises on the UK leadership position that it demonstrates on the sustainable rehabilitation of brownfields land (SURF-UK www.claire.co.uk/surfuk), the soft re-use of brownfields (e.g. for energy or amenity rather than buildings www.thelandtrust.org.uk); effective end-use directed risk management for contaminated land, and sustainable remediation.

This project provides an evaluation and adaption of existing innovative methodologies for integrating sustainable remediation with urban planning and public realm design that supports the development of low input strategies for land management, sustainable remediation and community enterprise for brownfields and marginal land areas, focusing on renewable energy and carbon sequestration potential in China. The outputs are split into defined chapters as detailed below and have been developed to support national policy advisors and also local project designers and decision-makers in identifying options for developing the greatest overall value from "soft" (i.e. non built) re-use of brownfield land; using renewable energy applications and wider project services such as carbon management, biomass, biochar application and bioenergy recovery, wider renewable energy.

OVERVIEW

The project provides details on:

- **The state of sustainable remediation today**: identify the major actors as well as current tools, best management practices, frameworks, guidance documents, and other resources available to various stakeholders working to implement and disseminate information about sustainable remediation
- **A decision support tool (DST) using a step-wise approach** that identifies what parameters/environmental criteria need to be considered for implementing sustainable remediation strategies focusing on renewables energy and carbon management: the Brownfield Opportunity Matrix (BOM). Chinese and English version of the tool made freely available on the China UK partnership for contaminated land management website (http://cnukcontaminatedland.com/uk/)
- **Guidance and strategies for renewable energy applications and wider project services** such as carbon management, biomass, biochar application and bioenergy recovery, wider renewable energy opportunities on brownfields (e.g. Photovoltaics (PV), wind etc.) transferring state of the art knowledge from the UK, the rest of the EU and North America to China and identify how these can be adapted to local settings.
- **The benefits of and concerns about sustainable remediation through detailed case study scenarios** for implementing an integrated sustainable remediation approach.
- **A policy brief for relevant Ministries to assist in the development and adoption in the 13th five year of urban Brownfield regeneration planning**. It will also inform and guide China's policy on the future of sustainable remediation in practice, examining challenges to implementation, strategies for incentivizing its use, and how these approaches will fit within the existing regulatory framework.

The project outputs were tested with stakeholders at a focus group workshop meeting comprising of selected stakeholders from practitioners to government officials. The workshop was organised along with the 1st Brownfield Contamination & Environmental Remediation Conference, Clean-up China 2016 (http://cleanup.er-china.com/) to maximise opportunities for partnership approaches for UK companies that want to operate in the Chinese market.

1.3 GUIDANCE ON HOW TO USE THE REPORT

The purpose of this report is to provide information on how adaption of existing innovative methodologies can be used for integrating sustainable remediation with urban planning and public realm design. These will support the development of low input strategies for land management, sustainable remediation and community enterprise for brownfields and marginal land areas with a focus on renewable energy and carbon sequestration potential in China. This report can be read in its entirety; alternatively it has been developed so each chapter can also be read independently. The report has been organised as follows:

Chapter 3. The Brownfield Opportunity Matrix (BOM): This chapter contains information on the origin of the BOM and its adaptation for the Chinese context. It also provides details how and when to use the BOM and provides practical case studies for reference at the end of the chapter.

Chapter 4. Detailed Technical Guidance Sections: The reader is provided details on low carbon remediation options such as phytoremediation and amendment additions, and how these remediation options have become available and developed in different countries. Details are also provided on the benefits of the production of renewable feedstocks and renewable energy generation.

Chapter 5. Sustainability appraisal and valuation: This chapter details qualitative tools that have recently been developed internationally over the last few years, showing the value and benefits that they can bring to life real case studies to help demonstrate transparency to decision making when sustainability is being considered.

In addition, r3 UK was also a partner in the Colombian Prosperity Strategic Programme Fund (SPF) project on "**Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies**". The output 2 of the Colombian project has strong synergies with the Chapters 3 and 4 of this report, as both projects have similar focus on low input remediation, low carbon and brownfields regeneration. The technical sources and content therefore have a very similar coverage to the Colombian Project final report. As far as possible the broad structure and text are as consistent as possible to ensure that conflicting guidance in the public domain is avoided. Both reports however have been developed independently in consultation with local stakeholders, and adapted to and focused on national requirements. The strong synergies between these projects have nevertheless allowed a robust transnational approach to be developed, providing added value to this China-focused assessment, and creating opportunity for more concerted and collaborative developments in the future."

2 Sustainable remediation: state of the art

Land recycling has been an integral concept of regeneration to prevent the use of Greenfield land since the 1970s; however it was not until the 1990s that how the land and groundwater has been remediated "cleaned up" was more closely considered as many activities are identified as inherently unsustainable. Poorly designed or implemented remediation methods can have a greater impact than the contamination that they seek to address (CL:AIRE 2010).

Internationally, there has been a huge amount of activity over the past ten years deciding what constitutes sustainability in remediation. There is now a consensus in this, with the development of frameworks, definitions and how to implement and measure a remediation project. This has all been brought together in the recent publication of an ISO standard in Sustainable Remediation published in 2016 (ISO, 2016).

The purpose of the ISO standard is to promote the use of more sustainable practices during environmental clean-up activities, with the objective of balancing economic, social and environmental impacts, whilst enhancing the overall quality of life for surrounding communities. In broad terms, concepts of sustainable remediation are based on achieving a net benefit overall across a range of environmental, economic, and social issues that are judged to be representative of sustainability. This is key to land regeneration, given the extensive global contaminated land legacy that exists and the large resources that are required to bring this land back into beneficial use for all.

Sustainable remediation covers a wider range of sustainability impacts and benefits in remediation of contaminated sites, and, for several of the groups involved in this area, extends to ideas of sustainable regeneration (e.g. the UK), sustainable land use, and sustainable soil management (e.g. the Netherlands). A related concept is "green remediation", being advanced by the US Environmental Protection Agency (US EPA) and which focuses on minimizing or mitigating the environmental impacts of remediation activities in mature site clean-up programmes and regulatory frameworks, such as Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), where social and economic factors are considered already. Sustainable remediation practice also has important contributions to make to emerging cross-disciplinary sustainable development practices in land-use planning (for example in the context of 'brownfields development'), urban design and management ('urban renewal') and transport ('transit oriented development').

SUSTAINABLE REMEDIATION: STATE OF THE ART

Sustainable remediation is an area of intense development across the world. Networks involved in sustainable remediation have developed include: various national bodies of the Sustainable Remediation Forum (UK, USA, Netherlands, Italy, Canada, China, Brazil, Colombia, Japan, Taiwan and Australia and New Zealand); the NICOLE Sustainable Remediation Working Group; RELASC (South America); Common Forum (European network of Regulators) on contaminated land; and the International Committee on Contaminated Land (ICCL). In addition, standards development work is underway at ASTM in the USA, aimed at providing standardised protocols and guidance for sustainable remediation practice. The consensus across these networks is described in depth in Rizzo et al. (2016).

A large amount of the development work in sustainable remediation has also taken place in the grey literature and in technical publications with specific sector focus. This has culminated in the publication of a Special Issue on Sustainable Remediation in 2016 in Journal of Environmental Management, 2016. This special issue has brought together, within the academic literature, current thinking and developments in sustainable remediation, incorporating comparisons of different networks how existing tools and framework have been tested, how they can be developed further and identifying new areas of research.

With the concept of sustainable remediation maturing and embedding into practice, new areas of research are focusing on the more challenging areas such as ensuring the social aspects are transparently being considered and full engagement of communities is occurring. New decision support tools (DSTs) are now paying greater attention to social aspects compared to earlier DSTs that focused on environmental impacts as typically these were easier to measure (Cappuyns, 2016). Practitioners are more aware of the importance of early stakeholder engagement, ensuring that tools are not complex, are transparent and that tools are adapted for the local country legislation.

The testing of existing frameworks and the publication of case studies is helping to embed sustainable remediation into everyday practice.

3 Brownfield Opportunity Matrix

This Brownfield Opportunity Matrix (BOM) is a simple Excel screening tool intended to assist national policy advisors and also local project designers and local decision-makers in identifying options for developing the greatest overall value from the "soft" (i.e. non built) re-use of brownfield / contaminated land (**Figure 1**). The BOM screening tool helps developers and decision-makers involved in brownfields to identify what services they can get from soft reuse interventions for their site, how these interact and what the initial default design considerations might be. It follows on from a major European Commission research project funded under their Framework 7 programme: Holistic Management of Brownfield Restoration (EU FP7 HOMBRE project - www.zerobrownfields.eu).

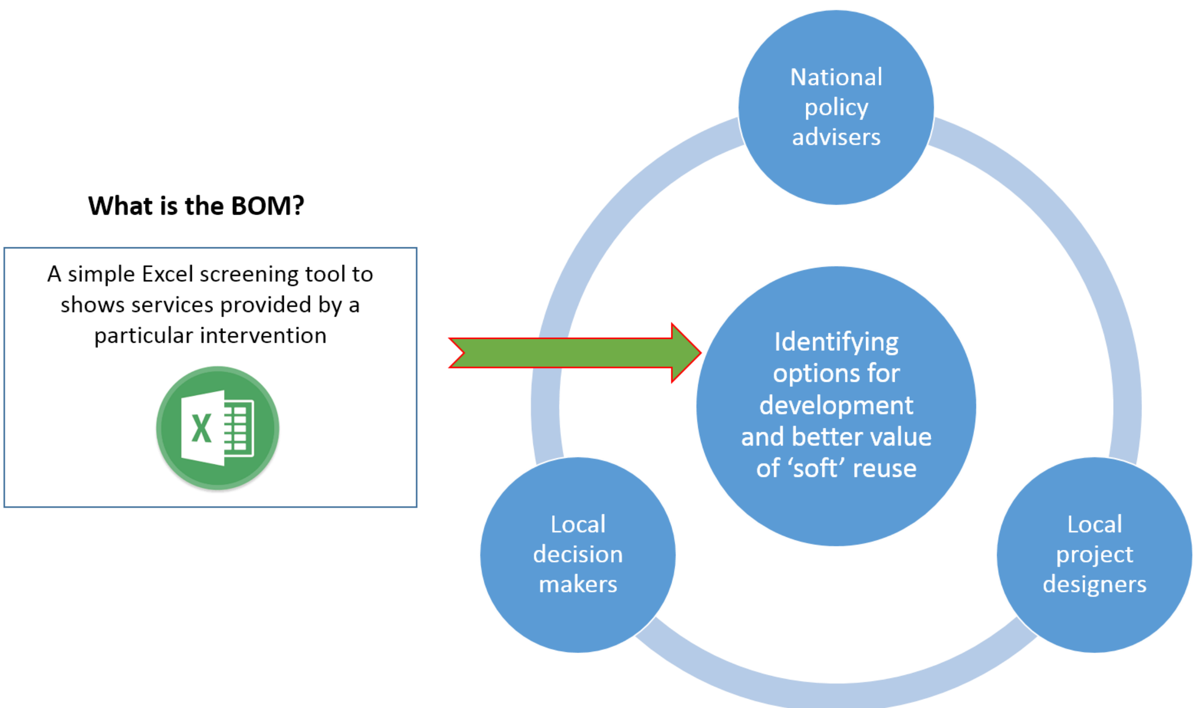

Figure 1 Application of the BOM (© r3 Environmental Technology, 2016)

Brownfield regeneration has tended to be considered primarily in the context of hard reuse such as housing or infrastructure developments, while, soft reuse such as for green space or biomass production has, until recently, tended to be overlooked (Bardos et al., 2015). However, there is a broad agreement among professionals that soft reuse of brownfields should be encouraged to enhance land regeneration and improve overall sustainability (Bardos et al., 2011 and 2016a; Cundy et al., 2016; Moffat, 2015). For example, use of brownfields for renewable energy generation has gained significant attention in recent years, as siting renewable energy projects on brownfields can have a number of wider environmental and economic benefits (Jensen, 2010; Hartmann et al., 2014; Adelaja et al., 2010; NALGEP, 2012). Urban green space is another soft reuse approach delivering significant benefits such as enhancing the environment, improving human health and stimulating the local economy (Cundy et al., 2013; the Land Trust, 2015a and 2015b).

Some services may generate revenue in their own right, some may be important assets to support societal development, and some may have direct or indirect benefits on the value of local land or local economy (e.g. providing local energy supply or other environmental services). Restoration projects that deliver a broad range of services have both improved overall sustainability and enhanced economic value.

A project service is an explicitly recognised and designed in outcome of a restoration project. To achieve the delivery of the service some form of intervention is needed, for example, remediation or soil improvement. The BOM is a simple tool to show how services can be connected with interventions and vice versa. In addition, it is a checklist to determine the range of possible services that could be provided, and the minimum (or optimum) number of interventions necessary to do this.

Examples of benefits of soft reuse

- Provision of open space such as parkland, for local communities, which brings benefits for well-being, health, leisure and a sense of place;
- Providing green infrastructure and services such as those related to water protection, improvement of air quality, providing shade and encouraging habitat and wildlife;
- Supporting the renaissance of and innovations in urban gardening, community gardens and urban farming;
- Supply of renewable energy and other environmental services (such as sustainable urban drainage).

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3.1 BOM DESCRIPTION AND ORIGIN

The BOM, first developed within the EU FP7 HOMBRE project, is a simple Excel based screening tool that essentially maps the services that might add value to a redevelopment project against the interventions that can deliver those services. **Box 1** provides a listing of the broad range of possible services from restoration of brownfield land for soft re-use.

Box 1: Potential Services from Soft Re-uses of Brownfield Land	

• Site value uplift / value uplift of surroundings /
• Renewable energy generation
  – Biomass based
  – Geothermal
  – Wind & Solar
• Renewable material generation
• Greenhouse gas mitigation (carbon offset revenue?)
• Synergies with waste processing and re-use, leachate management
• Shielding / sound-scaping
• Flood management – link with "Sustainable Urban Drainage Systems"
	• Amenity and leisure
	• Urban climate management (such as mitigation of urban heat island effect)
	• Air quality management
	• Habitat and conservation
	• Improved soil and water resources
	• Improved health and well-being
	• Opportunities for education
	• Community involvement
	• Ecological system services

- The original BOM is available for download and use from HOMBRE's "Brownfield Navigator" page at http://bfn.deltares.nl/bfn/site/index.php/standard/bfn_home. The Brownfield Navigator is an online environment which accompanies and supports decision makers through the different management phases in the land cycle which also includes tools for describing and note taking on a geo-spatial basis the various interventions and their opportunities.

- The Chinese version of the BOM tool is available from the China UK partnership for contaminated land management (CNUK) website at http://cnukcontaminatedland.com/

The BOM sets out which services are delivered by particular interventions, using a simple colour coding for each intersection of a possible intervention with a possible service, as follows:

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- **Deep green: The intervention generally directly delivers this service**
- **Light green: There is potentially a direct or associated service benefit depending on site specific circumstances**
- **Blue: While there is potentially a direct service benefit, there is the possibility that this intervention could be antagonistic to the service, depending on site specific circumstances, therefore an appropriate site specific management and design needs careful consideration**
- **Amber: The intervention is generally antagonistic to the service in question so some form of mitigation would be needed**

As illustrated in **Figure 2**, viewing across a row, from a particular intervention, it is possible to see how this intervention can deliver (or may impede) services across a broad range of categories. Looking at rows together allows a range of services to be maximised across two or more interventions. In both cases the decision is simply based on the range of colours: maximising the green intersections. Where there are blue or amber intersections then a more detailed consideration of the nature of the site and the nature of the intervention is needed. A very detailed "informational" version of the BOM provides supporting information and links to further citations and examples to facilitate this is available at http://www.zerobrownfields.eu/Displaynews.aspx?ID=568. However, as part of the FCO supported project, the goal has been to develop the simple version to use as a starting point for design discussions in China. Although a detailed informational version in Chinese would be a large undertaking, it may be justified in a follow on project depending on the interest in the simple BOM tool (i.e. a proof of concept).

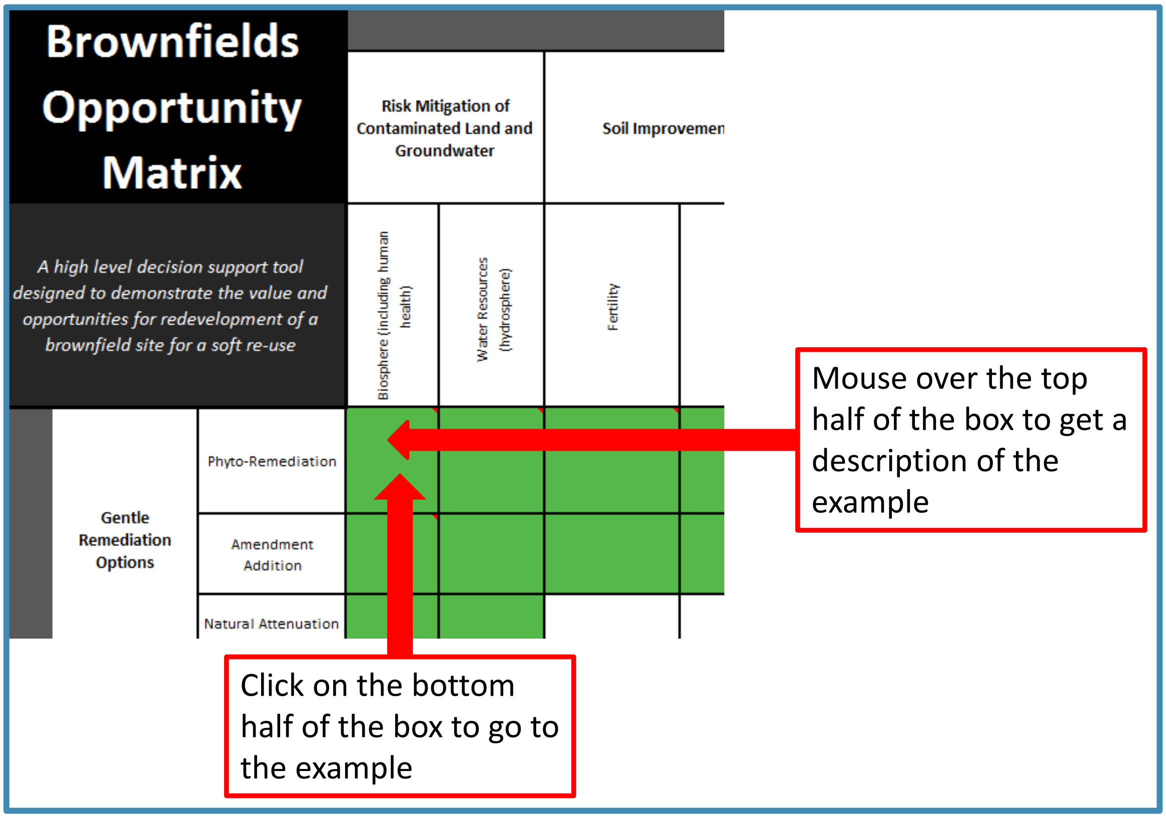

Figure 2: **View of the simplified Brownfield Opportunity Matrix**

The BOM is organised using a hierarchy of categories of services and interventions, as listed in **Table 1**. The simple BOM provides some additional guidance in each green or blue coloured intersection cells between intervention and service. This comprises a case study to illustrate the interaction between intervention and service and a web-link to further information about the case study. In this way users can directly migrate to examples of particular interventions and services that interest them. In the Chinese adapted version additional case study information has been provided to give links to more local examples, even if these are still only at a "pilot" stage (see **Section 3.4**).

Table 1: The overarching services and interventions considered within the Brownfield opportunity matrix

Services	Interventions
1. Soil Improvement 2. Water Resource Improvement 3. Provision of Green Infrastructure 4. Risk Mitigation of Contaminated Soil and Groundwater 5. Mitigation of Human Induced Climate Change (global warming) 6. Socio-Economic Benefits	1. Soil Management 2. Water Management 3. Implementing Green Infrastructure 4. Gentle Remediation Options 5. Other Remediation Options 6. Renewables (energy, materials, biomass) 7. Sustainable Land Planning and Development

3.2 ADAPTATION TO CHINESE CONTEXT

The BOM for China is available in both in English and Chinese (along with translated instructions) with some specific local information added to supplement the original content at http://cnukcontaminatedland.com/cn/downloads/. Adaptation work has been taking place in parallel with an FCO project taking place in Colombia on "Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies". For both projects, a "stakeholder engagement package" has been developed to support the use of the BOM including a meeting design as an outline agenda, briefing presentation for the meeting and supporting materials such as checklists, which are described in more detail in **Section 3.3**. Given that the matrix and the stakeholder engagement package were written from a Euro-centric expertise base, a number of concepts and terms needed to be explained, and indeed needed to be changed to be more meaningful in a Chinese context (Sam et al., 2016). This was facilitated via Xiaonuo Li from the State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing which carried out a placement at the University of Brighton over 2015/16 under the supervision of Prof Paul Bardos. The assistance and support of all parties are gratefully acknowledged.

3.3 HOW AND WHEN TO USE THE BOM

A successful project depends on a shared vision of what the desired services are from the restoration and re-use of the land, and the most effective ways of achieving these services, i.e.

the interventions needed. In stakeholder engagement, it is important that stakeholders understand the connection between interventions and services. For stakeholders, services can be understood as ambitions (political) and desires (local). The BOM shows how these soft reuse interventions are connected to services. The matrix is intended for discussion purposes in stakeholder engagement processes and helps in visualising the value projects may have for stakeholders, synergies between services or interventions and overall gives insight in the opportunities for restoration of the brownfield (Beumer et al., 2014). **Box 2** lists a number of key principles for effective stakeholder engagement when deploying "gentle" remediation technologies.

Box 2: Basic Principles for Stakeholder Engagement (Cundy et al., 2013, SURF US)
• Identify and engage core and noncore stakeholders early in the process • Adopt a proactive not reactive approach to engagement • Engage stakeholders at all stages of the GRO process • Plan for long-term stakeholder engagement • Develop effective communication structures that allow a reciprocal, two-way dialogue • Ensure engagement is transparent and recorded • Recognise that criteria for assessing GRO may need to be subjective and objective • Set out all assumptions and procedures for implementing and monitoring GRO at the start of a project • Follow a logical, stepwise approach to engagement to avoid circular arguments and clearly address subjective issues

Effective stakeholder involvement has been identified as a key requirement for the application of sustainable remediation strategies, and in site regeneration more widely. Stakeholder engagement when remediating land for soft end-use, particularly in urban and sub-urban settings, is perhaps more wide ranging and more complex than in many other remediation fields, for several reasons (Cundy et al., 2013):

1. The number of interested parties may be wider for soft end-uses because their multiple services and scale mean that there is a greater range of beneficiaries and organisations or individuals affected.

2. The range of issues may be more complex because of the range of "services" anticipated and the use of slower low input (or gentle) remediation techniques which may be deployed to achieve restoration (see **Chapter 3**).
3. The risk management proposition is may be more complex.
4. Deployment may also be affected by a number of technical and natural uncertainties related to the services provided as well as the restoration measures deployed.

Figures 3 and 4 provide two different examples of scenarios for a progression of discussions in a restoration project development. These are closely related. For example in both cases there is an initial conceptual stage where someone or some group have initial ideas, these are then developed by a small group of individuals, to a stage where they are presented to a wider group of stakeholders to deliver a more broadly agreed vision. This vision then needs further technical elaboration to provide an implementation plan. All of these stages may undergo several iterations.

The straightforward visualisations provided by the BOM are intended to facilitate these discussions by

- Support initial identification or benchmarking of soft reuse options for brownfields at early stage
- Support exploratory discussions with interested stakeholders
- Provide a structure to describe an initial design concept, in support for example of planning applications
- Provide a structure for more detailed sustainability assessment of different reuse combinations, and similarly for cost benefit comparisons

The matrix can be used in stakeholder engagement processes at different moments and activities: during initial phase of collecting ideas, during more profound phase of redefining ideas on desired services and interventions, and during the review of the initial design of the brownfield to be regenerated.

