

# Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies.

**Output 2. Guidance and strategies for re-use of land by transferring state of the art knowledge and successful implementation from the UK, EU and North America, and adapting it to the local situation as circumstances dictate.**

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## Acknowledgements

This report is one of the outputs of the Colombia Prosperity Fund project on *"Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies"*

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## Executive Summary

Colombia has an enormous opportunity for the generation of renewable resources, such as energy from its land, for example from photovoltaic energy. Linking the safe re-use of mining brownfields (following application of low input "gentle" remediation techniques) with the generation of renewables presents a "virtuous" opportunity for land (re)use for several reasons.

- A variety of local energy market arrangements are possible: The approach is scalable--workable from community based projects to large projects with major mining companies.
- The income from renewables can help offset the cost of making the land safe, for example, from mobile mercury species.
- The use of this degraded land is a more sustainable approach to providing renewables than converting habitat or agricultural land over to renewables production.
- Colombia gets a lot of energy for free from the sun compared with many other countries in the developed world (e.g. the UK).
- There may also be opportunities for income from Carbon Offset.

This approach can also bring wider societal and economic benefits in Colombia. Income from renewables (and potentially also from carbon offset) can be recycled locally. Combining it with other land uses may also be very valuable, for example, with public parks or leisure. Well managed public parks are proven to deliver quantifiable health and wellbeing benefits to local communities as well as aiding social cohesion and economic uplift in the vicinity. These might be combined, for instance, as a "mosaic" with renewable energy production to improve overall project acceptability and viability; as well as improving local support and hence project security.

This short guidance document provides an overview of the information needed to: (1) assess opportunities for the joint deployment of gentler remediation and renewables production on sites in Colombia, (2) understand the technical parameters of the approaches available, and (3) perform assessments of overall sustainability and link this to cost benefit analysis (CBA).

### *Opportunities Guidance*

Opportunity guidance is based on the "Brownfield Opportunity Matrix" (BOM). This is a simple *MS Exce*l tool to help stakeholders identify wider potential sustainability / value gains from brownfields restoration. It works by mapping possible interventions to possible services that might be delivered along with illustrating potential linkages with case studies. It shows the wider synergies, benefits, services and sustainability/value gains that might accrue from a judicious selection of interventions (for example, by choices of approaches to remediation and renewables). The spreadsheet is supported by a package of stakeholder engagement guidance. All of these materials can be downloaded (at no cost) and customised for use in Colombia from <http://www.r3environmental.com.co/es/descargas.html>.

### *Technical parameters for gentle (low input) remediation and renewables production on brownfield sites*

The accepted international norm for determining how to remediate a site is risk based decision making. 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 remedial intervention. The crux of a combined remediation and renewables approach is that the project manages the risks causing concern, and also generates renewables, but in a way, that does not create any additional risks. Indeed, in some cases the remediation process may also be the renewables production process (which is the case for biomass based approaches). More generally, a risk management approach may integrate interventions at different levels. For example, partial contaminant 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). Recently, building on earlier ideas about low input approaches, the concept of Gentle Remediation Options (GRO) has emerged. *GRO are 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; this is especially important where a "soft" end use for a site (such as urban parkland, biomass/biofuels production etc.) is being considered.

A range of techniques that allow generating renewable energy can potentially be deployed on brownfields, including biomass production, photovoltaics, wind, and potentially geothermal / geological sources. Renewable energy production exploits sources that are carbon friendly and hence help mitigate global warming. Deploying renewables 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. It is an attractive solution both for energy providers (i.e. to comply with GHG emissions requirements) and consumers (i.e. providing 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. 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, thus reducing potential land-use conflicts.

### *Sustainability assessment and valuation*

Internationally interest has been growing in integrating sustainability as a decision-making criterion for remediation projects i.e. to select an approach that achieves a balanced net benefit when considering wider environmental, economic and social impacts. Sustainable remediation has become an area of intense development across the world, with public and private sector organisations involved in a number of projects and networks intended to improve remediation practice and make it more sustainable, including in the UK and Colombia. Using a site conceptual model of sustainability as a common thread through the different tiers of sustainability assessment leading towards a quantitative valuation in financial terms can be very helpful. The use of CBA can be highly controversial for a number of reasons. However, CBA underpins both policy decision making in many cases and, of course, investment decisions, for public as well as private funds. Subsequent valuation (CBA) based upon the same shared sustainability model and showing how specific valuation techniques have "best fit" to different aspects of this shared model (in a transparent way) enables CBA that is robust and consistent with sustainability assessment.

## *Additional resources*

This report is supported both by supplementary information in the annexes and by references signposted from this guidance. Additional information is also downloadable from <http://www.r3environmental.com.co/es/descargas.html>, including a Spanish language version of the opportunity guidance described herein and the other publicly available outputs of this project:

- Output 1: Strategies for rehabilitating mercury- contaminated mining lands for renewable energy and other self-sustaining re-use strategies [*An onsite field testing plan for techniques that promise to be replicable to other similarly contaminated sites, based on technology evaluations and bench scale test work*]
- Output 3: A policy brief for regional and national governments in Colombia. [*A policy brief for regional and national governments in Colombia. The brief will address Law 1658 of 2013, Colombia's commitment to the UN Minamata Convention (i.e. The Unique Plan of Mercury), the 2015 Paris Climate agreement, and Colombian accession to the OECD*]

## *Next steps*

This report is only the beginning of the story in Colombia to develop a strategy to deal with contaminated mining lands and reap the energy benefits of effective reuse. The next phase of work would be: (1) to conduct demonstration / exemplar projects in Colombia to provide national proof of concept trials, (2) to extend local skills and know-how, (3) to create opportunities for international collaboration between the UK and Colombia, and (4) to provide opportunity for technical refinements to this guidance to better suit local conditions in Colombia. Ideally, this guidance might also be updated in a subsequent project as experience grows with practical implementation of renewables with gentle remediation in Colombia.

The potential benefits of jointly applying gentle (low input) remediation along with the production of renewables does not exist in Colombia alone. A parallel FCO project has been investigating similar opportunities in China (http://cnukcontaminatedland.com/uk/downloads). A further opportunity exists to create collaborative, mutually beneficial demonstration / exemplar projects across several countries in different regions, including, for instance, Colombia, Peru, Mexico, Brazil, China, and India. These collaborative projects would develop a truly international cohort of remediation/renewables deployments based on the core expertise developed by this project and the project in China.

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# 1. Introduction



## 1.1 Brownfields restoration context in Colombia

Colombia is endowed with abundant minerals, metals and fossil fuels; for example, it is the largest coal producer in Latin America. The increasing extraction of finite natural resources such as gold is driving economic growth. However, such extraction is also a major cause of pollution of soil and water, degradation of sensitive ecosystems, and increased risks to human health. Over the first decade of the millennium, the area covered by mining titles rose from 1 million ha to 8.5 million ha (about 8% of the land area). Although international companies are major industries, artisanal and small-scale mining are also important. Artisanal mining accounts for 70% of the gold mined in Colombia, and provides a livelihood for about 200 000 poor people (OECD, 2014)

A recent study conducted by the Ministry of Environment for Environment and Sustainable Development (MADS, 2016) found nearly 1843 locations in Colombia potentially considered as brownfields or contaminated sites for all economic sectors. This information corresponds to secondary information derived from official reports of different institutions and local environmental authorities in Colombia.

According to this report, the mining sector represents 42% of these sites, followed by the oil and gas sector with 24%, and the waste sector with 14%. Figure 1 shows the complete distribution by sector (MADS, 2016).

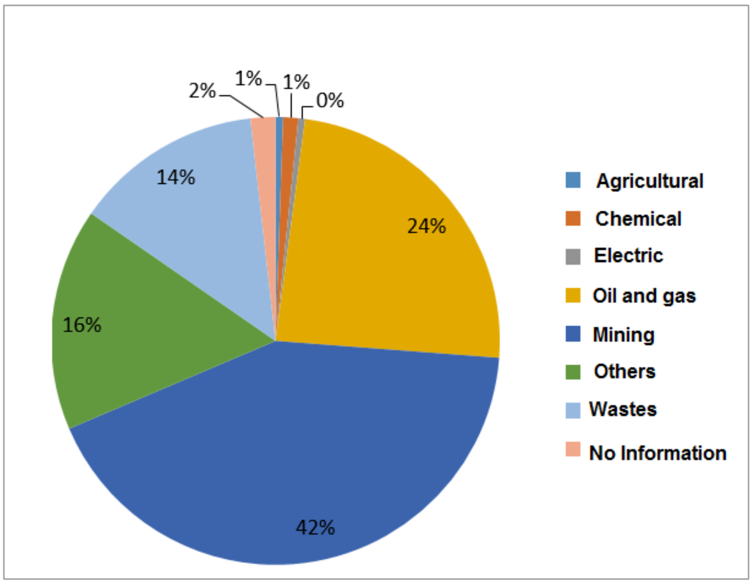


*Figure 1. Distribution of brownfields and contaminated sites in Colombia. Source: (MADS,2016)*

Colombia's 2010-14 national development plan (PND) included concrete targets and measures to promote environmental sustainability and risk prevention, and to improve the environmental quality of life (OECD, 2014). Likewise, under Colombian Law, the extraction of any natural resources or the performance of any activity or project that has the potential to affect the environment is subject to the control of the environmental authorities. However, the country has not yet developed an overarching and comprehensive policy or a set of regulations and guidance for addressing historic contaminated sites or brownfields.