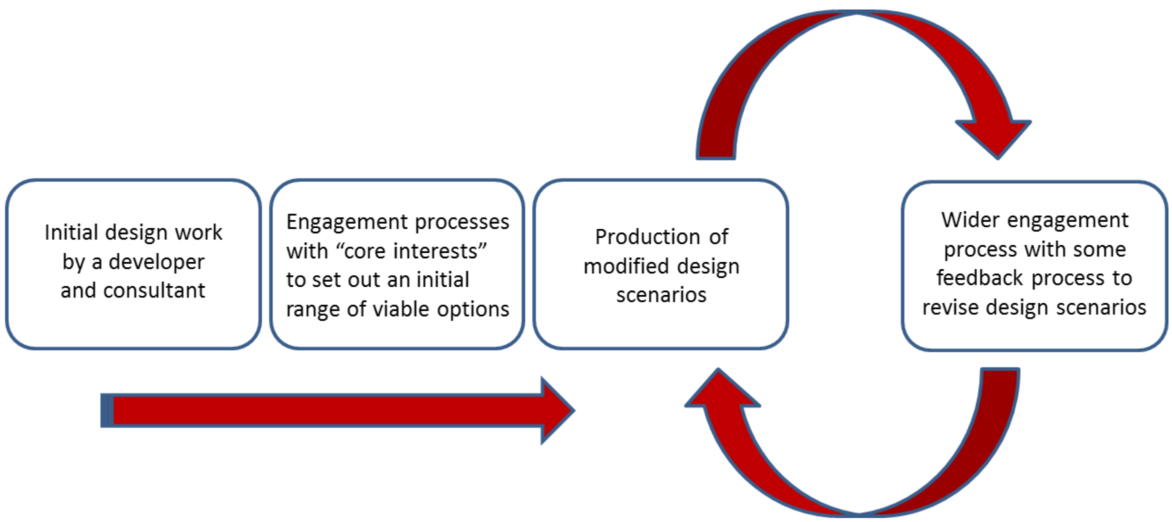

Figure 3: An example “private” restoration project development design scenario (Cundy et al., 2013)

- **Inception**: a group of interested parties decides to take am project forward (for example via a public agency, or a community led NGO)
- **Stage 1**: a limited group of stakeholders connected with the initialisation of a project develop their ideas and ambitions sufficiently for presenting them to other interested or involved parties.
- **Stage 2**: a broader group of stakeholders agree an outline regeneration scheme. This is often an iterative process containing three phases
- **Stage 3:** detailed design, when the agreed scheme is developed in detail for implementation based on site specific attributes and information.

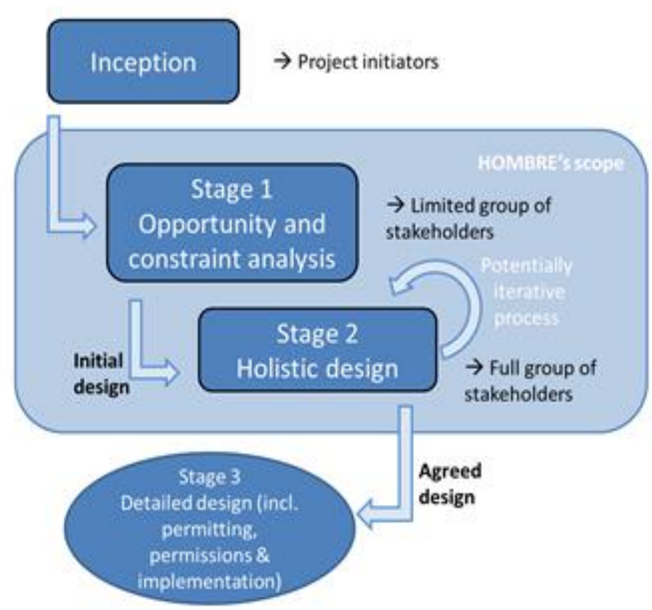

Figure 4: A coalition based project development process (Beumer et al., 2014)

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The BOM is seen as having several functions during project conceptualisation and early planning, as illustrated in **Figures 5**, to help those involved in initiating and championing a project to identify the services they might gain from land restoration and the interventions necessary to deliver those services. The BOM can also then be used to explain choices made to decision makers at local and national levels (or to directly involve them). The HOMBRE project has also developed a more detailed BOM version to support later stages in project design. These have not been included in the current China project as firstly we are interested to see the level of interest in China for this decision making aid, as the level of effort needed to implement the detailed BOM in China would be substantial, and require a longer term project.

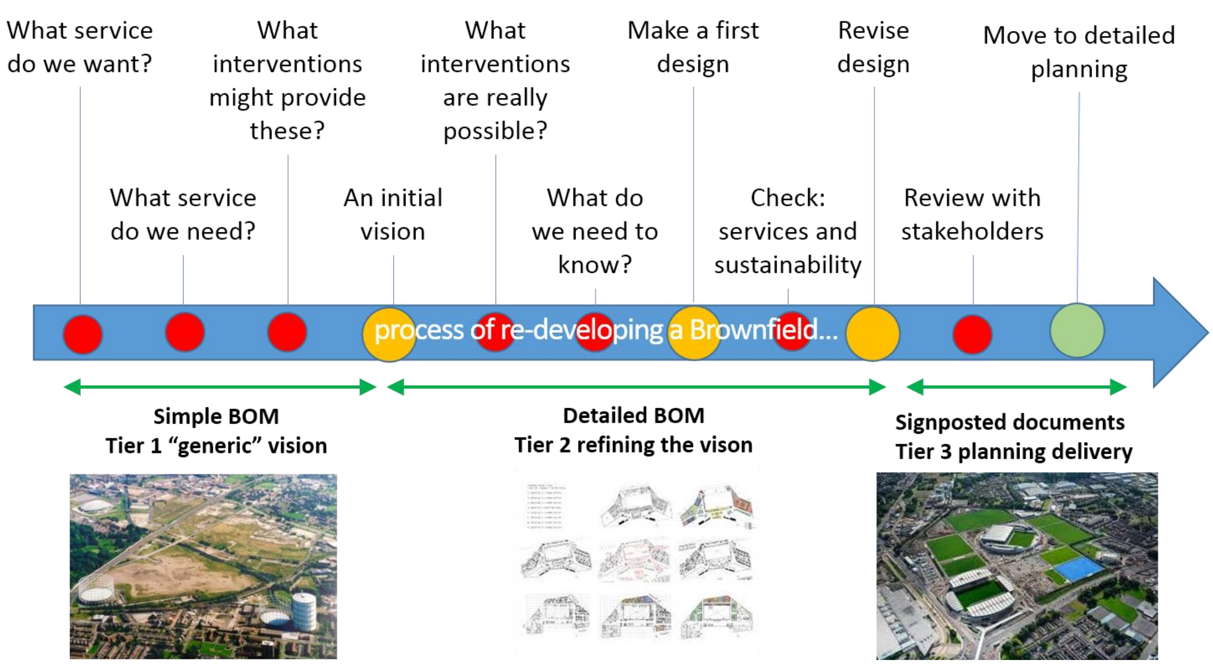

Figure 5 Timing of the use of the BOM (© r3 Environmental Technology, 2016)

The BOM is intended to be used as part of a structured engagement process consisting of a range of activities, managed by a facilitator to assist the different stakeholders in the process of reaching an agreement. The costs and effort of mobilising different stakeholders as well as providing a facilitator and reporting are significant. Therefore the *modus operandi* suggested is to include activities within a single meeting, and then follow-up amendments by e-mail. Activities are as follows:

- Meeting set up and aims
- Mutual introductions of meeting participants (two minute "elevator pitches")
- Briefing of soft re-use, interventions, and services and how these might deliver value from brownfield restoration
- A "World Café™" format discussion for stakeholders to work together in small groups to identify the services of most interest to them.
- A guided use of the simple BOM by the facilitator in plenary session to find the optimum set of interventions that appear able to deliver the services desired. The matrix itself includes examples and on line links to illustrate the various service/intervention opportunities that are available.
- A round-table discussion to use these outcomes to develop an initial shared vision for the brownfields re-use, identify ongoing information needs and next steps.
- Meeting reporting by the facilitator and commenting by e-mail to arrive at an initial project concept.

As mentioned in **Section 3.2**, to support these activities a number of components have been produced as a "stakeholder engagement package", and are available in Chinese at http://cnukcontaminatedland.com/cn/downloads/. The package includes:

- Meeting agenda proforma
- The simple BOM version
- A complete meeting slide deck
- Checklists (for services, interventions and forms of value)

A series of international stakeholder engagement resources providing supplementary information and good practice guidance is also provided in **Box 3**.

Box 3: International Stakeholder Engagement Resources	
World Bank Stakeholder Engagement Synergies with waste processing and re-use, leachate management	https://www.ifc.org/wps/wcm/connect/938f1a0048855805beacfe6a6515bb18/IFC_StakeholderEngagement.pdf?MOD=AJPERES
World Bank Stakeholder Engagement and Grievance Mechanisms	http://siteresources.worldbank.org/INTRANETENVIRONMENT/Resources/244351-1279901011064/StakeholderEngagement-andGrievanceMechanisms_111031.pdf
World Bank A Strategic Approach to Early Stakeholder Engagement (Extractive Industries)	https://commdev.org/userfiles/FINAL_IFC_131208_ESSE%20Handbook_web%201013.pdf
World Bank Innovative Approaches for Multi-Stakeholder Engagement in the Extractive Industries	https://commdev.org/userfiles/FINALWebversionInnovativeApproachesforMultiStakeholderEngagementintheEI.pdf
USEPA Superfund Community Involvement Toolkit Files	https://www.epa.gov/superfund/community-involvement-tools-and-resources
USEPA Environmental Justice Outreach & Engagement	https://www.epa.gov/environmentaljustice/ej-2020-outreach-engagement
USEPA Risk Communication Guidance Documents	https://www.epa.gov/risk/risk-communication

3.4 CASE STUDIES: BOM APPLICATION IN CHINA

The information was provided by the relevant partners of the China-UK partnership for contaminated land management (CNUK Team) in the form of a brief case study card detailing the site history and current situation, the stakeholders involved, particular problems and how the Brownfield Opportunity Matrix (BOM) has been used to inform and support the decision making process. Please note in some occasions, the BOM was used retrospectively; for example where the remediation of a site was already underway or the site was in a transition phase. While this meant that conclusions from the BOM could not be validated to some extent in those cases, the stakeholders involved in those sites were able to indicate the potential usefulness of the BOM if it would have been available from the outset of the project. Many expressed interest in maintaining contact with the SPF partners and using the tools and concepts in future projects. Stakeholders from the case study sites found that collaboration with the CNUK team has opened up new perspectives on the regeneration process in China.

Case study 1: Huifeng Agri-Chemical Plant, Yancheng City, Jiangsu, China

CASE STUDY NAME AND PROVINCE: Huifeng Agri-Chemical Plant, Yancheng City, Jiangsu, China	
Brief overview	The site is the first site that is going to be investigated and remediated at Dafeng township, Yancheng City. The Site is located in a farmland area at Dafeng district, Yangcheng city of Jiangsu province, China. The site was a Chemical plant from 1991 – 2015, manufacturing various pesticides. The major contaminants are the source materials that were used to produce pesticides, intermediate products, and pesticides, which include VOCs, SVOCs, TPH, and Chlorinated pesticides. The area of the Site is approximately 100,000 m^2.  The stratigraphy of the site from top to bottom include fill, silt, fine sand, and silty clay. The groundwater level is 1 m below ground surface (bgs). Both soil and groundwater are likely to be contaminated. The old plant will be demolished in 2017. The site will be remediated and a modern, more environment friendly plant will be built after the remediation. The Phase I site investigation has been completed and the Phase II investigation is going to be conducted in January 2017. The remediation action plan will be developed after the completion of the site investigations.
Site remediation main drivers	The site has been contaminated from the leak from the old storage and piping system of the chemical plant due to the lack of environmental management system in 1990s. The new Environmental Law and Regulations require that the site owner put in place an environmental management system and ensures that the plant met the new environmental standards. Therefore a new chemical plant will be built on the site and a new environmental management system will be developed to manage the plant environment. The surrounding land farm owners require that no contamination will be released from the chemical plant.

Stakeholders involved	• Local authorities including Dafeng township, Yancheng municipality, local DEP • Hufeng Chemical plant owner, plant workers, • Farmland owners of the surrounding farmlands.
Actions taken with the BOM	Meetings were held with the site owner, plant workers to develop a 'conservative' or 'soft' remediation plan. Instead of excavation, pump & treat, and in-situ thermal remediation technologies, the plant owner inclined to choose a 'soft', long term remediation approach including source control, hydraulic control, and long term monitoring.
Additional comments/references related to the case study	This is the first environmental remediation case in Yancheng municipality of Jiangsu province. Using the BOM approach will guide the remediation technology selection and implementation to develop a sustainable, long term environmental remediation example.

Case study 2: Remediation of Heavy Metal Contaminated Farmland Using Energy Plant, Jiangxi Province, China

CASE STUDY NAME AND PROVINCE: Heavy Metal Contaminated Farmland, Jiangxi Province	
Brief overview	The pollution arise from a smelting plant in an inland province of East China which was setup in the early 1980s. Over the 30 years production, large amount of slags, wastewaters and waste gases was released which resulted in a severe contamination to the surrounding environment. More than 166 ha (about 412 acres) of farmland around the smelting plant were heavily polluted by heavy metals (mainly Cu and Cd). Fortunately, surface water and groundwater has not been polluted in this region. 1-3: Before Remediation  4-6: During Remediation  7-9: After Remediation  After a detailed investigation and risk assessment of the contaminated farmland, a remediation strategy of "Regulate-Reduce-Recover" was proposed as follows: (1) **Regulate**: Firstly, regulating the surrounding environment by methods of physical adjustment and chemical modification (passivation and complexation); (2) **Reduce**: Then, reducing

	the total or available heavy metal concentration in the contaminated soil by combined physicochemical-plant/biological methods; (3) **Recover**: Finally, recovering the ecological function of contaminated soil by combined plant and agronomic management techniques. The cultivation of a kind of bioenergy plant, Jujun grass, contributed greatly to heavy metal reduction in the contaminated soil. The project started in 2011 and was completed in 2014.
Site remediation main drivers	The large area of farmland around the smelting plant was seriously polluted for many years. Crops production did not perform well and farmers' income has been reduced significantly. The ecological and environmental quality of the surroundings were also affected. Therefore, farmers were unhappy with the enterprise. They wanted the enterprise to find solutions to prevent further pollution and address the existing pollution issues.
Stakeholders involved	The main stakeholders were farmers, local residents, extractive industries and smelting plant operator, regulators including the local Environmental Protection Agency and the Government and the remediation contractors. (1) Farmers got better economic benefits. The yield of rice increased; the concentration of heavy metals in crop seed decreased and the quality of crop seed improved after the remediation. The Jujun grass which has a large biomass (7-21 tons per year per ha), was used to generate electricity because of its higher carbon content and higher calorific value. The power generation of Jujun grass per mu was equivalent to 2-3 tons of standard coal. (2) The disputes and tensions between the extractive industries, the local residents, farmers and the government which existed for a long time were solved. (3) The expertise and ability of the local environmental protection was greatly improved through the implementation of this project. Local enterprise and farmers also gained a better understanding and knowledge to deal with heavy metal contamination. (4) The economic burden of for the extractive industries was reduced since a low-cost remediation strategy was adopted. The costs of treatment was only about 10-20$ per ton of soil.
Actions taken with the BOM	• **Discussions about reuse of contaminated land.** After several meetings and iterations between the different stakeholders between Nov and Dec 2015, the conclusion was that the contaminated farm land could be used for the production of biomass and flower nursery stock. It will well illustrate an integration of site remediation and biomass energy production. • **Meeting about remediation strategy selection.** In this project, large areas of farmland were seriously contaminated. So most of the commonly used technologies on industrially contaminated sites

	including dig and dump, soil leaching, solidification and stabilization, thermal desorption and phytoremediation, etc. were not suitable due to the large amount of contaminated soil amount that needs to be treated, the high cost, and the potential impacts of the physicochemical methods on the soil properties and characteristics with subsequent impact on crop production. Therefore, an integrated strategy of physicochemical-phytoremediation-agronomic methods was adopted. This remediation strategy tries to achieve a good combination between soil remediation and landscape beauty, ecological reconstruction and economic efficiency. • **Field visit and Remediation demonstration.** The site will be developed to provide a demonstration and validation platform for heavy metal contaminated land remediation, metal recovery and energy production. During the project implementation, several research staffs, remediation enterprises, government officials from other district and/or province, mainly concerned with agricultural and environmental protection, came to visit this site. Experience gained on this site will help decision making and remediation strategies for other heavy metal contaminated site. The success of this project had been well-regarded by Mr Lu Xinshe, the governor of Jiangxi province.
Additional comments/references related to the case study	After remediation, the concentrations of available heavy metals in the farmland soils decreased greatly and crop plant are growing well. The plants covered the bare ground surfaces, retained the water and reduced the runoff of heavy metals therefore controlling the infiltration to groundwater. The landscape of the contaminated areas was also improved and it is now provided scenic panorama. The vegetation has recovered and provides a habitat for insects and birds reproduction. The ecosystem was restored and its environmental quality was significantly improved.

4 Technical guidance and strategies for renewable energy applications

Where brownfield or marginal land is contaminated, then the risks of that contamination need to be assessed to determine if any form or management (such as remediation) is needed. Risks might be posed to human health or the wider environment, i.e. water, ecology (Defra 2011; Nathanail and Bardos, 2004). For a contamination risk to be present three components need to be in place a source of hazardous substances, a receptor that might be affected by them and a pathway that links the source to the receptor (as illustrated in **Figure 6**). This combination is called a contaminant linkage or a pollutant linkage. In the majority of developed countries the process of land contamination is one of Risk Based Land Management (Vegter et al., 2002) to a lesser or greater extent (Nathanail et al., 2014). Extensive guidance has been developed in several countries. In the UK this high level guidance for this is contained in a series of Model Procedures (Environment Agency and Defra, 2004).

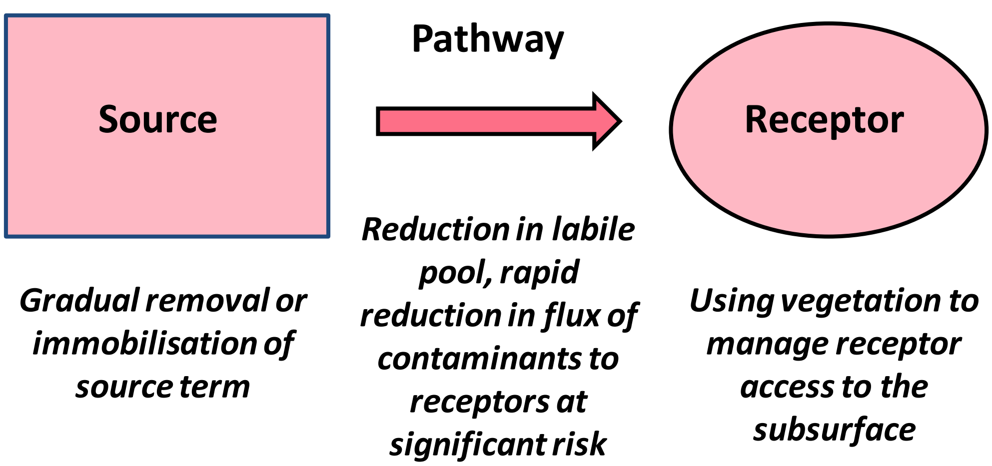

Figure 6: A contaminant linkage, and different gentle remediation interventions at the level of source, pathway and receptor.

More recently, with the advent of sustainable remediation concepts (see **Chapter 5**) the new model is Sustainable Risk Based Land Management. This approach encapsulates decades of learning from many countries. For example, the first land restoration projects in the UK (the Lower Swansea Valley) began to be planned in the 1950s. Countries at the beginning of the development of contaminated land management policies and frameworks can benefit from this learning and avoid considerable costs and many technical mistakes. For example, a recent UK Prosperity Fund project has encapsulated this learning for China (Coulon et al., 2016).

Risk management is the process of assessing risks and deciding what needs to be done about them; that is, whether the risk is significant and, if so, whether it needs to be mitigated by some form of remediation intervention. The structure of contaminant linkages also indicates the principle points of intervention that can be used to manage risks (Nathanail et al., 2007), as follows:

- At the level of the source; for example, as a source removal action
- At the level of the pathway; for example, managing the spreading of a groundwater plume, including by monitored natural attenuation
- At the level of the receptor; for example, by dense planting to prevent human access or by some form of planning (institutional) control to limit the allowable use of the land (e.g. not for housing with gardens).

A risk management approach may integrate interventions at different levels. For example, partial source removal for pathway management to deal with residual contamination may be combined with additional protection via a planning control (e.g. restrictions on use of water from particular boreholes). **Figure 7** gives examples of these interventions in a gentle remediation context.

A special case exists for land where biomass is produced. Biomass itself may become a pathway for spreading contamination to people, even for non-food crops, depending on how and where the biomass is utilised. This situation may

- render biomass unsuitable for use,
- yield biomass suitable for use only in controlled facilities, such as waste to energy facilities, or
- necessitate mitigation measures, such as the use of *in situ* stabilisation to reduce plant uptake (Andersson-Sköld et al., 2014; Jones et al., 2016).

Conventional approaches to remediation have focussed mainly on containment, cover and removal to landfill (or “dig and dump”). From the late 1990s onwards there has been a move towards treatment-based remediation strategies, using *in situ* and *ex situ* treatment technologies such as soil washing, “pump and treat” of contaminated groundwater, coupled with the widespread adoption of a risk-based approach to contaminated land management. Recently, building on earlier ideas about low input approaches, the concept of **Gentle Remediation Options (GRO)** has emerged. GRO are defined (e.g. Cundy et al., 2013) as risk management strategies/technologies that result in a net gain (or at least no gross reduction) in soil function as well as risk management.

This emphasis on maintenance and improvement of soil function means that they have particular usefulness for maintaining biologically productive soils, which is important where a "soft" end use for a site (such as urban parkland, biomass/biofuels production *etc.*) is being considered (Cundy et al., 2016).

This section provides technical guidance on a range of key GROs based on outputs from the European Commission Framework 7 research project (Gentle Remediation of Trace Element Contaminated Land (www.greenland-project.eu) and the HOMBRE project mentioned in Chapter 2, supplemented by information from the US EPA on phytotechnologies for remediation (https://clu-in.org/techfocus/default.focus/sec/Phytotechnologies/cat/Overview).

GROs encompass a number of technologies including:

- The use of plant or fungal microbiological processes for removal, degradation or immobilisation of contaminants, discussed in **Section 4.1**; and
- In situ stabilization (using biological or chemical processes, for example sorption to biochar) or extraction of contaminants, discussed in **Section 4.2**.

Biologically productive soils include those used for agriculture, habitat, forestry, amenity, and landscaping, and therefore GROs will tend to be of most benefit where a "soft" end use of the land is intended.

Gentle remediation options are best deployed to remove the labile (or bioavailable) pool of inorganic contaminants from a site (e.g. via phytoextraction), to remove or degrade organic contaminants (e.g. phyto-degradation), protect water resources (e.g. rhizofiltration), or stabilise or immobilise contaminants in the subsurface (e.g. phytostabilisation, in situ immobilisation/phytoexclusion). These approaches can also be tailored along contaminant linkages as suggested above (Cundy et al., 2016).

The GREENLAND project has developed a simple and transparent decision support framework for promoting the appropriate use of gentle remediation options and encouraging participation of stakeholders, supplemented by a set of specific design aids for use when GRO appear to be a viable option (Cundy et al., 2015). The framework is presented as a three phased model or Decision Support Tool (DST), in the form of a Microsoft Excel-based workbook, designed to inform decision-making and options appraisal during the selection of remedial approaches for contaminated sites. It can be downloaded from www.greenland-project.eu.

Intelligently applied GRO can provide: (a) rapid risk management via pathway control, through containment and stabilisation, coupled with a longer term removal or immobilisation/isolation of contaminants; and (b) a range of additional economic (e.g. biomass generation), social (e.g. leisure and recreation) and environmental (e.g. CO_2 sequestration, water filtration and drainage management, restoration of plant and animal communities) benefits (Cundy et al., 2016). Phytoremediation techniques involving *in situ* stabilisation of contaminants or gradual removal of the labile (i.e. bioavailable or easily-extractable) fraction of contaminants present at a site can be durable solutions as long as land use and land management practice does not undergo substantive change causing shifts in pH, Eh, plant cover etc. This requirement suggests that some form of institutional or planning control may be required. The use of institutional controls over land use however is a key element of urban remediation using conventional technologies (e.g. limitation of use for food production), so any requirement for institutional control and management with phytoremediation continues a long established precedent (Cundy et al., 2013).

4.1 GENTLE REMEDIATION - PHYTOREMEDIATION

Phytoremediation is the direct use of living green plants for in situ risk reduction for contaminated soil, sludge, sediment and groundwater (ITRC, 2009). Phytoremediation also re-establishes a vegetative cover at sites where natural vegetation is lacking due to high metal concentrations in surface soils or physical disturbances in superficial materials, which may be supported by amendments to reduce metal toxicity to plants (Nwachukwu and Pulford, 2008). Restoring vegetation to sites decreases the potential migration of contamination through wind erosion transport of exposed surface soils and leaching of soil contamination to groundwater (US EPA 1999). Phytoremediation is seen as offering a cheap and low input method for remediation of areas that are not candidates for conventional regeneration (Bardos et al., 2010). There are various kinds of phytoremediation approach, summarised in **Table 2**.

Table 2: Phytoremediation process variants (adapted from Nathanail et al. 2007)

Types	Applications
Phytoextraction	Use of plants that accumulate contaminants in harvestable biomass. Hyper-accumulators are plants that can accumulate metals to % levels of dry matter, mainly Cruciferae. Few commercially practical types exist. More common is the use of woody biomass such as willow and poplar. A few trials have been carried out using chelating agents such as Ethylene-Diamine-Tetra-Acetic (EDTA) to flood soils and so increase metal availability, and hence uptake, by plants such as Indian Mustard (Bardos *et al.* 2001)
Phytovolatilisation	Use of plants for extraction of volatile contaminants from shallow aquifers which are dispersed to atmosphere by the aerial parts of the plants.
Phytostabilisation	Immobilisation of contaminants in soil and groundwater in the root zone and/or soil materials. Immobilisation may be a result of adsorption to roots and/or soil organic matter (e.g. of PAHs), or precipitation of metals. These effects may be a direct effect of plant growth, or result from soil microbial and soil chemical processes caused by root growth. The net effect is to reduce contaminant mobility.
Phytocontainment (alternative covers)	Use of plants and cultivation techniques (such as the regular addition of organic matter) can increase depth of topsoil, which can establish a cover layer over sites, such as spoil heaps and on landfill caps and reduce the migration of contaminants. Plant growth and organic matter addition may also produce a stabilisation effect, e.g. by controlling pH and redox conditions in the subsurface and phytostabilisation effects described above. Phytocontainment may also interrupt contamination of aquifers by percolating water, through interception of water by plant roots (although this effect is seasonally dependent).
Phytodegradation	Degradation of organic contaminants through plant metabolism, which may be within the plant (by metabolic processes) or outside the plant (through the effect of enzymes or other compounds that the plant produces).
Phytostimulation/ biostimulation	Stimulation of microbial biodegradation of organic contaminants in the root zone, e.g. the roots provide conditions favouring microbial establishment and activity; this microbial activity results in the degradation or stabilisation of organic contaminants.

Phytoremediation is thus a gentle remediation option (GRO) which can provide rapid risk management of organic, inorganic and radioactive contaminants via pathway control, through containment and stabilisation, coupled with a longer term removal or immobilisation of the contaminant source term. In North America, application of GRO is arguably more developed than in Europe with the US Interstate Technology & Regulatory Council listing 48 sites, largely within the USA, as hosting "full-scale" phytoremediation trials (ITRC, 2009). GRO application generally in North America ranges from relatively small-scale phytoremediation projects that are driven and implemented by the local community to larger "green-technology"-based remediation programmes at Superfund sites which involve tree planting, soft cover etc.

Phytoremediation should primarily be deployed to gradually remove the labile (or bioavailable) pool of inorganic contaminants from a site (phyto-extraction), remove or degrade organic contaminants (e.g. phyto-degradation), protect water resources (e.g. rhizofiltration), or stabilise or immobilise contaminants in the subsurface (e.g. phytostabilisation, in situ immobilisation). It potentially offers a cost-effective in situ alternative to conventional technologies for remediation of low to medium-contaminated matrices, e.g. soils, sediments, tailings, solid wastes and waters.

Examples of circumstances which do not favour existing treatment-based remediation solutions, but which may be highly amenable to phyto-based risk management approaches, include:

- Large treatment areas, particularly where contamination may be causing concern but is not at strongly elevated levels
- Where biological functionality of the soil is required after site treatment
- Where other environmental services related to soil quality (e.g. biodiversity, carbon sequestration) are valued highly
- Where there is a need to restore marginal land to produce non-food crops and avoid major land use changes
- Where there are budgetary constraints
- Where there are deployment constraints for land remediation process plant (e.g. as a function of area and location).

Conversely, phytoremediation has limited potential where sites require immediate redevelopment (i.e. within 1 year), where the majority of the site is under hard-standing or has buildings under active use, and where local regulatory guidelines are based on total soil concentration values. Deployment is site specific, depending on local soil type, depth of contamination, climate, site topography and other local factors. Comprehensive technical resources are available from www.greenland-project.eu, www.clu-in.org/techfocus/default.focus/sec/Phytotechnologies/cat/Overview, and ITRC 2009. The pros and cons of phytoremediation deployment are summarised in **Table 3**.

Table 3: Pros and cons of phytoremediation

Advantages	Disadvantages
• May provide an opportunity for the recovery of usable biomass (e.g. as feedstock or for energy), as well as a range of other services related to for example water management and soil improvement. • Phytoextraction has the potential to remove metals from contaminated soil, and furthermore these metals may be recoverable in ash from harvested biomass, in particular if "hyper-accumulators" are used. • Phytoextraction can provide rapid removal of dissolved forms of metals limiting the capacity of metals to spread and therefore valuable as a pathway management application to protect water resources and ecological receptors. • Phytodegradation, phytotransformation, and rhizodegradation can provide a long term solution for a range of organic contaminants, including some recalcitrant forms such as PAHs. • Processes of phytocontainment, rhizofiltration and phytostabilisation can provide pathway management solutions for a broad range of organic and inorganic contaminants in parallel. • Phytovolatilisation may be an effective means of removing some volatile organic compounds from shallow groundwater.	• Phytoextraction processes may take many years (decades), and some metals may be inaccessible or unavailable to the phyto-extraction process. Hence phyto-extraction is limited in its suitability as a source management tool for removing bulk metals from soil. • Very few types of hyper-accumulator are suitable for practical remediation use. • Harvested biomass needs to be evaluated (and potentially monitored) to show that contaminants have not migrated to it. In some cases harvested biomass may not be readily usable as its content of metals may require special permitting from regulators. • May require cultivational measures, re-grading or decompaction, or other soil improvement measures to support adequate plant growth. • Usually requires ongoing management and monitoring, e.g. fertilisation (which may be via recyclates), to prevent pest damage, and/or recover biomass. • Benefits, both as a remediation technique and for providing other beneficial services may be seasonally limited, e.g. diminishing during periods of plant dormancy Remediation effectiveness may also be limited to rooting depth. • Phytovolatilisation is the transfer of contaminants from matrix (groundwater) to another (air) and as such may raise regulatory objections.

4.2 GENTLE REMEDIATION - AMENDMENT ADDITION

One form of "gentle remediation" is the use of amendments which can be incorporated into the soil surface to achieve remediation by in situ stabilisation (Jones et al. 2016). The processes of stabilisation are a form of pathway management as the contaminants remain in situ but their mobility and bioavailability are reduced, thus also reducing leaching through the soil profile. Processes of immobilisation include sorption to biomass, sorption to soil organic matter (for example PAHs to humic matter), and sorption to surfaces of introduced materials such as charcoal (Bardos et al. 2010). For trace metals, the most important processes involved in this immobilisation are precipitation, dissolution, adsorption/desorption, complexation processes and ion exchange. Amendments may be materials specifically designed for specific functions, such as modified chars; or bulk materials, such as composts and slags. Immobilisation may also follow amendment of soil pH, for example by lime addition. However, this is usually considered reversible and not suitable as a long term measure. Nonetheless, in some cases amendments can generate soil pH decrease due to mineralisation processes, and are therefore recommended to be combined with liming agents (Kumpiene et al., 2008).

Many brownfield sites that are contaminated are complex by nature and may be polluted by a wide ranging mixture of contaminants. As a result, it may be necessary to apply more than one remediation technique across a site, and/or combine processes in a treatment train to reduce the concentrations of pollutants to acceptable levels (risk assessed levels that will not cause harm). The selection of treatment approach is heavily dependent on site specific conditions and contaminants.

In situ stabilisation is primarily deployed to mitigate risk of harm from contamination to acceptable levels for revegetation and groundwater resources. Example amendments and the contaminants they treat include:

- **Modified charcoals / specific chars**: there is extensive research on the use of biochars for the immobilisation of heavy metals and organic compounds (Ahmad et al., 2014; Lehmann and Joseph, 2009). A range of products have been developed, or are in development. These may be based on specific feedstocks, such as bone biochar or chars including modifying agents such as zerovalent iron. An emerging application may be the use of charcoals as a carrier for microbial inocula to promote in situ biodegradation (bioaugmentation).

- **Other proprietary amendments** such as Daramend™, which is a mixed organic material with zerovalent iron and is used to treat organic contaminants which are susceptible to reductive degradation.
- **Liming agents**: calcite, burnt lime, slaked lime, dolomitic limestone
- **Phosphates and apatites**: metal immobilisation, and in particular lead immobilisation, has been successful when using a range of high phosphate materials, such as synthetic and natural apatites and hydroxyapatites, phosphate rock, phosphate-based salts, diammonium phosphate, phosphoric acid and their combinations.
- **Composts and other organic recyclates**: composts and organic amendments such as sewage sludge have been found to reduce mobility of inorganic and organic species. However, the effect is highly specific to material and site, and dissolved organic matter has been found to mobilise metals in some tests (Park et al., 2011; Nason et al., 2007).
- **Slags**: some types of slags, in particular blast furnace slags, have been used to immobilise metals in situ.
- **Zeolites**: there is a strong of research interest in the use of naturally occurring zeolite materials for the immobilisation of metals in situ to facilitate revegetation (Shi et al., 2009; Leggo, 2013).
- **Iron / iron products**: iron oxidises in soil and mobile species may be sorbed to the oxides / hydroxides produced and the oxidation process. Amendments rich in metal oxides combined with compost, fertilisers, beringite, cyclonic ashes or lime have been found to effectively immobilise trace metals and enhance plant growth (Cundy et al., 2008).

The pros and cons of deploying in situ stabilisation are summarised in **Table 4**.

Table 4: Pros and cons of *in situ* stabilisation

Advantages	Disadvantages
• Rapid immobilisation of mobile species facilitating revegetation and protection of water receptors affected by contamination spreading from the site. • Combinations such as compost and char can be used to achieve risk management and soil improvement services in parallel. • The use of chars / biochars may achieve (temporary) carbon sequestration in soils. • Amendments can restore soil quality by balancing pH, adding organic matter, increasing water holding capacity, re-establishing microbial communities, and alleviating compaction. • Compatible with many other interventions, including measures to achieve improved conservation, biodiversity (depending on the amendment selected). • Amendments can usually be deployed using readily available agricultural equipment. • Use of some amendments represents a means of sustainable reuse of waste products (agricultural and industrial).	• Care is needed when several amendments are combined as they may interfere with each other. • Validation and verification may be relatively complex, in particular to make the case of a long term protective effect to regulators. • Unlikely to be protective of human health where direct contact is a major exposure pathway. • Some amendments (e.g. composts and digestates or sewage sludge may be associated with nuisances from odour or bioaerosols. Others may cause nuisance from dust emissions off site. It is particularly important to find organic amendments of high stability and low odour, and to apply application methods that minimise emissions of odour bioaerosols and/or dust

4.3 PRODUCING RENEWABLE BIOMASS, BIOFEEDSTOCKS AND SECONDARY RESOURCES

- **Biofeedstocks and non-food/industrial crops**: biofeedstocks describe materials from plants or animals that are processed by industry or manufacturing to make value added products. Typically a biofeedstock crop is processed to reduce the biomass to precursors commonly used in process industry, such as methanol, fatty acids etc. The principal application of biofeedstocks is for biofuels production (see **Section 4.4**) but a range of wider applications is possible, for example in plastics manufacture. Non-food crops encompass a wide range of crops grown for fibres (such as flax), dyes (indigo), essential oils (lavender) or other purposes. The attraction of brownfields for non-food crops or biofeedstocks is that this land is unlikely to be in conflict for food production; and the downstream processing of the crop is less likely to create unacceptable contaminant linkages. Secondary resources describe reclaimed materials which can substitute for virgin materials (for example milled demolition waste substituting for aggregates). Production of biomass and biofeedstocks (such as timber) can also provide important carbon sequestration benefits (US EPA, 2012).

A range of non-food crops can provide usable feedstocks, for example for energy (see **Section 4.4**) but also as inputs to production processes could be produced on brownfields, for example for fibres, bioplastics, dyes, essential oils and a range of other uses outside food chains. An emerging application is the conversion of organic residues, in particular lignocellulosic residues, to usable organic compounds in "biorefineries". A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass. The biorefinery concept is analogous to today's petroleum refinery, which produce multiple fuels and products from petroleum.

Even food production may take place on brownfield sites, as long as this does not introduce a risk via contamination of food products. A common context is the development of community farms on urban brownfields (US EPA, 2011; Mok et al., 2014). Food production on brownfield land can be a possibility depending on whether or not harmful pollutant linkages might be introduced in the food chain. A common example is urban farms and allotments set up on former brownfields. The use of brownfields for grazing is also fairly common, for example on former landfills and mine spoil sites, however, risks will require careful assessment (Green et al., 2014). Some crops like flax can have both food and non-food applications.

- **Topsoil substitute / aggregates production**. On some sites the availability of relatively clean aggregates may open an opportunity for top soil substitute production by mixing different aggregate grades with organic matter (WRAP, 2012). A further potential development from this is turf production, although care would need to be taken to avoid any off site export of contaminated turf. For some sites on site recycling can greatly reduce the need for imported virgin materials for restoration purposes. Other recoverable materials include fill materials (ballast) which can be used for geotechnical purposes such as sands or gravels. These may be of use in re-grading or re-contouring areas of a site, or off-site, as well as in building civil engineering features such as sound or flood protection barriers (Defra, 2009). Hub and cluster approaches, i.e. temporary centralised processing serving a number of sites, may make materials recovery more feasible, especially where there are several ex situ operations in reasonable proximity taking place over a number of areas of a brownfield or in the vicinity of a brownfield [**Note**: in EU countries there may also be regulatory barriers to the re-use of recyclates, particularly off site].

The use of brownfields for biofeedstocks and non-food crops is currently dominated by inputs for biofuels. However, non-food production on brownfields overall remains an emerging concept and little public or peer reviewed information has been produced with the exception of biomass for energy.

- **Timber / woodland (including wood fibre)** is a potential re-use for brownfield land. The re-use of brownfields for woodland establishment is well developed and detailed guidance is available from a number of sources (Cotton et al., 2012; Willoughby et al., 2007). The use of wood fibre from short rotation coppice produced during phytoremediation has had some discussion in the academic literature (Licht and Isebrands, 2005).

Brownfield sites are of increasing interest as locations for new recycling facilities and also for processing biofeedstocks. In Sardinia, former industrial land is used both as the location of a biofeedstocks processing centre (for bioplastics production) but also as a hub for biofeedstocks production from both agricultural and degraded land. The pros and cons of using brownfields for renewable biomass, biofeedstocks and secondary resources are summarised in **Table 5**.

Table 5: Pros and cons of using brownfields for renewable biomass, biofeedstocks and secondary resources

Advantages	Disadvantages
• May provide an opportunity for the recovery of usable biomass (e.g. as feedstock or for energy), as well as a range of other services related to for example water management and soil improvement. • The energy and carbon balance benefits for recovery of biomass for use in feedstocks or products may be greater than that of recovery simply for energy. • May form part of a phytoremediation strategy to manage contaminated land risks. • May contribute to urban greening and city farm projects which have wider sustainability and community benefits. • Suitable for land unsuitable for building purposes for geotechnical reasons. • Associated with the development of soil and biomass carbon stocks as well as fossil fuel displacement which has both carbon balance benefits and opens the potential for carbon financing. • Compatibility with other forms of land use (e.g. crops, grazing animals, parkland are all feasible depending on site context.	• Harvested biomass needs to be evaluated (and potentially monitored) to show that contaminants have not migrated to it. In some cases harvested biomass may not be readily usable as its content of contaminants may require special permitting from regulators. • May require cultivational measures, re-grading or decompaction, or other soil improvement measures to support adequate plant growth. • Usually requires ongoing management and monitoring, e.g. fertilisation (which may be via recyclates), to prevent pest damage, and/or recover biomass. • Benefits, both as a remediation technique and for providing other beneficial services may be seasonally limited, e.g. diminishing during periods of plant dormancy Remediation effectiveness may also be limited to rooting depth. • Phytovolatilisation is the transfer of contaminants from one matrix (groundwater) to another (air) and as such may raise regulatory objections. • Brownfield site size could be a limiting factor. Detailed viability assessment should reveal how efficient a project could be (i.e. in terms of economic and environmental terms at least).

4.4 RENEWABLE ENERGY GENERATION

A range of techniques that allow generation of renewable energy can potentially be deployed on brownfields, including biomass, photovoltaics, wind, and geothermal/geological sources .

TECHNICAL GUIDANCE AND STRATEGIES FOR RENEWABLE ENERGY APPLICATIONS

Renewable energy exploits sources that are carbon friendly and hence help mitigate global warming. Renewable energy production supports achieving independence from volatile fossil fuel markets and may be particularly useful in areas of energy scarcity or variable supply. Thus renewable energy production is both a reliable and sustainable mean to produce energy and a strategy to gain security in energy supply and makes it an attractive solution both for energy providers (i.e. comply with GHG emissions) and consumers (i.e. count with a reliable supply at controlled prices). Compared to conventional energy sectors, studies have revealed great potential for job creation in the green and renewable energy sector (UKERC, 2014).

Applied in the context of brownfield regeneration, renewable energy supply is a potential source of revenue for ongoing site management. It also avoids the use of Greenfield sites for renewables production, reducing potential land-use conflicts.

Typical renewable energy variants include the following:

- **Wind power**: independently of the size of the brownfield site (from a few 100 m^2 up to several hectares), wind turbines size (i.e. power) and number can be easily adapted for minimizing disturbances like noise and visual impact. Wind power generation can be easily combined with several other uses on a brownfield site; i.e. residential, commercial and other soft re-use such as parks and gardens (allotments). The presence of wind turbines in urban areas may offer better efficiency as losses due to transport of energy on long distances are minimized. The installation of wind turbines on brownfield sites reduces the consumption of pristine green space and improves its ecological footprint. The presence of wind turbines on brownfields may have little impact on the fate and transport of contaminants eventually present on the site. However bigger wind turbines may need substantial ground works for foundations. Their installation therefor should be undertaken after a detailed soil investigation has taken place to prevent inappropriate works in contamination hot spots that could mobilise contaminants. Limiting factors for installing wind power on brownfields are those linked with the economic viability of the project, i.e. considering supply capacity (i.e. regularity of wind conditions) and demand (peak of demand).

- **Solar power**: solar technologies can be broadly grouped in passive and active systems. Passive systems are those applied in urban areas and construction design in order to gain maximum benefit of the sun’s radiant energy to heat buildings efficiently (i.e. choosing appropriate orientation of built elements towards the sun, using appropriate materials and space layout to distribute heat in the building etc.). Passive solar techniques have shown similar benefits as those of green infrastructures as they contribute to mitigating urban heat island effect and improve urban comfort. As such, at local scale, their combination with soft re-uses on redevelopment sites may provide investors and users with substantial benefits (i.e. improved quality of life through thermic comfort, energy efficient buildings and attractive asset value).

Active solar techniques include the use of photovoltaic panels and solar thermal collectors to capture energy. Active solar power systems can either be installed directly on the ground or on building roof tops depending on the purpose and desired power capacity. Experiences in pioneer countries around the world have shown that efficiency of heat producing solar power systems can be increased in combination with seasonal thermal energy storage (STES) systems. These systems are capable of storing heat for months at a time. Thus, solar heat collected primarily in summer can be used for all-year heating. Solar-supplied STES applications include individual buildings and district heating networks. STES thermal storage media include deep aquifers; native rock, heat exchanger equipped boreholes; large, shallow, lined pits that are filled with gravel and top-insulated; and large, insulated and buried surface water tanks. Thus, when combined with heat storage systems, the viability assessment of solar power systems on brownfields should contemplate possible constraints on interventions in the subsurface where underground infrastructures and/or the presence of contaminants could hinder or complicate operations.

- **Geothermal power**: geothermal power is energy provided from heat naturally present in the underground (rocks, soil, groundwater etc.). Techniques to collect heat may consist in systems like geothermal heat pumps i.e. ground source heat pumps whereby infrastructures are buried in shallow underground depths (few meters). Other disposals may reach deeper heat sources (hot rocks, geothermal sources at several hundreds of meters). Recently geothermal energy has found wide applications for heating buildings, making it a reliable and sustainable source of energy for housing and other buildings (heat or power generation) and contributing in reducing GHG emissions and mitigate climate change. Depending on the technology, exploitation of geothermal heat may require minimum surface of soil for burying underground infrastructures and enabling heat exchange to take place. This makes the technology perfectly suitable in areas of mixed soft and build uses, where residential or industrial buildings are heated with geothermal sources. Brownfield regeneration projects that foresee geothermal energy production on site should consider possible constraints linked with the presence of underground infrastructures. Their installation therefor should be undertaken after a detailed soil investigation has taken place to avoid obstacles and prevent inappropriate works in contamination hot spots that could mobilise contaminants. In the case of shallow contamination hot spots, contractors may take advantage of groundworks to dig contaminated soil out for further ex situ treatment, either on or off site, depending on context specific parameters and costs. Banks describes a UK example of energy from mine water (Banks, 2012).

- **Biofuel energy creation**: biofuels are liquid or gaseous fuels produced from living organisms. These are generally plants or plant derived materials, i.e. biomass. The fuels are obtained from the conversion of biomass via thermal, chemical and biochemical processes. Liquid biofuels include bioethanol produced by fermentation of starch (i.e. from wheat, barley, corn, or potato) or sugars (i.e. sugarcane or sugar beet), and biodiesel produced by trans-esterification of oil crops (including rapeseed, soybeans, sunflower, palm, coconut) and animal fats. New generation of biofuels produced from the residual non-food parts of crops and from other forms of lignocellulosic biomass such as wood, grasses and municipal solid waste have been developed so that competition between energy and food sectors is lowered. Beyond the transport sector, bioethanol offers prospects in the sectors of chemical industry and power through fuel cells technology.

- **Biomethane/biogas** can be produced by anaerobic digestion of biodegradable materials grown on brownfield land. Biogas is also generated in landfills containing degradable wastes. Landfill biogas, if not properly captured contributes to GHG emissions and global warming. Adequate containment and landfill biogas valorisation contributes both to mitigating climate change and provides a renewable source of energy supply.

- **Thermal conversion of biomass** from brownfields to generate electricity and heat has been extensively demonstrated. It encompasses single solutions that could be applied to particular kinds of areas in particular regions, for example, phyto-extraction into willow short rotation coppice (SRC) for an area affected by smelting fallout, or phytostabilisation using a grass crop or oil seed rape with harvestable biomass for an area affected by polynuclear aromatic hydrocarbons (PAHs) etc. (Bardos et al., 2010; Lord et al., 2010).

The reconversion of brownfields into soft uses for biofuel feedstock offers investors an opportunity for supplying the renewable energy sector with raw material either in combination with other feedstock resources (CLUSTER) or as a unique source. If biomass conversion facilities are located and operated on site or nearby, this activity may contribute in generating green jobs in deprived areas and boost local economy. By-products of biofuel generation processes can be converted into high quality compost for agriculture, gardens and landscaping (i.e. digestates produced via anaerobic digestion) or food stock for cattle (i.e. by-products of bioethanol production from cereal crops). Hence, brownfield reconversion for biofuel generation offers multiple benefits and services for investment made. Last but not least, the production of biofuels from feedstock grown on former brownfields avoids both competition with agricultural land (i.e. crops for foodstock production) and reduces land consumption, thus contributing to mitigate GHG emissions and climate change. The pros and cons of using brownfields for different forms of renewable energy production are summarised in **Table 6**.

Table 6: Pros and cons of using brownfields for renewable biomass, biofeedstocks and secondary resources

Advantages	Disadvantages
• Brownfields can offer opportunities for siting renewable energy that are better supported by local communities. • Renewable energy provides income in support of brownfields management and restoration. • Renewable energy can provide a wide range of wider economic, social and environmental benefits for communities affected by brownfield land; and may also support or work in tandem with other site management needs (for example leachate management via biomass). • Compatibility with other forms of land use (e.g. crops, grazing animals, parkland are all feasible.	• Economic benefits may not be sufficient to fully cover brownfield restoration costs (but can still provide a useful offset). • Renewable energy supply typically requires long term use of a site (circa 20 years) which may reduce its longer term potential for new redevelopments. However, temporary installations may be possible, e.g. interim biomass energy plantations or movable photovoltaic installations. • Brownfield site size could be a limiting factor. Detailed viability assessment should reveal how efficient a project could be (i.e. in terms of economic and environmental terms at least).

4.5 CASE STUDIES

Case Study 1: Biomass Production and Phytoremediation (China)

Background and Site Description

The remediation site is located in the northwest of Guangxi Province, Southwest China. The region is renowned for its rich nonferrous mineral resources, especially lead (Pb) and zinc (Zn) and therefore mining activities in the region are important. In 2001, a Pb/Zn mine's tailing dam close to a major river collapsed due to significant flooding in the region. This caused mining waste spills to spread onto farmland downstream.

It was estimated that approximately 700 ha of farmland was contaminated by heavy metals. From 191 soil samples collected on the affected area, heavy metal concentrations were ranging between 19 – 55 mg kg^{-1} for arsenic, 0.2 - 0.4 mg kg^{-1} for cadmium and 285 - 416 mg kg^{-1} for lead. In addition, 50% of the collected soil samples had heavy metal concentrations exceeding the national limits for heavy metals in soil for agricultural use. Due to the toxicity of the soil contaminants, the most severely affected area could no longer sustain growth for conventional agricultural crops (**Figure 1.1**).

For the area less impacted, agriculture continued, however agricultural yields were significantly affected and there were concerns over food safety

Fig. 1.1. Site soil condition prior to the remediation

Studies showed that most of the local agricultural products were containing high concentrations of As, Cd and Pb, exceeding the national food standard level by more than 13%, 27% and 33%, respectively.

Phytoremediation Project Plan and remediation outcomes

Phytoremediation was considered as the most appropriate approach due to cost-effectiveness and the potential for restoring the local soil ecology.

Following site investigation and an initial feasibility study, a phytoremediation demonstration project was planned and carried out on three selected sites:

- **Site A** (11.1 ha) had the highest level of contamination. The key remediation target was to extract of the contaminants using selected metal accumulating plants. i.e. *Pteris vittata* and *Sedum alfredii*.
- **Site B** (5.6 ha) and **Site C** (2.8 ha) were moderately contaminated, therefore a intercropping system was planned to plant *Pteris vittata* and *Sedum alfredii* amongst cash crops.

On site B, sugar cane was selected as the intercrop, whereas mulberry tree was selected for site C.

Phytoremediation plants, *Pteris vittata* and *Sedum alfredii* were harvested every year from all three sites and the biomass burnt on site in a combustor purposely built for the remediation project.

After two years of phytoremediation, the concentration of As, Cd and Pb in the three sites was reduced by 55%, 86% and 30%, respectively.

All three remediated sites met the national standards for agricultural production and the sites showed evidence of improved soil productivity (**Figure 1.2**).

Fig. 1.2. Improved soil condition following the 2-year remediation project

Cash crop products cultivated during the remediation period met the national standards and provided some financial subsidies to local farmers.

Project Cost-Benefit Analysis

Costs per ha of the remediated land are summarised in **Table 1.1**. The remediation cost consists of the initial capital investment and operational costs, representing 46% and 54% of the total cost, respectively.

Table 1.1. Costs of the phytoremediation project

Breakdown of the costs	Cost per ha (US$)
Initial capital investment	
Pollution survey	825
Establishment of the remediation strategy	825
Land preparation	577
Plant nursery equipment	5894
Irrigation system	5987
Roads, bridges, and culverts	9548
Combustor	7217
Other initial capital investment	3812
2-year operational cost	
Seedling	165
Plow	781
Transplant	206
Fertilisation	124
Insect control	124
Irrigation	124
Weed control	412
Harvest	186
Other labour costs	658
Seedling tray	83
Hyper accumulator seedlings	165
Crops seedlings	2522
Farm chemicals	41
Fertilizer	14,892
Other material costs	923
Harvest machine	297
Incineration machine	322
Disposal of dangerous wastes	206
2-year operational cost	
Production compensation	357
Rent of land	309
Fuel and power cost	1948
Construction supervision	74
Environment supervision	4011
Regular monitor	3299
Staff wage	990
Administrative expenses	825
Travel expenses	3889
Cost of water and electricity	2006
Other indirect cost	755
Total cost	**75,375**

During the two years of remediation, intercropping with cash crops has returned significant economic benefit to subsidise the remediation project.

From selling products including sugar cane and mulberry tree, incomes of **US $90,932** and **US $45,220** were achieved.

Following the remediation, the remediated sites were returned to agriculture use. These areas of restored farmland are now yielding agriculture products on average worth US$ 160,700 each year. Therefore, it is expected that the direct income during and following remediation will offset the remediation costs in approximately 8 years.

In addition to direct income, the remediation has also achieved a number of intangible benefits including increased ecosystem services, enhanced land value and investment. However, the exact financial value of these benefits is difficult to capture therefore this is not accounted for within this case study.

Besides, the biomass derived from the phytoremediation project was combusted only as a waste management strategy. However, if the energy from the combustion process was recovered to subsidise the energy requirement for the site operation, further reduction in the operational cost could be expected.

Acknowledgement: The authors wish to thank Prof Mei Lei and Dr Xiaoming Wan at the Center for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (CAS) for providing the project information

Case Study 2: Using Solar Power-Assisted Enhanced Soil Vapour Extraction (SVE) for Organic Soil Pollution Treatment (China)

Background

SVE is an effective technology for treating organic soil pollutants. However its application and remediation efficiency is dependent on seasonal temperature changes. SVE projects normally achieve significantly better outcomes during spring and summer time when temperatures are high. One possibility to produce heat is to use solar panels. Solar energy is an unlimited renewable energy source.

The pilot study site is located in Beijing (39°48’ N, 116° 28’E), where the average daily sunshine is 10 hrs, the average annual sunshine is 2800 hrs and the average solar irradiance is 800 W m^{-2}. The climate conditions in the region is significantly affected by the monsoon and characterised by its clear distinction of four seasons - short windy spring, long hot summer, cool pleasant autumn and long chilly winter.

Considering the climate conditions and the availability of solar energy resources, an innovative solar power-assisted SVE technology was developed and tested. Since its development, this technology proved to be effective in enhancing the remediation end points for organic soil pollutants remediation, and it is particularly suitable for projects requiring large earthwork and short turnaround time.

Contamination of soil and pollutants

The main contaminants at the site are volatile organic compounds, mainly benzene, naphthalene. The specific pollution parameters are summarised in **Table 2.1**.

Table 2.1. Costs of the phytoremediation project

	Benzene	Naphthalene
Initial conc. mg/kg	220	179
Target remediation conc. (mg/kg)	50	50
Boiling point °C	80.1	217.9
Vapour pressure (pa)	12689	26
Molecular weight	78	128
Solubility (in water)	Slightly soluble	Insoluble
Initial conc. mg/kg	220	179
Target remediation conc. (mg/kg)	50	50

Equipment

The remediation was carried out on site using an *ex-situ* vapour extraction system. The system consists of a solar assisted heating system and a vapour extraction system. The solar assisted heating system comprises solar collector tubes, electric heating apparatus and heated water circulation system. The vapour extraction system comprises a vacuum pump, extraction pipelines, vapour collection and transport pipelines, a liquid/gas separator, gas cleaning apparatus, liquid cleaning and collection apparatus and an integrated control system.

The layout of the SVE system and the experiment setup are shown in **Figures 2.1 and 2.2**. During operation, the solar collector tubes heat up the water in the storage tank. The storage tank has a build-in electrical heating element with a thermocouple. When there is insufficient solar power to heat the water to the set temperature, the electrical heating system automatically starts. The water is then pumped into soil pile A for heat exchange. A control soil pile B was also set up without soil heating in order to compare the remediation efficiency with pile A.

Extraction pipelines were installed underneath the soil pile. A layer of gavel (particle size of 10 cm, layer thickness =10 cm) and a layer of No. 60 (0.250 mm) mesh were used to improve gas diffusion and separated soil from entering the pipeline. Extraction pipelines were fitted with pressure gauges and flow meters. In addition, sampling port and regulators were also installed. Contaminated soil piles were placed on the gravel layer, extraction pipelines were connect firstly to a liquid/gas separator, then a filtering system and finally a XGB high pressure vortex vacuum pump (power =7.5 kW, max flow rate = 480m^3/h, max pressure = 42 kPa). The extracted gas was cleaned using an active carbon based gas cleaning system before release into the atmosphere. The layout of the extraction system is shown in **Figure 2.1**.

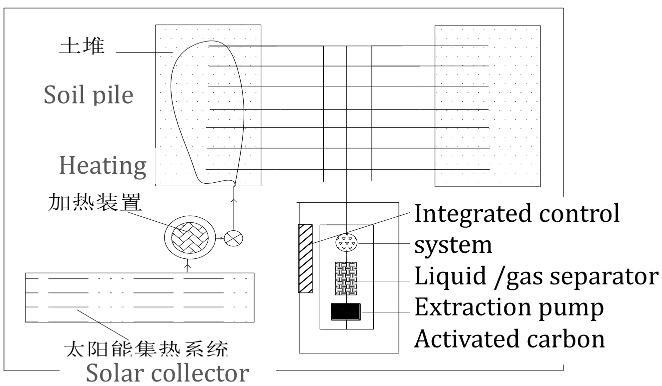

Figure 2.1. System layout

Figure 2.2. Views of the remediation site

The pile bottom width is 4 m and 14 m in length；The pile top width is 2 m and 12 m in length. The grading of the piles slopes is 1: 0.4. To optimise the system performance, the negative pressure in the soil pile, pumping rate, the efficiency solar collector tubes and the pollutant content in the extraction pipe were considered during the pile design. Soil temperature was monitored in the soil piles at 7 different depths as shown in **Figure 2.3**: H_1 (20cm), H_2 (50cm), H_3 (75cm), H_4 (100cm), H_5 (120cm), H_6 (140cm), H_7 (170cm).

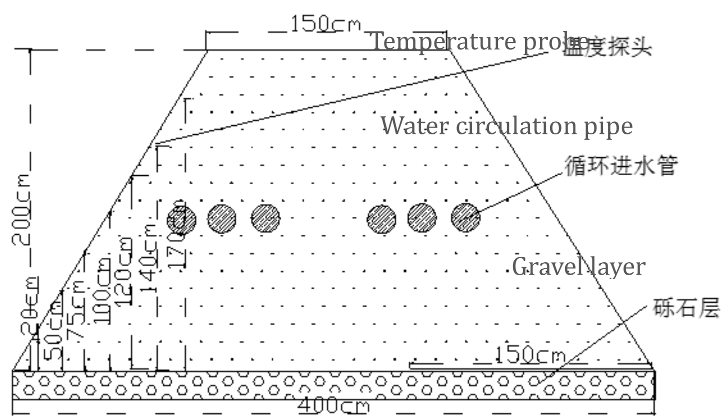

Figure 2.3. Soil Pile Design

Solar Assisted Heating System Assessment

The size of the solar energy insolating tubes is Φ0.05 × 1.4 m, with 0.07 m^2 per tube for solar energy insolation. The surface area of our solar collecting system is 14 m^2 in total and its average solar energy collection is about 17.28 $MJ.m^2.d^{-1}$. Based on the above data, the solar energy captured by the system is calculated as follows:

$Q = A \times J \times s \times (1-m)$

where Q: energy captured by our system; A: total solar energy insolating tube areas; J: daily total solar energy = 17.28 $MJ.m^2.d^{-1}$; s: heat exchanger efficiency = 0.50; m: heat loss from pipeline; an empirical value of 0.1 was used in this pilot study.

So, the total solar energy captured is:

$Q = 13.67 \times 17.28 \times 0.50 \times (1-0.1) = \mathbf{1.1\ 10^8\ J\ d^{-1}}$

Theoretical heat loss from the extraction process

The volume of the soil that need to be treated is 65.4 m^3 (98 t). The soil heat capacity is 1.4 10^3J/(kg °C) and the average soil water content is 12%. When extraction is in operation, soil temperature reduces by 3.04℃ on average; therefore the heat loss under the pilot study condition through extraction can be calculated as follows:

$Q_{lost} = 1.4\ 10^3 J/(kg\ .\ ℃) \times 3.04℃ \times 98000\ kg + 4.2\ 10^3 J/(kg\ .\ ℃) \times 98000 \times 12\% \times 3.04℃ = \mathbf{2.78\ 10^8\ J}$

Based on the calculated results, the solar power input is not sufficient to compensate the heat loss through vapour extraction process ($Q_{lost} > Q$).

For this reason, extraction only operates intermittently and during winter heating was largely dependent on electrical heating.

Soil temperature spatial distribution

Soil temperatures at 7 depths, H1 (20 cm), H2 (50 cm), H3 (75 cm), H4 (100 cm), H5 (120 cm), H6 (140 cm), H7 (170 cm) were monitor using temperature probes (see **Figure 2.3**).

Table 2.2. Soil temperature spatial distribution (ambient temperature @ -1℃)

Before extraction		After 0.5h extraction		After 1h extraction	
Sample No	Temp.°C	Sample No	Temp.°C	Sample No	Temp.°C
H1	10.3	H1	8.9	H1	6.6
H2	10.8	H2	8.4	H2	9.9
H3	16.0	H3	13.8	H3	11.7
H4	18.1	H4	15.2	H4	16.6
H5	15.6	H5	14.6	H5	11.8
H6	10.5	H6	10.0	H6	9.6
H7	10.4	H7	4.6	H7	-1.4

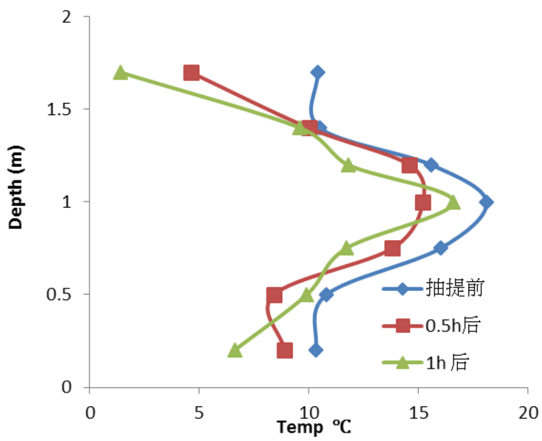

Figure 2.3. Soil temperature change at different depths (blue: before extraction; red 0.5 h after extraction and green 1 h after extraction)

The soil temperature changed in relation with the length of extraction operation time as shown in the **Figure 2.3**. The temperature depth profile was as follows $T_{1.0} > T_{1.5} > T_{0.5}$. For example, if extraction was not in operation, the water temperature was at 40°C before entering the soil pile. Once it entered in the soil pile, the soil temperature at each depth was as follows: $T_{1.0}$ =12.1°C, $T_{1.5}$=18.5°C and $T_{0.5}$=28.6°C. When the extraction was in operation, the water temperature was at 23°C and the soil temperature at each depth was $T_{1.0}$ = 14.3°C, $T_{1.5}$ = 17.2°C, $T_{0.5}$ = 15.2°C, respectively (Note: the thermal pipe was installed at depth of 1 m).

Remediation outcomes

The volatile organic compounds extraction was operated intermittently. Soil samples were collected at 0.8 m and 1.5 m respectively for chemical analysis and verification of the treatment process (**Tables 2.3 and 2.4**).

Table 2.3 Contaminant concentrations after 17 days operation)

Sample No.	Sampling layer	Benzene (mg/kg)	Naphthalene (mg/kg)
1	1st	135	127
	2nd	169	153
2	1st	151	132
	2nd	142	136
3	1st	121	133
	2nd	156	176
4	1st	186	164
	2nd	113	124

Note: Table summarizes results after 17 days' operation. 1st layer depth = 0.8 m and 2nd layer depth = 1.5 m

Table 2.4. Contaminant concentrations after 30 days operation

Sample No.	Sampling layer	Benzene (mg/kg)	Naphthalene (mg/kg)
1	1st	36	43
	2nd	45	48
2	1st	25	37
	2nd	42	44
3	1st	33	31
	2nd	47	42
4	1st	21	24
	2nd	32	42

Note: Table summarizes results after 17 days' operation. 1st layer depth = 0.8 m and 2nd layer depth = 1.5 m

After 17 days operation, the removal of benzene and naphthalene achieved was between 15-48% and 14-30%, respectively

(**Table 2.3**). Contaminants migrated from the top soil layer to bottom layer due to negative pressure generated by the extraction and the gravity. The contaminant removal was therefore found to be more significant in the top soil layer of the soil piles.

After 30 days operation, the concentrations of soil contaminants reduced significantly. The removal of benzene and naphthalene were between 85-90% and 75-87%, respectively (**Table 2.4**). Thus, the solar power-assisted enhanced SVE allowed to achieve for both benzene and naphthalene the remediation targets.

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Case Study 3: Brownfields to Green Energy (USA)

Background

The Brockton Brightfield, Brockton, MA, United States Located in a site previously occupied by a gas plant in, the Brockton Brightfield[1] solar energy farm is owned by the City of Brockton, MA, USA. With a population of 95,000 inhabitants, the town is located around 32 km south of Boston, MA. The Brightfield is equipped with 1,512 SCHOTT solar modules and is capable of generating up to 465 kW which supplies energy to sustain 77 homes. This facility is considered to be the largest and most successful Brightfield project funded by the U.S. Department of Energy (De Sousa & Spiess 2013)

Site history and environmental remediation

The Brockton gas plant operated between 1898 and 1963. The plant comprised retort house, purifier house, coke storage areas, above and below ground oil thanks, tar wells, and gas holders. Coal gasification related materials (CGRM), namely tars, spent purifier wastes, coal ash, coal fines, clinkers and cinders were common by-products resulting from gas manufacturing. Demolition of the plant took place in 1964 resulting in an 11-ha contaminated surface

[1] The term Brightfield defines the conversion of a contaminated site into usable land by building pollution-free solar energy generation and high-tech manufacturing.

area. The soil at the site was found to be polluted with volatile organic compounds such as benzene, toluene, ethylbenzene, styrene, and xylenes as well as semi-volatile organics (e.g. polycyclic aromatic hydrocarbons).

The city initiated its Brownfield to Brightfield project to develop PV arrays as a Solar Energy Park in 2000 (see **Figure 3.1**) with the following goals and objectives:

- Redevelop brownfields in an environmentally friendly manner
- Develop a new local and clean energy source for city use
- Expand the city tax base
- Enhance Brockton's image
- Develop "Brockton Solar Champions" concept and built on "City of Champions" logo, by making Brockton first in the state
- Attract PV manufacturers to Brockton.

The remediation of the site was completed in 2004 and involved actions in two different zones denoted as Lot 19 and Lot 55. Actions in Lot 19 included the disposal of 9.2 m^3 of coal tar, the consolidation of 1,853 m^3 of contaminated soil under a 1.4 ha impermeable high-density polyethylene (HDPE) geo-membrane and a separate 0.66 ha cap of clean fill. For Lot 55 the actions were the installation of a permeable cap covering 0.67 ha, consolidation of 732 m^3 with a 0.75-ha HDPE cap. Additionally, site grading was performed to improve drainage, prevent erosion as well as avoid contact with contaminated soil (Jensen 2010).

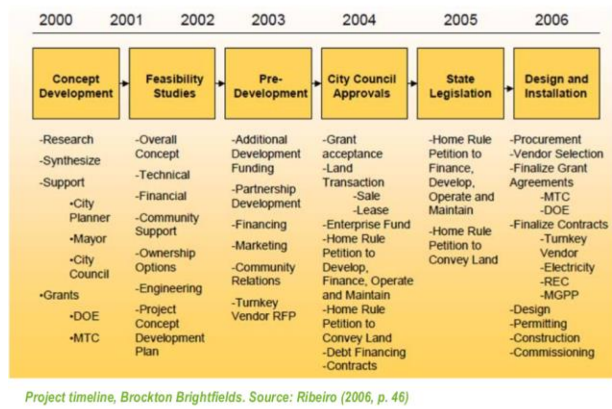

Figure 3.1. Project timeline

Brightfield project description

The origin of the Brockton Brightfield was an innovation grant awarded by the U.S. Environmental Protection Agency to the City of Brockton to study the implementation and financing of long-term renewable energy solutions on brownfields (**Figure 3.2 and 3.3**). In this case, the objective consisted in demonstrating to green power developers the long-term financial viability of projects by using renewable energy certificates (RECs). Being a tradable commodity, a REC represents proof that 1 MWh of electricity was generated by an eligible renewable energy source. The Brightfield secured a 20-year agreement with Constellation New Energy, a regional energy company, for the acquisition of RECs and electricity. During the initial 5-year period, RECs were sold at a variable rate of $180 per MWh, whereas the price was fixed at $180 per MWh during the subsequent 10 years. Additionally, the company accepted to buy electricity generated by the Brightfield at a rate of 7 cents/KWh for the first 10 years and at market values for the final years of the contract (U.S. Environmental Protection Agency 2011).

Brockton Brightfield (2009)

Figure 3.2. Solar panel installation

The overall budget for the project totalled $3 million, which was paid for through state and federal grants, a municipal bond as well as proceeds from land sales. As of 2010, the Brightfield has generated $145,000 per year; this revenue has been used toward paying off the costs to build and maintain the facility. Once the loan obligation is satisfied by 2026, the City of Brockton will directly benefit from the sale of RECs and electricity.

The Brightfield was commissioned in September 2006 and, after going online, has produced approximately 2,300 MWh of renewable energy which accounts for a reduction of 1.7 tons of carbon emissions (Figure 3.3).

Project design, Brockton Brightfields. Source: Ribeiro, Brownfields to Brightfields.

Figure 3.3. Project design overview

Case Study 4: Steel Winds, Lackawanna, (USA)

Background

Lackawanna, New York, United States

During eighty years Lackawanna, New York was known as one of the main centres of the U.S. steel production. Nevertheless, the Bethlehem Steel Company (BSC) closed in the mid-1980s and the former activities left behind contaminated land with a surface area of 647 ha by Lake Erie (**Figure 4.1**). In 1990 the site was classified as a Resource Conservation and Recovery Act Facility Investigation (i.e. Superfund property).

Modifications of state and federal environmental regulations were introduced in 2002, which provided incentives for brownfield redevelopment such as brownfield tax credits and liability protection from the costs of remediation.

Figure 4.1. Steel Winds in Lackawanna, New York (Source: Google Maps)

The strategic location of BSC in terms of wind patterns as well as the New York State policy of payments in lieu of property taxes for wind energy generation facilitated the construction of one of largest urban wind farms in the world.

Site history and environmental remediation

With a surface area of 445 ha, the former BSC Works occupied two municipalities with the majority of the site in Lackawanna and a small fraction in the town of Hamburg. The BSC plant was commissioned in 1909 and shut down in 1982. Achieving an annual production of 7 million tons per year, BSC became the fourth largest steel mill in the United States. The products resulted of the manufacturing process were coke, coke by-products, structured steel, steel coal, steel bars, and speciality products. As a result of this activity, steel slag was dumped into Lake Erie, which resulted in 178 ha of man-made land denoted as slag fill area (SFA). In addition to slag, the SFA also received other refuses such as wastewater sludge and dredge materials. Contamination at the site occurred because of three primary operations namely, coal to coke production, iron ore to steel production and support operations. Hence, the most abundant pollutants were coal tar, sodium phenolate, ammonium sulphate, naphthalene, light oil, sulphur and slag. The Steel Winds parcel occupies a strip of the SFA by Lake Erie shoreline. The remedial actions consisted of clearing the site of existing vegetation, covering with 30 cm of clean soil (i.e. a total volume of 29,000 m^3), and seeding to generate a vegetative cover. Additionally, enhanced aerobic bioremediation was applied to attenuate groundwater pollution. With this purpose, Oxygen Release Compound Advanced® filter socks were installed in up gradient monitoring wells: three off-site and two on-site (Jensen 2010).

Steel Winds Project description

After a study conducted by the University of Buffalo on wind energy development, a 12-ha parcel was selected as a potential source in the SFA (**Figure 4.2**). In 2006, the U.S. EPA determined this parcel clean enough for wind development. Subsequently, the City of Lackawanna in partnership with BQ Energy and UPC wind (now Apex Wind Energy Inc. and First Wind, respectively) implemented the two-phase project known as Steel Winds.

Figure 4.2. Windmills at Bethlehem Steel Company (Source: Doug Benz for the New York Times)

Steel Winds I started in September 2006 with excavation procedures for foundation. In June 2007, the deployment of eight operational turbines (2.5 MW) was completed, which yielded a total capacity of 20 MW. As a way of lowering expenses, the project design incorporated existing infrastructure (e.g. roads and transmission lines) so that the overall cost of Steel Winds I was $34 million. The second stage of the project, Steel Winds II, came online in February 2012. In this case, the total capacity of the wind farm was increased to 35 MW after the installation of six additional turbines. There are now fourteen wind turbines supplying electricity to approximately 15,000 homes in western New York State. In financial terms, Steel Winds generate $190,000 in annual tax revenues for local authorities. Additionally, the electricity generated at Steel Winds is sold as RECs to Constellation New Energy, a local utility. This agreement facilitates Constellation to meet its renewable energy target under New York state renewal portfolio standard that requires 30% of the electricity to be generated from renewable sources. Apart from energy generation, the Steel Winds project acts as magnet for redeveloping the post-industrial Lake Erie's coastline: a community centre, a commerce centre, a clean burning power plant (1,100 MW), and a greenway and bike trail are some of the projects already in place (U.S. Environmental Protection Agency 2012).

Case Study 5: Using Short-Rotation Coppice to Provide Effective Risk Management and Remediation Solutions to Metal Contamination (UK)

Background

Liverpool and St Helens, North West England, United Kingdom Five brownfield sites in the region of Liverpool and St. Helens in NW England were selected on the basis that they were perceived to be contaminated by the Local Authority or other landowners, following previous desk studies and Phase I surveys (**Table 5.1 and Figure 5.1**). The 5 sites had differing former land uses (landfill, industrial waste, and sewage-sludge) and site investigations confirmed the existence of a varied range of trace element contamination as summarised in **Table 5.2**.

Table 5.1. Locations of experimental trials and outline site descriptions

Site Abbreviation	Details
SUG	A 3.8-ha urban derelict site adjacent to busy road in a commercial and residential location. Formerly allotments, but neglected grassland and scrub prior to onset of study.
FAZ	Formerly a sewage farm but now adjacent to a modern sewage treatment works. Substantial recent re-engineering of landscape at ca. 15 ha of the site. Sewage-sludge and sewage cake treatments applied to one experimental plot prior to planting.
KIR	34 ha landfill site within an agricultural landscape. Livestock grazing on poor grassland (15 cm topsoil depth) since closure of the landfill site in the 1970s.
MER	6.6 ha of intensively mown amenity grassland, used for public recreation, within a residential and industrial area. Shallow soils (10-30 cm). An alkali works from 1873 within an industrial landscape, and subsequently an industrial waste site.
CRM	8.8 ha of mown amenity grassland with shallow soil overlying former landfill site in a residential and industrial area.

Nine trial plots (each 30m × 30m or 21m × 21 m, with 1-3 plots per site) were located across the sites. Biomass cultivation was carried out at all sites by turning the soil (using a tracked excavator) to an approximate depth of 30 cm, followed by (tractor-mounted) rotovation and a glyphosate weed-control treatment.

Figure 5.1. A typical brownfield site at Cromdale Gove with amenity grassland on shallow soil (10-30 cm depth) overlying a former landfill site that received domestic, industrial and chemical waste (including colliery spoil, ash and rubble) in the 1960s and 1970s surrounded by residential buildings and light industry (French et al., 2006)

Further, weed control using a combination of strimming and herbicides was required during the first 2 years of cultivation.

Table 5.2. Contaminants concentration ranges in soil

Contaminants	Range in soil samples across all plots (mg kg^{-1})
Cd	0-7.9
Zn	2.8-1300
Cu	10-880
Ni	10-109
Pb	45-1770
As	4.9-5266

Plots were planted with 5 taxa of *Salix*, 2 *Populus* hybrids, *Alm1s, Bet11ia and Larix* (**Table 5.3**) in a fully randomised block design (10 blocks per taxa, 12 plants per block, double rows 1.5 m × 0.5 m spacing).

Table 5.3. Woody species and varieties planted across all plots in a randomised block design

Taxa	Abbreviation
Larix X *eurolepis* Henry	LAR
Betula pendula Roth	BET
Alnus incana (L.) Moench	ALN
Populus deltoides X *nigra* 'Ghoy '	GHY
Populus trichocarpa 'Trichobel '	TRI
Salix caprea X *cinerea* X *viminalis* 'Calodendron'	CAL
Salix viminalis 'Orm'	ORM
Salix caprea X *viminalis* 'Coles'	CLS
Salix bwjatica 'Germany'	GER
Salix *viminalis* X *schwerinni* 'Tora'	TOR

Following the standard practice for management of short-rotation coppice management, *Salix* and *Populus*, but not the other species, were manually cut back after 1 year. Above-ground biomass of all *Salix, Populus* and *Alnus* was then manually harvested after a further 2 years. Standardised foliar sampling (top third of the inner 8 trees per block) for metal determination was carried out after the first growing season and at the end of the third year; at the latter time, sampling focussed on trees planted within contamination hotspots and stem samples were also collected at harvest.

Remediation outcomes

In this case study, Cd and Zn were found to be particularly mobile in the soil-plant continuum. Both are widespread contaminants that commonly occur in urban environments, but Cd is a much more zootoxic metal and of more concern to human health and to food chains. *Salix* accumulated Cd in concentrations that substantially exceeded soil concentrations. The taxa CAL and GER contained 7-9 times more Cd in stems than EDTA extractable soil concentrations, and 9-13 times more in foliage. These data can be combined with biomass yield data in predictive models of longer-term metal off-take. These are speculative models that assume continued metal lability, consistent soil physico-chemical properties, same productivity and same rates of uptake. Obviously, they should be treated with caution. However, over a typical 20-year life cycle of the crop, this would amount to a reduction of 5.6 mg Cd kg^{-1} and 96 mg Zn kg^{-1} from the soil by the most efficient taxon (CAL).

Productivity of coppice

Overall mortality of plants, apart from Larix (LAR) was low (mean 11%) and was not related to contamination, except at the site with highly elevated As (MER). LAR mortality was very high (20-77%) at all sites. Mortality of *Betula* increased from 7% to 29% between Years 1 and 3, visibly due to competition from other faster-growing taxa.

Plants yields calculated using data from the Year 3 harvest (Fig. 3) showed considerable variation between the Salix and Populus taxa, and comparably high yields of *Alnus*. There was also wide variation between sites (<2-9 t ha^{-1} $annum^{-1}$) and plots (e.g. at MER). In the UK it has been considered that economic return is achieved when woody biomass yields exceed 8-10 t ha^{-1} $annum^{-1}$. In the case study, three sites (CRM, FAZ, KIR), four *Salix* taxa (*CLS, GER, ORM, TOR*), and *Alnus* were either close to, or exceeded, this threshold.

Concluding remarks

In the situations demonstrated in this case study, the project outcome suggest that planting woody biomass does not increase the lability of metals or their mobility to the wider environment, at least during the first 3 years. Ground cover with trees is likely to reduce the re-entrainment of particulates and contamination of the wider environment.

Thus, woody biomass may provide an effective form of phytostabilisation or monitored natural attenuation. Cultivation of woody plants for biomass provides aesthetic improvement and economic benefits (Paulson et al., 2003).

Time scales for clean-up using phytoextraction are long, but there is now gathering evidence that this can provide a significant contribution to the integrated management of brownfield land.

Yields of Salix, Populus and Alnus were economically viable, showing that short-rotation coppice has a potentially valuable role in community forestry. Mass balance modelling demonstrated that phytoextraction potentially could reduce contamination hotspots of more mobile elements (Cd and Zn) within a 25-30-year life cycle of the crops.

Acknowledgement

This case study is an excerpt from the published work of French CJ, et al (2006)

Please refer to the original report for further project details.

Case Study 6: Exelon City Solar, Chicago, Illinois (USA)

Background

The Exelon City Solar project is the largest urban solar power plant in the United States (**Figure 6.1**). City Solar was constructed in a vacant industrial zone in West Pullman (Chicago, IL).

Figure 6.1. SunPower PV panels mounted in single-axis tracker systems in Exelon City Solar (Source: SolarServer)

The project resulted from a collaboration between Exelon Corp. (an energy company with headquarters in Chicago), SunPower (a California-based manufacturer of solar panels), as well as the Departments of Environment and Community Development of the City of Chicago. This 10-MW installation can supply electricity to power 1,500 homes. Construction began in July 2009 and the plant was dedicated by July 2010 (SolarServer 2011).

The West Pullman neighbourhood represented the core of the Chicago's industrial activities between the 1880s and the 1980s. During these years, companies such as Pullman Car Works, Dutch Boy Paint, AM Forge and Ingersoll Products were located there. Locomotive brake shoes, farm machinery, railcars, and lead-based paint production were the main products manufactured in West Pullman (S.B. Friedman & Company 1997).

As a result of deindustrialization, the West Pullman Industrial Redevelopment Area (WIRA) was created in 1998 as an Industrial Park Conservation Area (IPCA)-Tax Increment Financing (TIF) district and Illinois Enterprise. The IPCA-TIF promoted the recovery of WIRA by assembly efforts, soil remediation projects and infrastructure improvement. In this fashion, areas known as 10, 11 and 12, which span 16 ha, were selected for the construction of City Solar.

Chicago Malleable Castings occupied Area 10. A survey conducted in this area found polycyclic aromatic hydrocarbons (PAHs), metals, and asbestos as the main pollutants. Areas 11 and 12 accommodated International Harvester stock sheds and manufacturing plant, respectively. Area 11 was mainly contaminated with asbestos, while light non-aqueous phase liquids, polychlorinated biphenyls (PCBs), polynuclear aromatics (PNAs), hydrocarbons, metals and asbestos were found in Area 12 (Jensen 2010). In the three aforementioned areas, remedial actions involving the removal of underground storage tanks and of 2,930 tons of asbestos containing materials (ACM) took place between 1999 and 2000.

Oily liquids from vaults and sewers along with PCB contaminated materials were cleaned up as well. Additionally, in-situ treatment of groundwater contaminated with chromium (III and VI) was completed by 2007.

The remedial objective for PCB was set at 1 mg/kg. Soil containing over 50 mg/kg PCB was excavated and disposed of in a Toxic Control Act landfill.

Lead-contaminated soil was disposed of at an appropriate facility in Illinois. Finally, materials containing hydrocarbons, PNAs, along with soil and concrete having PCB concentrations under 50 mg/kg were discarded as non-hazardous special waste in local landfills (Jensen 2010).

On-site assessment and remedial actions conducted in Areas 10 and 11 totalled $800,000 paid by the City of Chicago. Additionally, $200,000 were expended due to additional remediation needed during the construction of the solar power plant. When it comes to Area 12, the U.S. Environmental Protection Agency supported with $950,000 remediation activities from 1998 to 2007.

Exelon City Solar Project description

Figure 6.2. Exelon City Solar, Chicago Illinois (Source: Turner Constructions)

The 10-MW plant, designed and constructed by SunPower, comprises 32,292 SunPower watt monocrystalline modules mounted on SunPower T0 single-axis tracker systems (**Figure 6.2**). This proprietary design allows panel rotation following the sun. When compared with fixed array systems, T0 not only increases sunlight capture by 25%, but also provides higher electricity generation with a smaller footprint. The panels convert sunlight into 14,000 MW-h of electricity per year (Exelon 2016). The overall project cost was $60 million. Financial support through the American Recovery and Reinvestment Act (ARRA) resulted critical for the viability of the project as ARRA includes bonus depreciation so that a 50% deduction of the adjusted basis of the property in 2009. The remaining 50% of the adjusted basis to be depreciated over the regular depreciation schedule (Jensen 2010).

5 Sustainability assessment and evaluation

The UK Sustainable Remediation Framework (SuRF-UK) for assessing the sustainability of soil and groundwater remediation and all of its guidance, has been developed on the basis of consultative processes with a wide range of practitioners drawn across different stakeholder types (CL:AIRE, 2010). From the outset, SuRF-UK identified the requirement for simple, robust and transparent approaches to assist sustainable remediation decision-making to enable it to be easily transferrable across different regulatory regimes and therefore can be adapted and adopted in different countries. This was key as often in the past sustainability has been considered too complex, costly and too subjective and sometimes be seen as a substitute criterion for risks to human health and the environment.

SuRF-UK identified a number of key principles that clearly underpin the primary role of risk assessment and management in contaminated land decision making for effective sustainable remediation (**Table 7**). In addition, SuRF-UK explicitly advocates a tiered approach to minimise cost and complexity in decision making and has provided guidance on identifying which sustainability considerations should be considered to ensure a consistent and holistic approach, shown in **Table 8** (CL:AIRE, 2011). The tiered approach, coupled with the SuRF-UK framework's with underpinning principles has been adopted in the recently published ISO standard (ISO, 2016).

Table 7 Key principles associated with sustainable remediation

Principles	Sustainable remediation
Principle 1: Protection of human health and the wider environment.	Remediation [site-specific risk management] should remove unacceptable risks to human health and protect the wider environment now and in the future for the agreed land-use, and give due consideration to the costs, benefits, effectiveness, durability and technical feasibility of available options.
Principle 2: Safe working practices.	Remediation works should be safe for all workers and for local communities, and should minimise impacts on the environment.
Principle 3: Consistent, clear and reproducible evidence-based decision-making.	Sustainable risk-based remediation decisions are made having regard to environmental, social and economic factors, and consider both current and likely future implications. Such sustainable and risk-based remediation solutions maximise the potential benefits achieved[2]. Where benefits and impacts are aggregated or traded in some way this process should be explained and a clear rationale provided.
Principle 4: Record keeping and transparent reporting.	Remediation decisions, including the assumptions and supporting data used to reach them, should be documented in a clear and easily understood format in order to demonstrate to interested parties that a sustainable (or otherwise) solution has been adopted.
Principle 5: Good governance and stakeholder involvement.	Remediation decisions should be made having regard to the views of stakeholders and following a clear process within which they can participate.
Principle 6: Sound science.	Decisions should be made on the basis of sound science, relevant and accurate data, and clearly explained assumptions, uncertainties and professional judgment. This will ensure that decisions are based upon the best available information and are justifiable and reproducible.
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Table 8 Overarching SuRF-UK Sustainable Remediation Categories

	Environmental	Social	Economic
1	Emissions to air	Human health and safety	Direct economic costs and benefits
2	Soil and ground conditions	Ethics and equity	Indirect economic costs and benefits
3	Groundwater and surface water	Neighbourhoods and locality	Employment and employment capital
4	Ecology	Communities and community involvement	Induced economic costs and benefits
5	Natural resources and waste	Uncertainty and evidence	Project lifespan and flexibility
			© CL:AIRE, 2016. Reproduced by permission

SuRF-UK is coordinated by an independent organisation CL:AIRE, and since 2009 it has produced a wide range of outputs, these outputs are listed in **Figure 8** and are freely downloadable from www.claire.co.uk/surfuk.

The SuRF-UK range of publications and tools has helped to deliver a range of benefits for sustainable remediation practitioners that are available to all. These include:

- Supporting effective risk management
- Generating value by finding optimal solutions for soil and groundwater projects
- Identifying and avoiding project risks
- Demonstrable compliance with government and/or corporate policies and goals for sustainable development
- Providing a positive contribution towards delivery of corporate social responsibility (CSR) programmes, reputation and public relations

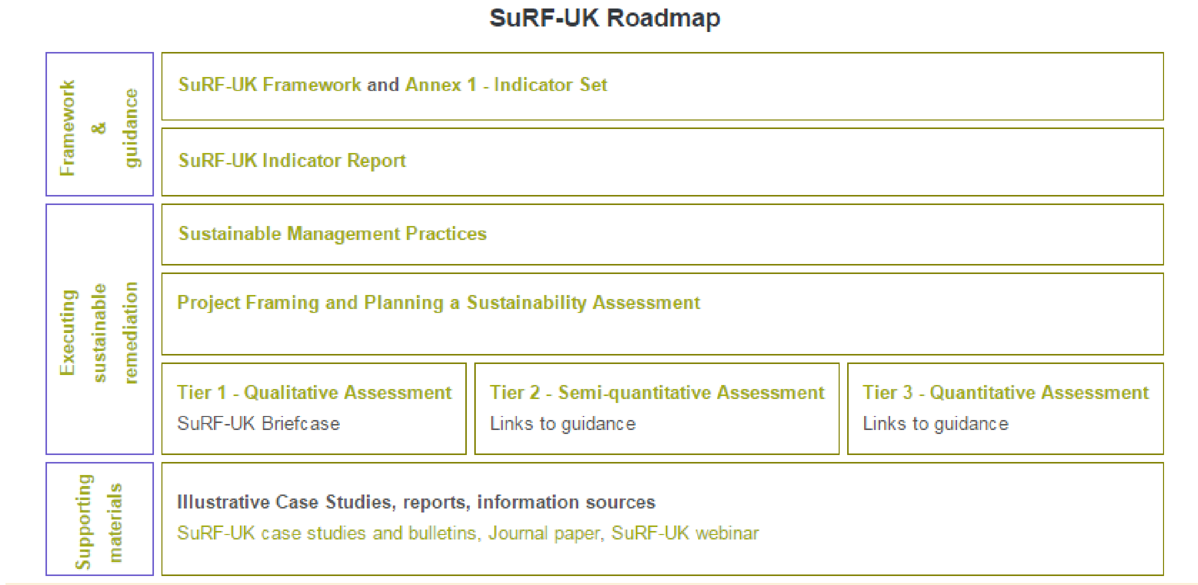

Figure 8. SuRF-UK Outputs

In parallel to providing a framework and guidance for the management and assessment of sustainability in remediation decision making, SuRF UK also recognised that simple operational guidance could significantly improve the sustainability of contaminated land practices so has published "Sustainable Management Practices for Management of Land Contamination" (CL:AIRE, 2014b). SuRF-UK defines sustainable management practices (SMPs) as 'relatively simple, common sense actions that can be implemented at any stage in a land contamination management project to improve its environmental, social and/or economic performance' (CL:AIRE, 2014 a & b). This identifies two starting points for enabling more sustainable contaminated land management approaches, as part of a tiered process as shown in **Figure 9**:

- Simple good management practices to mitigate known negative impacts and promote known benefits (sustainability management practices)
- Qualitative sustainability assessment for planning, design and option appraisal.

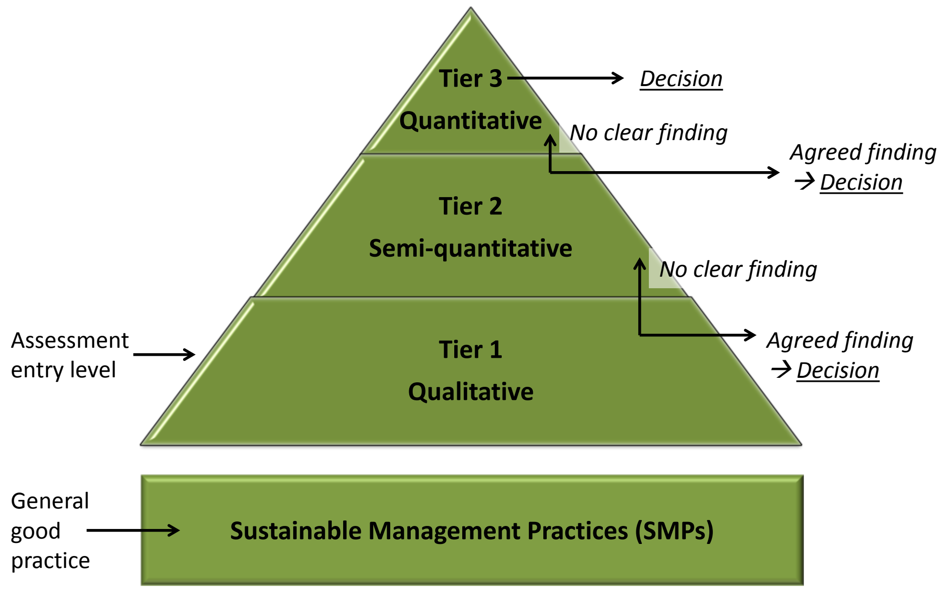

Figure 9: Tiered approach to sustainability assessment

SMPs can be used in many ways, e.g. to improve the benefits (e.g. resource efficiency, cost) or reduce the negative impacts (e.g. spillages, complaints) of a project, leading to project 'sustainability gains'. SMPs are intended for use without the need for a formal sustainability assessment. They may also be used where sustainability gains are sought at a programme of work level using generic criteria or standards that can apply to a range of project types. Hence, the use of SMPs is seen by SuRF-UK as an entry level activity underpinning whatever additional sustainability based decision making takes place. **Figure 10** describes the implementation process for making use of these SMPs.

The SMPs provide practical and generally inexpensive actions that can yield demonstrable 'sustainability gains' for a project. They should be selected where there is a clear benefit in doing so on a project-by-project basis. The SMPs are provided in an Microsoft Excel spreadsheet file, downloadable from www.claire.co.uk/surfuk. A report is also available that describes the development of SMPs and instructions for use of the SMP spreadsheet (CL:AIRE, 2014b).

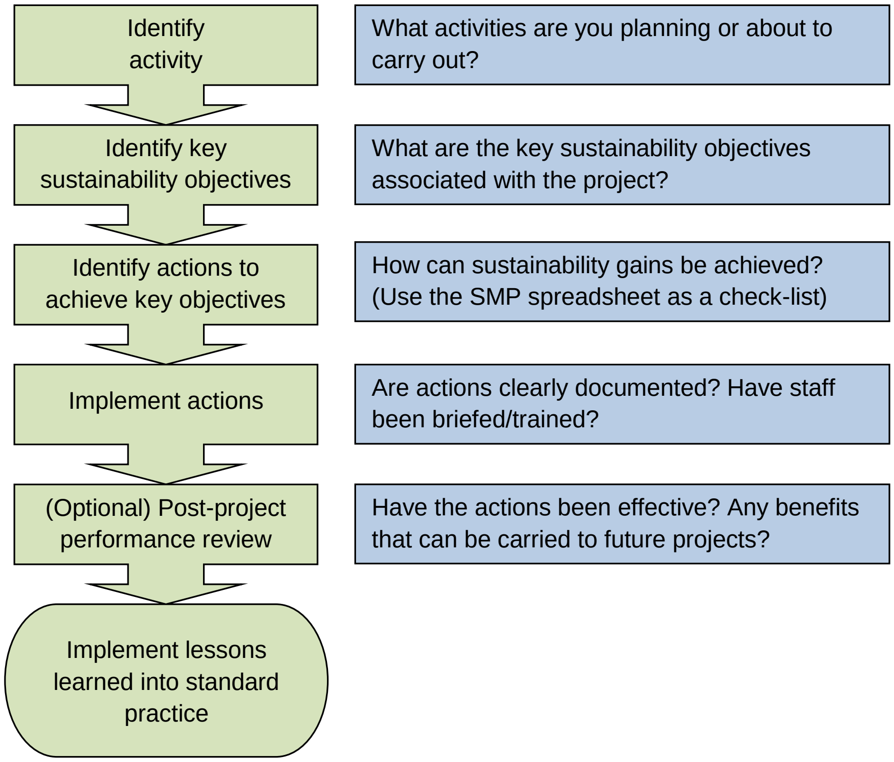

Figure 10: Making use of SuRF-UK Sustainable Management Practices

5.1 GUIDANCE ON FRAMING A SUSTAINABILITY ASSESSMENT

SuRF-UK does not advocate prescriptive tools to carry out quantitative or semi-quantitative sustainability assessment but to assist industry with a tiered appraisal, they provide broad rules that can be applied to carry out a sustainability assessment. These broad procedural steps are illustrated in **Figure 11**, to support consistency across all methodologies in the assessment, design, implementation and reporting of sustainable remediation schemes and so establish a reproducible, transparent and robust approach. The application of these principles and procedural stages is specific to each site / project and SuRF-UK has called this implementation process the 'framing' of the sustainability assessment (CL:AIRE, 2010).

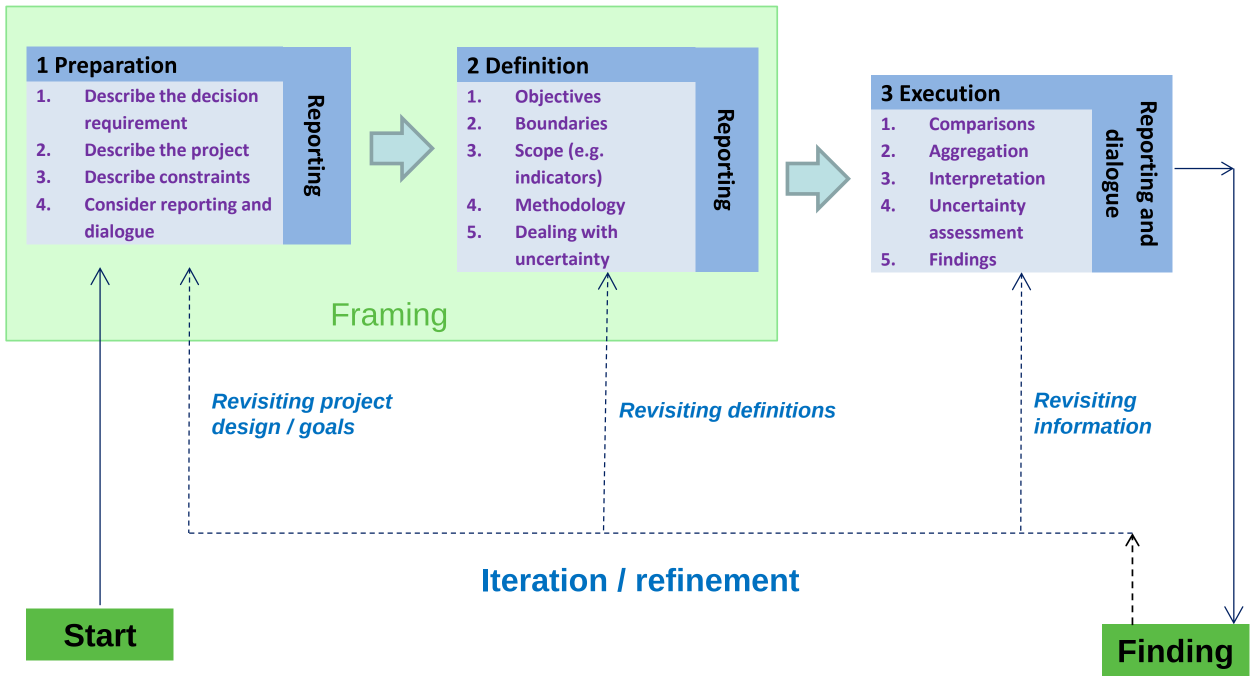

Figure 11: SuRF-UK approach to sustainability assessment (CL:AIRE, 2014a)

Appropriate framing should underpin all sustainability assessments, even if they are only qualitative in nature. This approach is also broadly consistent with the recently published ISO standard (ISO, 2016). SuRF-UK identified that very few published methodologies are available to support qualitative sustainability assessment, so in 2014 they published tools and guidance to support these elements which consist of guidance on framing a Sustainability Assessment (known as the “Briefcase”). This details how to frame a sustainability assessment and how to undertake a qualitative assessment. This guidance includes an interactive slide set (in Adobe PDF format) supported by a template for a ‘log-book’ to record decisions (in Microsoft docx format), and subsequently a spreadsheet to record assessments (in Microsoft xlsx format). These are all freely downloadable from www.claire.co.uk/surfuk and are summarised in CL:AIRE (2014a).

The framing process is needed for all tiers of a sustainability assessment process whether qualitative, semi-quantitative or quantitative. Framing includes two groups of activities each with a number of broad steps: the preparation for sustainability assessment followed by the definition of the sustainability assessment approach.

- There are four broad steps in preparation for a sustainability assessment:
  (1) describing the decision requirement,

(2) describing the project,
(3) describing opportunities and constraints and
(4) considering reporting and dialogue.

These preparation activities provide the broad frame in which the sustainability assessment must be defined.

- The process of definition considers five issues:
  (1) objectives,
  (2) assessment boundaries,
  (3) scope – sustainable remediation indicators,
  (4) sustainability assessment methodology, and
  (5) dealing with uncertainty.

The framing guidance is based on hyperlinked slides that take the user backwards and forwards between slides at different levels of detail according to their need. The 'logbook' is intended to assist note-taking by sustainability assessment teams (if required). The aim is to help project managers and sustainability assessors to frame their approach for a sustainability assessment, in several contexts:

- Use the framing slides as an interactive learning aid
- Use the framing slides as a step by step process of aide memoire to develop the sustainability assessment approach
- Use the framing slides to support discussions at meetings
- Use the logbook as a proforma for recording assumptions and findings.

The current international interest in 'sustainable remediation' has resulted in a rapid consensus on descriptions and definitions which SuRF-UK has been at the forefront of with the main principles having been reproduced into the newly published ISO standard (Bardos et al., 2016a).

5.2 GUIDANCE ON QUALITATIVE SUSTAINABILITY ASSESSMENT

Like the framing guidance, the SuRF-UK "guidance on qualitative assessment" comprises an interactive slide set (in Adobe PDF format) supported by a template for a 'log-book' to record decisions (in Microsoft docx format). A spreadsheet tool which systematically guides users through the key stages of preparation, definition and execution of a qualitative Tier 1 assessment, and encourages transparent documentation of decisions. These are freely downloadable from www.claire.co.uk/surfuk and summarised in CL:AIRE (2014a).

While Tier 1 is the simplest tier, it still requires that sufficient framing and planning for the assessment has been carried out in advance. Furthermore, while the assessment is qualitative, readily available quantitative information can and should be exploited. The output of the assessment is comprised of simple tables using qualitative categories, such as 'good' or 'neutral' or 'better', or simple rankings (see **Figure 12**). If these provide suitably clear differentiation between the options being compared, then more detailed assessment at Tier 2 and 3 may not be needed. In addition a spreadsheet tool has also been developed to assist sustainability assessment work being undertaken on a commercial basis with multiple stakeholders. This is freely downloadable from www.claire.co.uk/surfuk.

	Option 1	Option 2
Environment	Better	Worse
Society	Equal	Equal
Economics	Worse	Better

Example using sustainability elements as criteria → options summarised across one table

Environment	Option 1	Option 2
Emissions to Air	Trivial	Trivial
Soil and ground conditions	Significant impacts	Trivial impacts
Groundwater & surface water	Trivial impacts	Significant impacts
Ecology	None	None
Natural resources & waste	Significant	Trivial

Example using headline categories as criteria → at least three tables will be needed

SOC 1 Human Health & Safety	Option 1	Option 2
Long term risk management performance	Meets targets	Exceeds targets
Short term risks from accidents	Does not meet targets	Meets targets
Health impacts of remediation process emissions	Exceeds targets	Meets targets

Example using individual indicators as criteria → multiple tables will be needed

Figure 12: Illustration of how the selection of level of detail for criteria across the SuRF-UK indicator set affect the comparison table outputs

Sustainability assessment is site specific and subjective. It depends on the inclusion of a wide range of factors across different stakeholder perspectives and therefore by taking a tiered approach to sustainability assessment it offers important advantages, starting from a qualitative assessment and moving through to semi-quantitative and quantitative assessments on an 'as required basis' only. These benefits are

1. The level of effort in decision making is proportionate;
2. A tiered approach supports a more inclusive and transparent approach;
3. The relative strengths and weaknesses of the different tiers are combined in a way that allows both a holistic assessment, and if necessary more detailed assessments can be carried out and
4. A tiered approach provides a clear rationale for detailed assessments to be specifically focussed on considerations of high importance.
5. Being a contributor to sustainable development.

Bardos et al., (2016b) suggest that qualitative assessment of sustainability can be made more explicit, and possible duplications in effects avoided by using a conceptual site model of sustainability. This idea is based on the use of "sustainability linkages" and so is a little similar to the use of "contaminant linkages" in the development of conceptual site models for risk assessment/management purposes. This approach fully fits into the SuRF-UK guidance although it is not a part of it. The detailed "Annex 1" indicator guidance from SuRF-UK (CL:AIRE, 2011) can be used as a convenient checklist to identify potential sustainability linkages. The sustainability linkage consists of three components:

- A factor causing a pressure or a change that can affect sustainability
- A receptor that might be affected (positively or negatively) by that pressure or change
- A mechanism that links the two

Work to develop the possibility of using conceptual site models for sustainability has been supported both by this project and shared by the SPF Colombia project mentioned previously, given the large investment in time required. A lot of the development work was carried out in the context of a specific brownfields rehabilitation project carried out by the Land Trust (the

Port Sunlight Riverside Park – PSRP – see **Section 5.5**) and was undertaken at the University of Brighton by a Chinese secondee student from the Chinese Academy of Sciences. The valuable in kind contributions of the Land Trust, the Chinese Academy of Sciences and the University of Brighton are gratefully acknowledged by this report.

The SuRF-UK "Annex 1" guidance provides a useful check list to identify which possible individual sustainability effects might lead to valid linkages. In **Figure 13** the "air category" from **Table 8** has been expanded out to list the various specific effects listed in the SuRF-UK "Annex 1" guidance. For each effect the first consideration is whether it is relevant (i.e. the substantive existence of a pressure or change). At the end of this step the possible linkages remain for assessment, and those not considered relevant are discarded with a rationale for why relevance was not considered substantive. This process is repeated for all of the SuRF-UK headline categories listed in Table 8. Mechanisms and receptors can then be added for the linkages remaining (see **Figure 14**). No mechanism or no receptor = no linkage.

SuRF ref.	Assessment Criteria	Individual possible linkages	Relevance (+ / -)	Evidence 1
	Environmental			
ENV 1	Emissions to air	A. Climate change - greenhouse gases (e.g. CO_2, CH_4, N_2O, etc.)	+	
		B. Acid rain - emissions of NO_X, SO_X	-	Not generated in sufficient amount to have a major acid rain impact, but could have a local air quality impact
		C. Ground Air quality - Particulates (especially PM5 and PM10), ground level ozone etc.	-	Locally effects only, not a major impact on atmosphere
		D. Ozone depleting substances (e.g. O3, VOCs, etc.)	-	Not generated in sufficient amount to have a major acid rain impact, but could have a local air quality impact

Figure 13: **Using the SuRF-UK Annex 1 guidance to check the relevance of potential sustainability linkages**

SuRF ref.	Assessment Criteria	Individual possible linkages	Pressure / Change	Mechanism	Receptor
	Environmental				
ENV 1	Emissions to air	A. Climate change - greenhouse gases (e.g. CO_2, CH_4, N_2O, etc.)	Greenhouse gases	Vehicle and machine emissions	Atmosphere
			Greenhouse gases	Degradation of capping	Atmosphere
			Greenhouse gases	Carbon sequestration	Atmosphere
		B. Acid rain - emissions of NO_X, SO_X			
		C. Ground Air quality - Particulates (especially PM5 and PM10), ground level ozone etc.			
		D. Ozone depleting substances (e.g. O3, VOCs, etc.)			

Figure 14: Using the SuRF-UK Annex 1 guidance to specify potential sustainability linkages

The conceptual site model for sustainability is built by aggregating the individual linkages in a network diagram, which shows three columns of blocks for "pressures"; "mechanisms" and "receptors" and the interconnections between them as shown in **Figure 15**. It can be helpful to show each block in a different shade depending on whether the mechanism leads to a benefit (white) or a disbenefits (grey). The interconnections can also be coloured to indicate if the linkage is within the environmental, economic or social elements of sustainability, for example using the Annex 1 guidance colours (green =- environmental; pink =- social and yellow = economic).

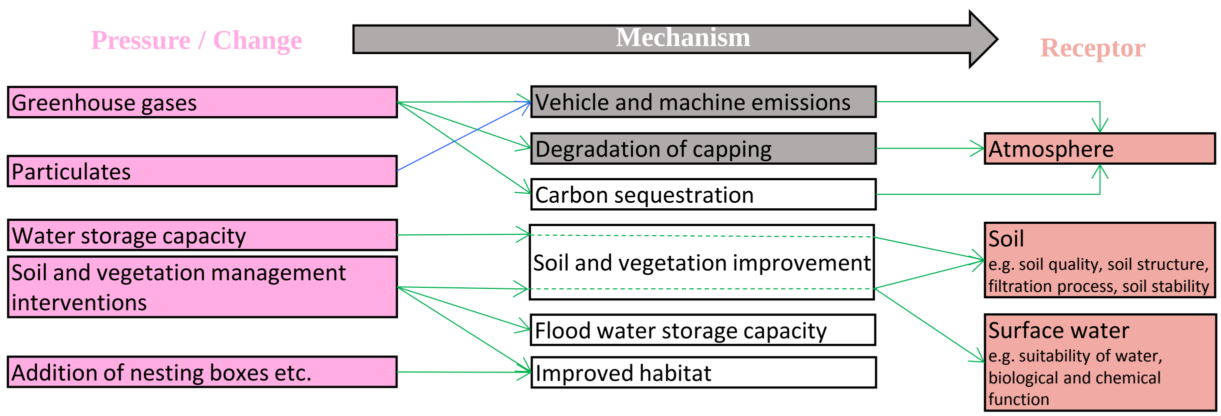

Figure 15: Conceptual model of sustainability, network diagram components

In many cases sustainability linkages have pressures, mechanisms or receptors in common. The process of building the network diagram should ensure that each pressure, mechanism or receptor is only mentioned once, although there may be multiple interconnectors between them. This discipline not only makes the diagram clearer, but it also ensures that duplicated linkages are removed. A case study of constricting such a conceptual site model of sustainability for the PSRP park improvement is provided in **Section 5.5**.

5.3 GUIDANCE ON QUANTITATIVE ASSESSMENT THROUGH VALUATION APPROACHES

Approaches to methodologies for semi-quantitative and quantitative tools remain diverse, however SuRF-UK recognises the need of practitioners to adapt and develop approaches specific to their own needs, but also identifies the need to provide some underpinning guidance ('framing') so that the overall structure of these approaches is consistent, and complies with a set of key principles. SuRF-UK has not developed specific methodologies for semi-quantitative or quantitative approaches to sustainability assessment because it considers that there are many scoring based systems (semi-quantitative) already in the market, and that suitable use of cost benefit analysis or assessment provides a suitable approach for quantitative assessments. However, this is a contentious opinion, and cost-benefit based assessments may not be acceptable to some key stakeholder interests, even although they may underpin private and public investment decisions (Bardos et al., 2016b).

The use of a conceptual site model for sustainability facilitates greater transparency in quantitative methods, in particular addressing concerns about less tangible qualities. Stakeholders can together agree which individual linkages belong to one of three groups as illustrated in **Figure 19** – **Section 5.5**. The three groups considered are as follows:

- **Direct financial returns** (related to particular services form the restored land, e.g. renewable energy supply, versus direct costs, e.g. deployment of a remediation system)
- **Wider effects that are economically tangible**, i.e. all stakeholders agree they the effect can be valued, for example uplift in surrounding property values.
- **Wider effects that are economically intangible**, i.e. not directly measurable in economic terms and where stakeholders may feel valuations are open to question.

One way forward that has been suggested to achieve the widest possible range of stakeholder approvals for looking at costs and benefits is to combine cost effectiveness and multi-criteria (scoring based approaches) for hard to value components (Rosen et al., 2015). The use of sustainability linkages provides a structure which facilitates this approach. However, there will be individual stakeholders with needs to provide a full valuation in currency terms.

Example situations might be where a project promoter wants to show investment benefits, e.g. every £1 invested generates £x of sustainability benefits; or where different interests have to make investment cases to support a project's funding. In this case the structuring of sustainability linkages can also be useful as it groups linkages in a way that the optimal valuation tools can be deployed (Li et al in preparation). This approach has been tested in the PSRP case study described in **Section 5.5**.

5.4 INTEGRATING QUALITATIVE AND QUANTITATIVE ASSESSMENTS WITH STAKEHOLDER ENGAGEMENT

Stakeholders' perceptions should be involved in the whole process of sustainability assessment. Typically the most practical approach is an iterative one, where a small (core) team develop the sustainability assessment, starting with the framing, and progressing to an initial qualitative ranking of available management options. A convenient way to store and process this information is to use a spreadsheet, such as the template available from www.claire.co.uk/surfuk. This template delivers a series of up to 15 rankings, one for each category listed in **Table 8**. These can then be combined to provide an overall ranking for each element of sustainability, and hence sustainability overall. Radar plots, such as those shown in **Section 5.5** can be a very transparent way to communicate outcomes.

This initial framing and qualitative assessment then serves as a starting point to make discussions with additional stakeholders more concrete. Of course these discussions may revisit the framing as well as the rankings, and this will have consequent effects on the assessment approach and outcome. Often the initial work will be undertaken by the site manager and their consultant, and then involve regulatory and planning agencies at a later iteration, and potentially wider interests beyond those in a third iteration. Clearly there other ways of ordering things. For example, for a community based project local action groups may be an important early consultee. In any case the advantage of having an initial assessment as a concrete platform for discussion is that most people have very limited time, hence it easier for them to respond to an initial model than start a thought process "from scratch". In many cases where only an outline view or comparison is needed a simple qualitative approach may be sufficient (Smith and Kerrison, 2013).

In more complex situations, or situations requiring a valuation then a conceptual model for sustainability will be helpful. The conceptual model for sustainability can be derived in parallel, in the same series of iterations. At initial design stage, a core group will input to a preliminary version of sustainability assessment framing. Under their authority, more stakeholders will be interviewed to identify wider services, key linkages and to refine the assessment framing, or it may be decided that no additional stakeholders are necessary for more information. Wider stakeholders' comments on linkage ranking, valuation methodologies and available information are also essential to reach a reliable and feasible valuation result. **Figure 16** summarises the sustainability assessment iterations that took place in the PSRP project. Initial discussions between three stakeholder groups as the "core team": the assessment team (Bardos and Li), Land Trust (the site leasers and developers) and Autism Together (the site managers). Many other stakeholders were possibilities (including the site owner, user groups, community groups, local authorities, action groups), but these would only be approached with Land Trust's permission. These initial discussions completed the information collection both for the framing and initial "SuRF-UK" qualitative assessment, as well as also reviewing the SuRF-UK "Annex 1" guidance in more detail as well, to provide input for the identification of individual linkages. Written comments on the initial framing and assessment were then collected from the meeting participants.

In parallel individual linkages were identified and compiled as a conceptual site model for sustainability by the assessment team. This was used to refine the rakings in the initial qualitative assessment which used their spreadsheet template. The overall scheme foresaw engagement with a wider range of stakeholders. However, it was felt that trying to engage them with the whole sustainability assessment would be too onerous. Therefore the approach planned was to approach additional stakeholders individually on the basis of specific questions about sustainability linkages where the core team felt their opinions would be influential, partly as a validation of the existing assessment and model. In the event the project ran out of time, and this wider engagement and validation was not undertaken.

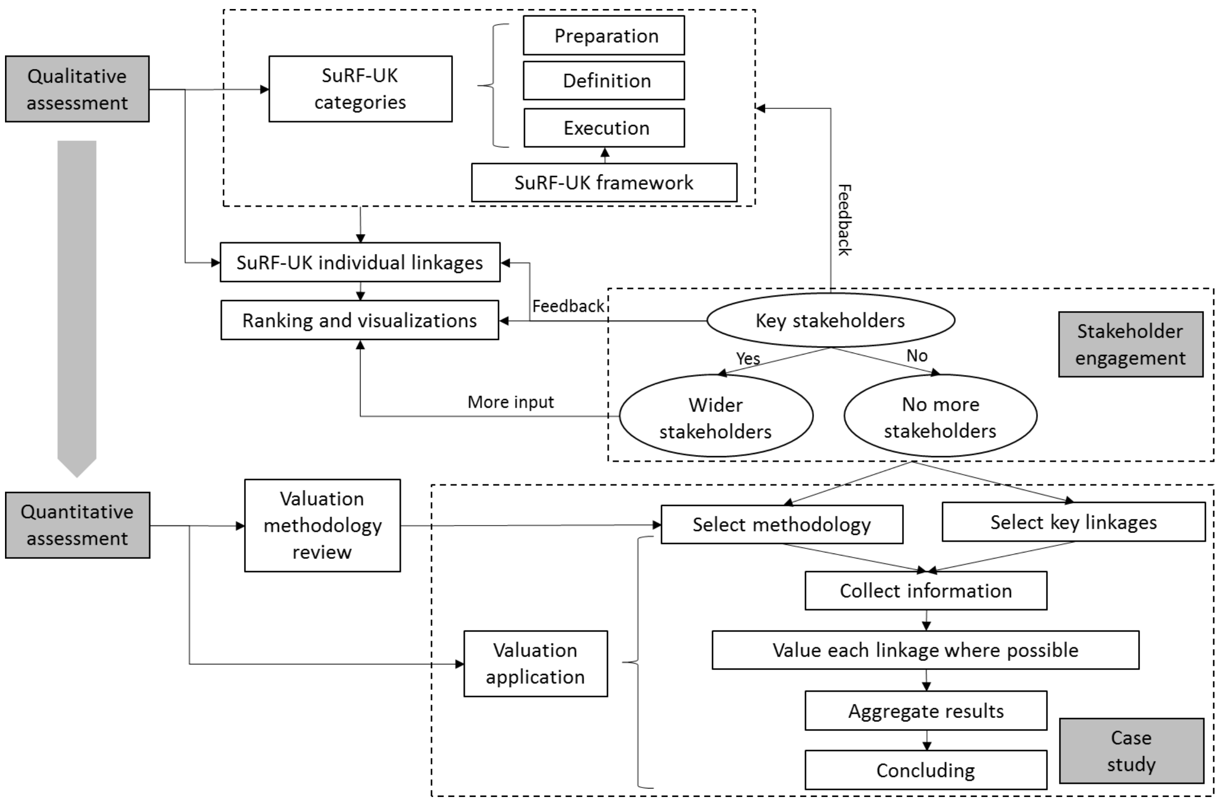

Figure 16: Example of technical roadmap for sustainability assessment[3]

A detailed review of valuation methodologies was undertaken as part of the PSRP project across a series of categories considered important in method selection, listed in **Table 9**. The aim was

[3] Taken from Li, Bardos *et al.* (2016) A Conceptual Site Model for the Sustainability of Brownfield Regeneration for Soft Reuse: A Case Study of Port Sunlight River Park (PSRP). Project Report to the Land Trust

to provide valuation approaches that are already well established, practical, reliable, comprehensive and relatively easy to undertake. A key aspect of practicality is the transparency of the method to a wide range of stakeholder types. In addition, these evaluation criteria were considered taking into account the different SuRF-UK headline categories (**Table 8**), as it seemed likely that what might be, for example, practical for one category might not be practical for another. In this way, as far as was possible, the review “mapped” optimal valuation methodologies to the 15 different SuRF-UK categories. The review was sent for peer review by a number of cost benefit assessment experts across Europe for comment, with familiarity with brownfields issues. Their comments provided a very useful level of refinement for the review. The rationale for doing this review was too complete an overall valuation in a robust way that was well based on evidence, was transparent in terms of the assumptions and assessments made, and had demonstrably world class approach to valuation. Land Trust were keen to know an economic valuation for sustainability outcomes, compared with investment inputs for the park. As shown this would have consisted of valuing the individual sustainability linkages in the conceptual site model separately, using the most appropriate valuation technique, based on the review undertaken, and then aggregating an overall value. Linkage valuations would also be tagged both against uncertainties, and also which of the three broad groups identified in **Figure 19** that they fell into. The PSRP study was retrospective, in that it looked back at a park development on a former landfill which had already taken place. While this was an excellent basis for method development and debate, unfortunately the passage of time meant that not all of the information needed to make the qualitative valuations could be provided, in reasonable time and cost. However, the methodology is complete and lends itself to forward looking options appraisal for comparing different approaches to a brownfield restoration project.

Table 9: Screening criteria used to assess valuation methods

Criterion	Rationale
Popularity	Widely used or discussed as promising methods in a range of current research
Practicability	Ease of use or communication due to relatively simple application, suggested by experienced expert
Reliability	As generally agreed by all, the better result the lower uncertainty
Comprehensiveness	Related to other criteria, which will lead to higher practicability and lower input, if a method can cover all benefits we want to value
Low-input	Financial or time cost, staff or other resources input required to implement the valuation are within acceptable limits.

5.5 PSRP CASE STUDY: PORT SUNLIGHT RIVER PARK (WIRRAL, UK)

Port Sunlight River Park (PSRP), a 28-hectare park on the Wirral, a peninsula in northwest England (UK). The PSRP was transformed from a former landfill at Bromborough Dock into a public green open space with £3.4m allocated for the site restoration, park creation and ongoing management. The Land Trust – which has extensive experience in taking over brownfield sites and converting them into public green spaces – has taken a 99-year surface lease of the site. Gillespies LLP and WSP Environmental Ltd (WSPE) were appointed to provide project management and design of landscape restoration works (WSPE, 2012a and 2012b). Biffa is responsible for the ongoing management and monitoring of the capping, landfill gas and leachate treatment plants adjacent to the site.

The park, which opened in 2014, provides visitors with a scenic waterfront and a variety of walks whilst a section of wetland to the north of the site, along with the adjacent River Mersey mud flats, is already an important site for large populations of water birds and is a site of special protection (**Figure 17**). Since opening, the park has been managed on a day-to-day basis by Autism Together, a specialist charity working with people with autism. Not only has the park provided its service users with a safe haven to improve their health and wellbeing through daily maintenance tasks, it has become well known as an autism friendly place to visit and as such, is having a positive impact on many social groups.

Figure 17: Views and joggers at PSRP (From http://thelandtrust.org.uk)

The overall goals of the project were (the Land Trust, 2015):

a. To provide a community resource for health, leisure and educational purposes;
b. To sustainability manage and enhance the Park's nature conservation value;
c. To reconnect local residents to the River Mersey;
d. To make the site safe and improve public access.

SUSTAINABILITY ASSESSMENT AND EVALUATION

To achieve the project goals, four primary project services underpinned the overall value of the PSRP project as follows:

- **Risk management**: wetland area reduces flooding risks and facilitates water quality management. Environmental control measures, health and safety measures required by legislation, guidance and best practice were implemented to minimize and mitigate the construction impacts on the site and the surrounding area during the site construction phrase.
- **Community benefit**: opportunities to encourage people to meet with others and participate in activities that are especially beneficial for human health and wellbeing.
- **Green infrastructure**: provide accessible high-quality green open space for amenity, exercise, leisure and recreation.
- **Biodiversity protection**: The river park site is bordered to the east and north by a SSI/SPA/Ramsar site (the Mersey Estuary and wetland pool) which is an important habitat for diverse and rare birds.

Based on the SuRF-UK framework, sustainability assessment for PSRP was carried out in three phases as illustrated in **Figure 18**.

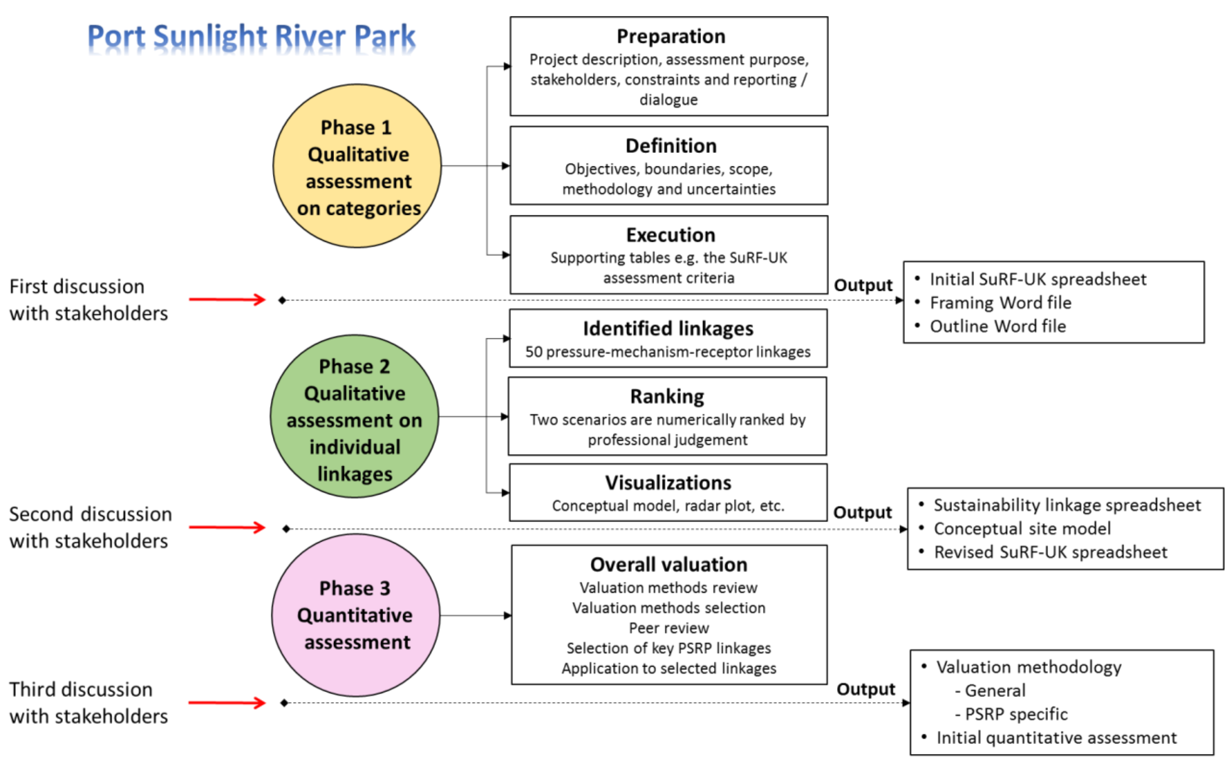

Figure 18: Flow diagram of sustainability assessment for PSRP

(1) **Phase 1 – qualitative assessment on categories**: a preliminary vision of sustainability assessment framing on each step along with essential components included in each step was agreed through face-to-face meeting between core stakeholders. Discussions were recorded to develop related files.

(2) **Phase 2 – qualitative assessment on individual linkages**: more discussions were needed to identify each linkage with pressure, mechanism and receptor under overarching categories. Then, each linkage in two scenarios were compared, ranked and summed to a total score, which showed the relative better or worse performance of different scenarios. To present a more explicit and intelligible assessment result, the quantified scores were visualized in the forms of a conceptual model and radar plot that can be easily understood by interested audiences. More outputs were available such as a linkage spreadsheet, conceptual site model and framing spreadsheet.

(3) **Phase 3 – quantitative assessment**: valuation methodologies for monetizing environmental, social and economic benefits were generally reviewed and screened responding to comments of economists and brownfield experts. The comprehensive benefits in monetary items delivered by the PSRP project can be finally aggregated by applying selected valuation techniques to specific single linkages. Final reports on valuation methodology and sustainability assessment were expected.

Phase 1 - Qualitative assessment on categories

Based on the SuRF-UK's guidance and interview with the key stakeholders (the Land Trust and Autism Together), three key processes including preparation, definition and execution enabled sustainability assessment to be carried out systematically.

- **Preparation** refers to description on what decision required for sustainability assessment, what's the project exactly about, the opportunities and constraints that may affect project implementation, who will be involved in the project and how to report and communicate the finding of assessment.
- **Definition** summarise the preparatory work carried out at the first stage and describes the objectives, boundaries, scope, methodology and uncertainties of sustainability assessment.
- **Execution:** When the preparation and definition stages have been successfully completed and agreed the execution stage can be undertaken. This was undertaken through the production and population of a number of spreadsheets where the assigned assessment criteria identified were compared against each of the remedial options. The specific information for

each option provided the basis for ranking from relatively poor to relatively good, and then optimal option can be evidenced based on the ranking result. The inherent uncertainties in making the assessment and the degree of uncertainty associated with assessment against each criterion were also be recorded for each option. The execution spreadsheet on category assessment was further updated using a detailed assessment results based on individual linkages.

Phase 2 - Qualitative assessment on individual linkages

Based on the Land Trust documents and discussions among stakeholders (from University of Brighton, the Land Trust and Autism Together) by web meeting, email and face to face interview, 50 sustainability linkages under 15 overarching categories (**Table 10**) were identified and presented as a "pressure-mechanism-receptor linkage" (**Figure 19**). Radar plots comparing the creation of the PSRP against a baseline of continuing ongoing management of the site as a landfill are shown in **Figures 20, 21 and 22**. In each Figure, the lower number is the better option, i.e. the most favourable in sustainability terms. The radar plots are based on the detailed average category rankings following an assessment of rankings across individual sustainability linkages.

Table 10: Overview of the 15 overarching categories considered

	Overarching categories	
Environment	Emissions to air	1
	Soil and ground conditions	2
	Groundwater & Surface Water	3
	Ecology	4
	Natural resources and waste	5
Economy	Direct economic costs and benefits	6
	Indirect economic costs and benefits	7
	Employment and employment capital	8
	Induced economic costs and benefits	9
	Project lifespan and flexibility	10
Society	Human health and safety	11
	Ethics and equality	12
	Neighborhoods and locality	13
	Communities and community involvement	14
	Uncertainty and evidence	15

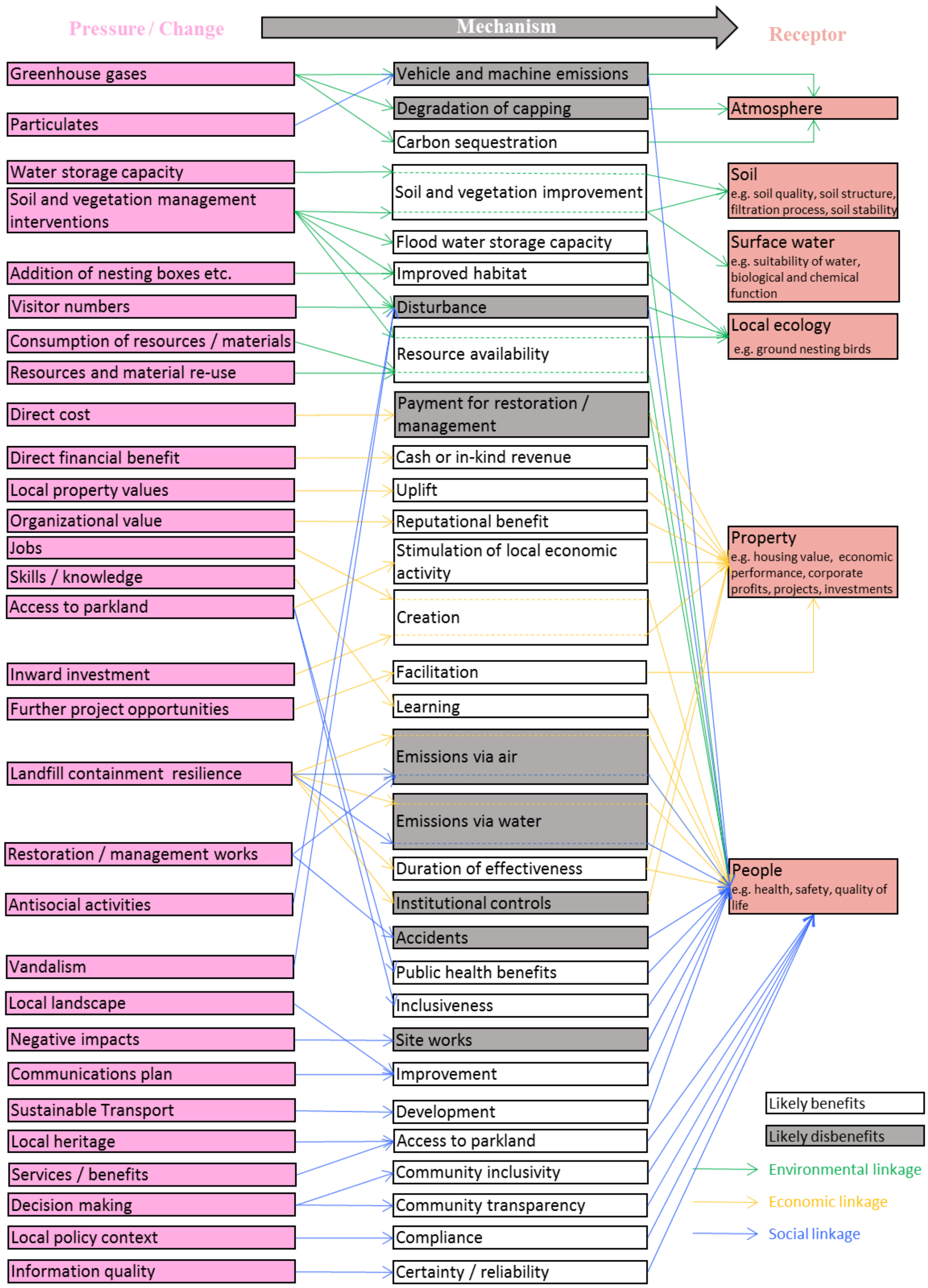

Figure 19: Pressure-mechanism-receptor linkage for sustainability assessment

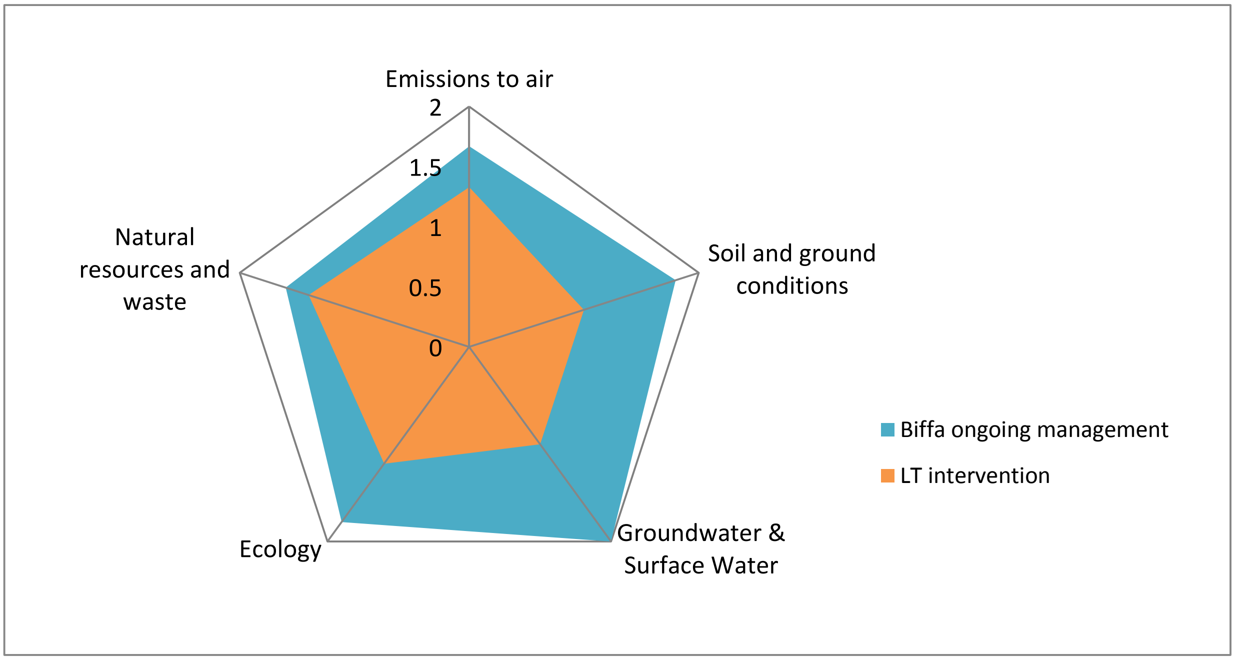

Figure 20: Radar Plot comparing the environmental rankings for PSRP against baseline, showing clearly superior performance across all categories

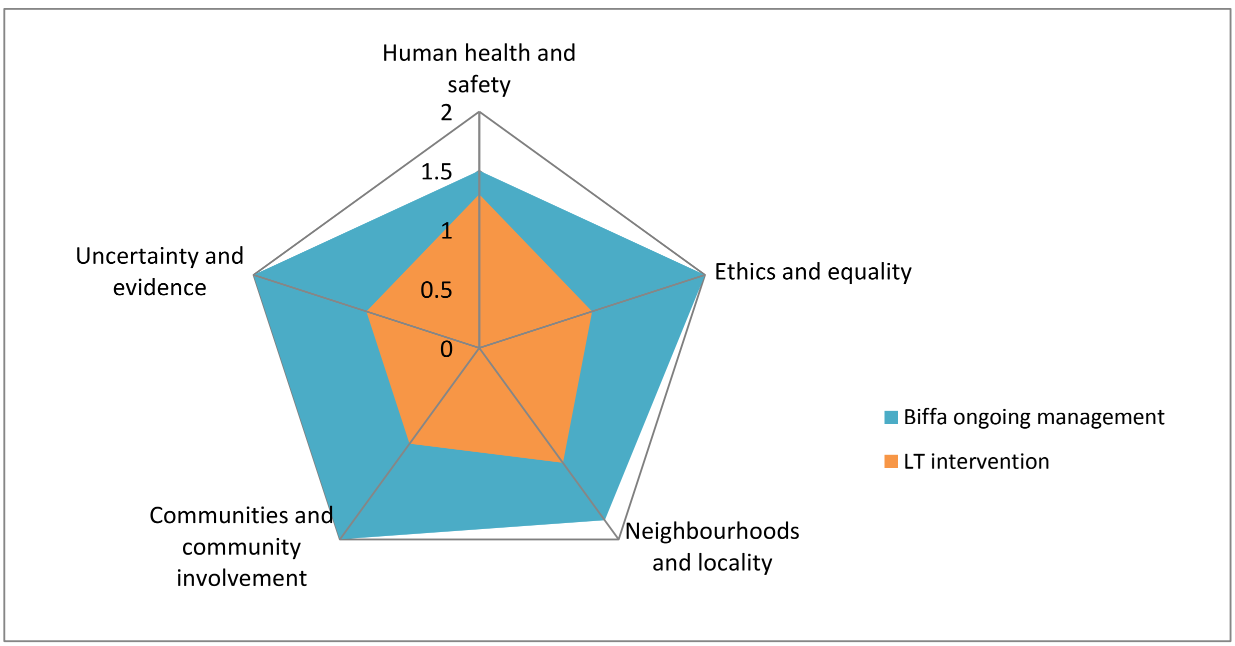

Figure 21: Radar Plot comparing the societal rankings for PSRP against baseline, showing clearly superior performance across all categories

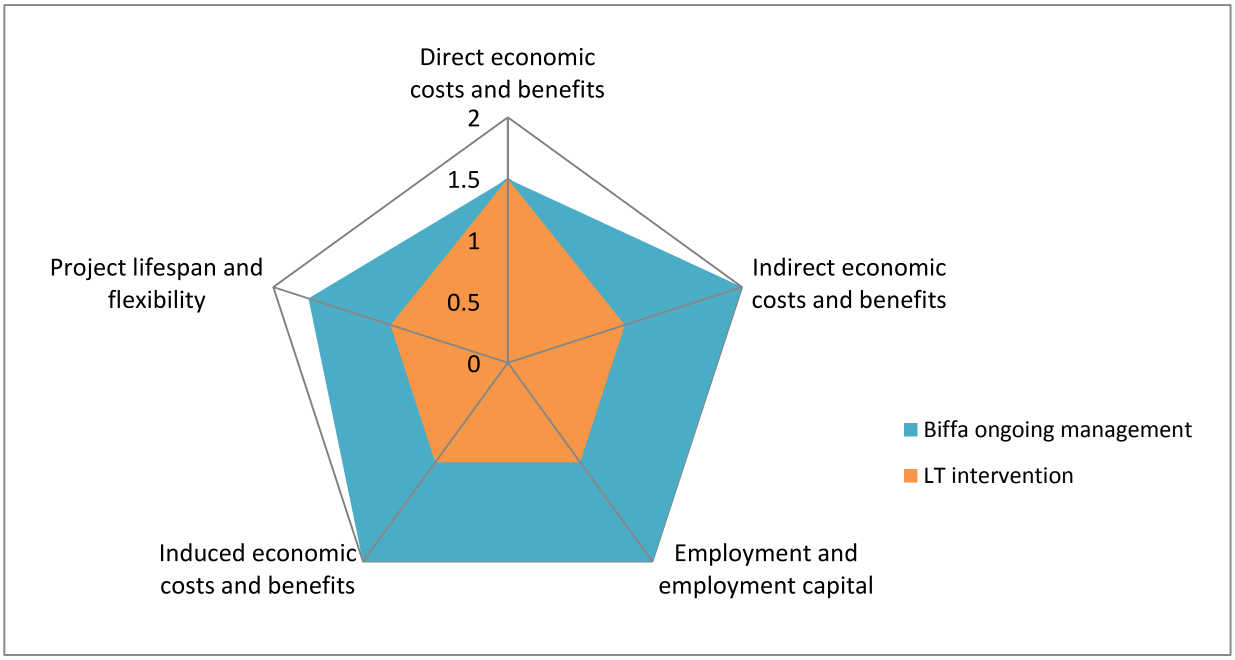

Figure 22: Radar Plot comparing the economic rankings for PSRP against baseline, showing clearly superior performance across four out of five categories

Phase 3 - Quantitative assessment on individual linkages

Five valuation techniques and four appraisal techniques were reviewed and assessed for the quantitative assessment of the 15 identified overarching categories as summarised in **Table 11.**

Table 11: Overview of the valuation and appraisal techniques considered

Valuation techniques				
Methodology	**Application**	**Variable / data**	**Advantages**	**Limits**
Contingent valuation method (CV) Ex ante	Estimate recreational benefits by eliciting respondents' WTP or WTA a good or services in hypothetical market	Describing a good or services (e.g. how a good or services will be provided, the method and frequency of payment), socio-demographic characteristics	Widely used, both use and non-use values of almost any ecosystem service, possible to specify environmental changes even if not yet occurred	Inaccurate and biased responses to hypothetical scenarios, high cost and time consuming
Choice experiment method (CE) Ex ante	Elicit nonmarket value of goods or services by indirectly estimating WTP based on respondents' trade	Relevant attributes (e.g. monetary cost, services, facilities, travel time), attribute level (basic, medium, higher), socio-demographic characteristics	Both use and non-use values, particularly suitable for policy decision making, friendly for respondents with qualitative ranking or	A developing theory and limited use, cognitive difficulty, great uncertainty, complicated

	off choice in hypothetical market		estimating relative values	application and technical experimental design
Hedonic pricing method (HP) Ex post	Observe direct economic effect on surrounding property values	House characteristics (square footage, year built, lot size, bedrooms, etc.), amenity characteristics (size, facilities, accessibility, etc.), neighbourhood characteristics (Euclidean distance, service facilities, traffic condition, etc.), site characteristics (contamination, current use, environmental assessment, etc.)	Widely used, relatively straightforward and uncontroversial on actual market prices, readily available data on real estate transactions and characteristics	Only for use value, difficult to obtain sufficient variables of interest, impossible to capture benefits delivered to people living far from the site
Travel cost method (TC) **Ex post**	Measure recreational benefits by investigating respondents' WTP or WTA for visiting in actual choice	Number of visits, travel costs, socio-demographic characteristics	Relatively straightforward and uncontroversial on actual market prices, relatively cheap	Only for use value, practical and theoretical problems e.g. choosing dependent variables, multi-purpose or multi-destination journey, and the cost of accessing
Benefit transfer method (BT) Ex ante or ex post	Transfer goods or services values from previously original studies to interest sites in similar contexts	Types of services, data requirement depending on source evidence	Cost and time saving	Inevitable transfer errors, limited original studies, low validity and reliability, disagreement on source values across stakeholders
Appraisal techniques				
Methodology	**Application**	**Variable / data**	**Advantages**	**Limits**
Cost benefit analysis (CBA) Ex ante or ex post	Value in monetary terms the net present value of internal and external economic consequences.	Cost (labour, money, resources and other input), benefit (environmental, social and economic criteria in market price)	Widely used, easily understood, high certainty in valuing market good or services	Constrained by the available valuation techniques, for instance, some environmental items inadequately included or

				uncertainly monetized
Social Return on Investment (SROI) **Ex post**	Broadly value environmental, social and economic benefits from the perspective of stakeholders who actually experienced the changes	Money, volunteering time, the number in each stakeholder group who actually experience the outcome, financial proxy on outcomes, reductions in values (e.g. deadweight, attribution, displacement)	Internationally recognized and widely used, easy to use and understand, more holistic	Ratio results cannot be compared, less rigorous and trustworthy on financial proxy, difficult to identify impacts or outcomes, high cost and time consuming
Natural Capital Account (NCA) **Ex ante or ex post**	Assess the values of ecosystem services provided by environment assets and the expenditure required to maintain these benefits	Types of environmental assets, provision of ecosystem services, the cost, discount rate the specific data required by valuation methodology	Detailed and comprehensive statistics for better decision making, widely used	Constrained by the available valuation techniques, overall, complicated and technical application, multi-uncertainties, high cost and time consuming
Payments for Ecosystem Services (PES) **Ex ante**	Pay for ecosystem services by a voluntary transaction between buyer and provider	Types of ecosystem services, buyer / provider / intermediary, data requirement depending on valuation approaches	Well developed, widely used	Constrained by the available valuation techniques, overall, highly technical, time consuming and complex implementation

- **Mapping valuation techniques to SuRF-UK categories**

To map the valuation techniques to SuRF-UK categories, the services / benefits were firstly grouped into provisioning service, regulating service, supporting service and cultural service, which were outlined in solid and filled with orange, green, yellow and blue, respectively. Then the broader services / benefits were mapped to SuRF-UK categories (outlined in dash) in terms of five environmental, five social and five economic aspects (**Figure 23**), which has the benefit of providing a more systematic and explicit assessment of services / benefits. At the third stage, based on the application of different valuation methodologies (outlined in long-dash-dot-dot), valuation techniques and appraisal techniques were mapped to specific categories for valuation of different services including ecosystem services, cultural services, any services and property values. Meanwhile, the methodologies were screened based on the screening criteria in Table 6 and general summation in Table 7, and were symbolized with ① (high popularity), ② (high practicability), ③ (high reliability), ④ (high comprehensiveness) and ⑤ (low input), which helps to make decisions on which set of methodologies to value which benefit.

Judged by the services being quantified and the five criteria described previously, the mapping outcomes in **Figure 23** showed that, a combination of Cost-Benefit-Analysis (CBA) supported by Travel cost method (TC) or Benefit transfer method (BT) is suggested as a primary consideration for valuation for overall wider benefits. Choice experiment method (CE), which is only characterized with high comprehensiveness for both use and non-use values, is relatively ineffective for benefit evaluation due to the cognitive difficulty, great uncertainty, complicated application and technical experimental design. Social Return on Investment (SROI) or CBA, with relatively high popularity and comprehensiveness, can systematically monetize benefits delivered by brownfield regeneration for soft reuse in all range of environment, society and economy. However, SROI is inferior to CBA due to lower robust of financial proxy.

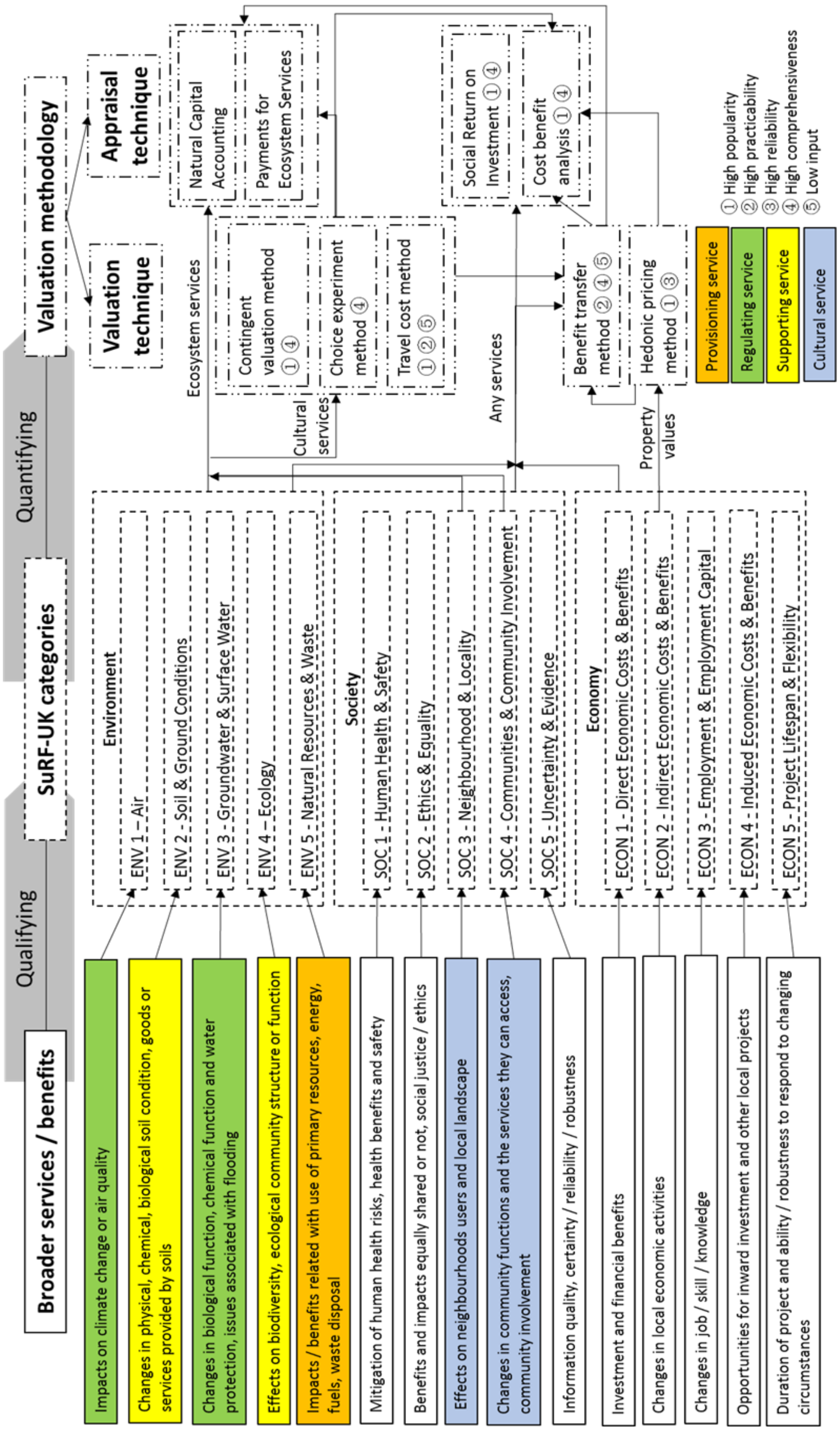

Figure 23: Mapping valuation methodologies to SuRF-UK categories

- **Applying quantitative techniques to the PSRP case study**

In order to map the individual sustainability linkages to ease the valuation, all the linkages were firstly grouped into direct financial, economically tangible and economically intangible relevance (**Table 12**). Then, based on individual linkages identified in **Figure 19**, the review of the valuation methodologies in **Table 11** and mapping outcome in **Figure 23**, the valuation methodologies on the basis of best fit were assigned for 23 linkages, alongside with qualifying method for 27 linkages that are economically intangible.

- **PSRP case study limitations**

Though the sustainability linkages are described based on detailed information obtained from documents and stakeholder interviews (primarily the Land Trust and Autism Together), three main limitations exist for methodology application to the PSRP case study:

1. Some economically intangible linkages mapped in the conceptual site model are difficult to value and are replaced by qualifying methods, which may underestimate the overall valuation. For instance, 'Soil and vegetation management interventions- Disturbance– Local ecology'.
2. For linkages with the same receptor, there is not enough information to prove the benefit contributed by each linkage, which may result in dual valuation and overestimation. For instance, soil and vegetation management interventions and addition of nesting boxes can both affect local ecology by improving habitat.
3. Regards valuing the PSRP initiative in an overall way, this is a large undertaking, even if all the evidence needed were to be available. Additionally, some of the valuation would be highly conjectural because, of course, the "no intervention" baseline is so speculative. This would limit its usefulness.

Table 12: Qualifying and quantifying services and benefit

<table>
<tr><th rowspan="2">SuRF ref.</th><th rowspan="2">Assessment Category</th><th rowspan="2">Relevance</th><th rowspan="2">Individual possible linkages</th><th rowspan="2">Methodology</th><th rowspan="2">Quantitative metric</th><th colspan="2">Information</th><th rowspan="2">Feasibility of effort needed</th></tr>
<tr><th>We need</th><th>We have</th></tr>
<tr><td rowspan="2">ENV 1</td><td rowspan="2">Emissions to air</td><td rowspan="2">Economically intangible</td><td rowspan="2">A. Climate change - greenhouse gases</td><td rowspan="4">Replacement cost method (RC)</td><td>• CO_2 storage capacity of different vegetation
• Carbon value</td><td>Data, maybe available from website, literature, etc.</td><td></td><td rowspan="2">Low</td></tr>
<tr><td>• Vegetation types and area</td><td>Site investigation from starting point: estimate of no intervention</td><td></td></tr>
<tr><td rowspan="3">ENV 2</td><td rowspan="3">Soil and ground conditions</td><td rowspan="2">Economically intangible</td><td rowspan="2">D. Changes in erosion and soil stability (incl. drainage)</td><td>• The cost of soil erosion preservation</td><td>Data, maybe available from website, literature, etc.</td><td></td><td rowspan="2">Low</td></tr>
<tr><td>• The annual soil loss, depends on rainfall erosivity, soil erodibility, topographic factors and vegetation management factors</td><td>Site investigation from starting point: estimate of no intervention</td><td></td></tr>
<tr><td>Economically intangible</td><td>A/B/C/E</td><td>Multi-criteria analysis (MCA)</td><td>• The level of changes in soil quality, structure, water filtration and geotechnical properties</td><td>Collect opinions from stakeholders in form of scoring</td><td></td><td>Low</td></tr>
<tr><td>ENV 3</td><td>Groundwater & Surface Water</td><td>Economically intangible</td><td>A/C/E/G (water conservation)</td><td>Shadow pricing (SP)</td><td>• Average precipitation
• Average</td><td>Data, maybe available from</td><td></td><td>Low</td></tr>
</table>

SuRF ref.	Assessment Category	Relevance	Individual possible linkages	Methodology	Quantitative metric	Information: We need	Information: We have	Feasibility of effort needed
					evapotranspiration • Cost to build an artificial lake that can be used for water reservation, e.g. reservoir	website, literature, etc.		
					• Vegetation area	Site investigation from starting point: estimate of no intervention		
ENV 4	Ecology	Economically intangible	A. Effects on flora, fauna and food chains	Travel cost method (TC)	• Socio-demographical (gender, age, income, education) • Number of visits and total population of each zone • Travel cost (transport, accommodation, ticket, souvenir, food, travel time) • Willingness-to-pay for biodiversity conservation	Response of visitors on questions in "metric" column		**Relatively high**
		Economically intangible	B/C/D	Multi-criteria analysis (MCA)	• The level of changes in ecological community structure, disturbance of	Collect opinions from stakeholders in form of scoring		**Low**

SuRF ref.	Assessment Category	Relevance	Individual possible linkages	Methodology	Quantitative metric	Information		Feasibility of effort needed
						We need	We have	
					construction on ecology and equipment affecting or protecting fauna			
ENV 5	Natural resources and waste	Economically tangible	A. Impacts/benefits for land and waste resources	Multi-criteria analysis (MCA)	• The level of the benefits reusing the land to create a park for local community and wild life	Collect opinions from stakeholders in form of scoring		**Relatively high**
		Economically tangible	B. Use of primary resources and substitution of primary resources within the project or external to it	Cost benefit analysis (CBA)	• The types , amount and market price of primary resources consumed during park generation	Report on PSRP restoration work, may be available from WSP/Gillespie		**Low**
		Economically tangible	C. Use of energy/fuels taking into account their type/origin and the possibility of generating renewable energy by the project		• The types, amount and market price of energy or fuels consumed during park generation	Report on PSRP restoration work, may be available from WSP/Gillespie		**Low**
		Economically tangible	D. Impacts / benefits for handling of materials on-site, off-site and waste		• The types and amount of recycled materials during park generation • The cost of wastes disposal	Report on PSRP restoration work, may be available from WSP/Gillespie		**Low**

SuRF ref.	Assessment Category	Relevance	Individual possible linkages	Methodology	Quantitative metric	Information		Feasibility of effort needed
						We need	We have	
			disposal resources					
ECON 1	Direct economic costs and benefits	Direct financial	A. Direct financial costs and benefits of remediation / management for organization	Cost benefit analysis (CBA)	• Payment for park generation and long term management		£3.4m from LT report	**Relatively high**
					• Direct financial benefit in cash or in-kind revenue	Data of financial benefits, may be available from LT report		
ECON 2	Indirect economic costs and benefits	Economically tangible	C. Changes in site/local land/property values	Hedonic pricing method (HP)	• Typical house type and transactions • Sphere of influence • Local market for property value • Other influences that could affect the property values in this area	Forestry Commission DLV work		**Low**
		Economically intangible	E/F	Multi-criteria analysis (MCA)	• The level of impacts on corporate reputation and an area's economic performance	Collect opinions from stakeholders in form of scoring		**Low**
ECON 3	Employment and employment capital	Economically tangible	A. Job creation	Social Return On Investment (SROI) / Financial proxies (FP)	• No of individuals getting a job, including volunteers and paid employment	Data, may be available from LT		**Relatively high**
		Economically intangible	C. Skill levels before and after		• No of individuals improving skills by taking part in park	Response of visitors, cost of courses to learn		**Relatively high**

SUSTAINABILITY ASSESSMENT AND EVALUATION

SuRF ref.	Assessment Category	Relevance	Individual possible linkages	Methodology	Quantitative metric	Information		Feasibility of effort needed
						We need	We have	
					maintenance works	horticultural or environment skills		
		Economically intangible	D. Opportunities for education and training		• No of individuals who learn about wildlife and natural	Cost of an outdoor educational experience	20.6%, from "PSRP social value survey data" spreadsheet	**Relatively high**
					• No of individuals learning new practical skills	Cost of courses to learn horticultural or environment skills	31.9% of response learning new skills but we don't know what skills they have learned	**Relatively high**
		Economically intangible	E. Innovation and new skills		• No of individuals learning new skills	Cost of courses to learn new skills, e.g. cycling		
ECON 4	Induced economic costs and benefits	Economically tangible	A. Creating opportunities for inward investment	Cost benefit analysis (CBA)	• New opportunities created by park for other charities like SUSTRANS, AT.	Net income created by park for each charity		**Low**
		Economically tangible	B. Use of funding schemes, ability to affect other projects in the area/by client to		• Additional projects facilitated	Economic benefits created by these additional projects		**Low**

SuRF ref.	Assessment Category	Relevance	Individual possible linkages	Methodology	Quantitative metric	Information		Feasibility of effort needed
						We need	We have	
			enhance economic value					
ECON 5	Project lifespan and flexibility	Economically intangible	A. Duration of the risk management benefit		• Cost of rehabilitation • Risk of failure of containment	Collect opinions from stakeholders		**Low**
		Economically intangible	C/E/F/G	Multi-criteria analysis (MCA)	• The level of robustness of solution to changing circumstances, climate change effects, altering economic circumstances, and ongoing institutional controls	Collect opinions from stakeholders in form of scoring		**Low**
SOC 1	Human health and safety	Economically intangible	A/B/C	Multi-criteria analysis (MCA)	• The level of risks of construction and park use on workers, visitors and neighbors	Collect opinions from stakeholders in form of scoring		**Low**
		Economically intangible	D. Human Health benefits	Financial Proxies (FP)	• No of individuals who report that the park helps them keep fit and healthy	Cost of GP consultation	SOC 1-D and SOC 3-B/C are already known but low reliability, because	**Medium to relatively high**
SOC 2	Ethics and equality	Economically intangible	A. Social justice and/or equality addressed		• No of autism sufferers who are engaged in PSRP activities	Cost of social and other care for autism sufferers		**Medium to relatively high**

SuRF ref.	Assessment Category	Relevance	Individual possible linkages	Methodology	Quantitative metric	Information		Feasibility of effort needed
						We need	We have	
SOC 3	Neighborhoods and locality	Economically intangible	B. Wider effects of changes in site usage by local communities		• No of individuals who report that the park helps to reduce crime and anti-social behaviors	Cost for an incident of anti-social behaviour	no evidence provided to support how proxies are related to levels of park use, which would never withstand detailed scrutiny	**Medium to relatively high**
		Economically intangible	C. Changes in the built environment, architectural conservation, conservation of archaeological resources		• Access cost for similar private leisure areas in this area	Response of visitors, willingness to pay to access the park		**Medium to relatively high**
		Economically intangible	A/D	Multi-criteria analysis (MCA)	• The level of local disbenefits (from traffic / parking etc.) and benefits (from development of Sustainable Transport)	Collect opinions from stakeholders in form of scoring		**Relatively high**
SOC 4	Communities and community involvement	Economically intangible	A. Changes in the way the community functions and the services they can access	Financial Proxies (FP)	• No of individuals who report that park helps bring the community together	Average spend on socializing	84% of response	**Relatively high**
		Economically intangible	B/C/D/E/F	Multi-criteria analysis (MCA)	• The level of the quality of communication	Collect opinions from stakeholders in form of scoring		**Relatively high**

SuRF ref.	Assessment Category	Relevance	Individual possible linkages	Methodology	Quantitative metric	Information		Feasibility of effort needed
						We need	We have	
					plan, effect of the project on local culture and vitality, involvement of community in decision making and compliance with local policy objectives			
SOC 5	Uncertainty and evidence	Economically intangible	A. Robustness of sustainability appraisal	Multi-criteria analysis (MCA)	• How uncertain the information is for the two scenarios	Collect opinions from stakeholders in form of scoring		**Relatively high**

6 Concluding remarks and recommendations

The rise and proliferation of sustainable remediation worldwide exemplifies the strength of innovation and collaboration to rethink the status quo and, in doing so, advance shared environmental and cultural goals. Thus this report is proposed to influence Chinese policies on 'sustainable remediation of contaminated land' and will set the groundwork to create commercial opportunities for the UK in that field that is growing in importance in China and where they are looking for international expertise.

The report was adapted from items from SURF UK (www.claire.co.uk/surfuk) and SURF International and draw on the SPF 15SU32 technical and scientific experts. The SuRF-UK framework provides a widely accepted basis for understanding the sustainability of remediation processes and selecting optimal approaches. Within this project in association with the Colombian project on "Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies", this report provides new guidance on the development of explicit site conceptual models of sustainability using specific sustainability linkages, and how these might be valued, for example as part of an investment appraisal comparing funding with notional economic valuations of wider sustainability benefits.

Methodologies to quantify these benefits are diverse in conception and implementation, and there are significant challenges in implementing them due to multiple factors such as among others non-market values for a range of services, cost and time restriction, unavailable data and conflicts among stakeholders. Integration of such diverse information to support decisions on sustainable remediation and sound prioritization of society's limited resources therefore requires a clear structure and reliable assessment tools. It also requires that stakeholders involved in brownfield remediation and redevelopment are willing to accept a holistic view on site remediation. A major challenge in making remediation sustainable is the transfer of knowledge between the stakeholders including problem holders, regulators, scientific, consultants, academics and the public. This transfer can be facilitated and shared by using methods such as the Brownfield Opportunity Matrix (BOM) that can be practically applied and readily used to gain experience and show real-world examples.

The BOM provides a simple screening tool that allows: (1) a structured and transparent decision making on the services and interventions desired; (2) identifying where there are strong synergies between the interventions and the services, and also the relatively infrequent occurrences of antagonism. Wherever a particular intervention delivers a service, this interaction creates an opportunity to add value. The matrix describes the kinds of value that each opportunity might generate; (3) a means for integrating quantitative and qualitative information into a comprehensive sustainability assessment; (4) integrating cost–benefit analysis of remedial actions, taking into account externalities such as effects on human health and provision of ecosystem services; (5) an overview of positive and negative effects of remediation alternatives and (6) a structure for displaying and investigating the impacts and sensitivity of different views and preferences among involved stakeholders. Thus, the matrix can be used to map the prospective range of opportunities that might be realised by a brownfield redevelopment project and the project's consequent sources of value.

The BOM tool has been implemented in Excel, which facilitates practical application and it can be downloaded on the CNUK website at: http://cnukcontaminatedland.com/cn/. However, as with any decision support tool, BOM produces results according to the chosen boundary conditions and the inputs used. Therefore users of the BOM tool should not use the BOM as a black box model and must familiarize themselves with the concepts and boundary conditions of the approach.

The report also provides useful context through a series of detailed case studies analysing the advantages, concerns and challenges and incentives surrounding sustainable remediation where renewable energy options and carbon management were considered. The case studies are used to illustrate how sustainable remediation can be integrated with urban planning and public realm design that supports the development of low input strategies for land management, sustainable remediation and community enterprise for brownfields and marginal land areas reuse.

Finally, the strong synergies between this project and the Colombian project on "Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies" have enabled a robust transnational approach to brownfield and marginal land reuse and creating opportunity for more concerted and collaborative developments in the future.

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