A particular case of brownfields with large impacts in Colombia is the gold-mining sector. In Colombia, artisanal and small scale mining is carried out by groups of individuals in areas of traditional exploitation and as well as in unexplored areas. These latter areas had not been accessed in the past due to their geographical location and/or social conflicts. Although there is a large number of people in some areas, applying similar techniques and technologies, each working mining face is unique, and no coordination and continuity in the extractive work and gold beneficiation is evident. A typical example is visible in operating fronts where one cannot distinguish between the phases of exploration, development, preparation and exploitation; Likewise, in the beneficiation process, gold is generally recovered gravimetrically as well as with the use of mercury. In many cases, slightly advanced and complex recovery, such as separation by metallurgical process, are not being used (PNUMA, 2012).

Gold mining has been responsible for large releases of hazardous chemicals to the environment – as much as 150 tonnes of mercury a year, according to UNIDO estimates. Air pollution near open pit mining areas is also of concern. It is the poor, working in illegal, traditional and unauthorised mining who receive the greatest exposure to hazardous substances such as dust (causing silicosis) and mercury (OECD 2014). There are 4,200 active and abandoned gold mines and some 3,000 artisanal locations (PNUMA, 2012).

99.6% of gold production in the country is concentrated in in thirteen areas (departments) of the country with 95% in just ten departments. According to historical statistics from SIMCO (Colombian System of Mining Information), the departments with higher gold production in the last five years have been, in order, Antioquia, Chocó, Bolívar, Caldas, Cauca, Valle del Cauca, Tolima, Nariño, Cordoba, Santander, Risaralda, Putumayo and Huila (PNUMA, 2012).

## 1.2 Project overview

The UK Prosperity Fund project in Colombia on Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies, ran from mid-2016 until early 2017. It is intended to deliver change by providing a range of science based strategies to rehabilitate land affected by soil mercury pollution in disadvantaged areas in Colombia and bring it back into productive use focusing on renewable energy opportunities and/or other services as most appropriate; supporting the FCO goals of increasing regional stability, facilitating sustainable economic growth, harnessing innovation in particular for low carbon development, supporting OECD accession, and identifying possibilities for new community enterprise.

Colombia's two most vital assets – social and natural capital – are at chronic risk after a half-century of conflict. Gold mining using mercury recovery techniques has resulted in severe health and environmental impacts, largely from mercury at perhaps more than 7,000 locations. This project considers both risk mitigation and community enterprise opportunities for the rehabilitated land.

The UK is at the forefront of research and practical investment in sustainable remediation, community engagement in regeneration, and brownfields re-use for renewables, amenity and leisure. This integrated approach offers improved health and environmental benefits, sustainable economic growth including commercial and community enterprise opportunities in Colombia, benefits to UK partners for future business and influence, and assists climate change adaptation and resiliency.



The project adapts UK, EU and US EPA thinking on brownfields rehabilitation for renewable energy and other soft re-uses for gold mining areas impacted by mercury contamination. It combines structural and policy level research with specific case study site investigations (at sites identified with the Colombian Environmental and Mining Ministries) to provide high level policy and overview guidance, design and decision support guidance, and proposals for further development at one or more sites. It evaluates and adapts innovative low input strategies for land management, sustainable remediation and commercial or community enterprise development (particularly for renewable energy) for mercury contaminated areas, e.g. areas blighted by artisanal gold mining, connecting the science and technical base for policy in Colombia to the international state of the art.

The focus on mercury links directly to Colombia's current concerns under the Minamata Convention which it joined in 2013. As well as desk study feasibility work relating to renewable energy production on mining lands, the project includes the testing of mercury immobilisations strategies at lab scale on samples from two locations in Colombia: Segovia in Antioquia and Tadó in Chocó. These locales were selected in consultation with the Colombian Ministries of Environment and Mining. Both areas have an extensive history of artisanal mining techniques for gold with their associated mercury releases and social impacts.

## 1.3 Background and Scope of Output 2

The Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies project has three public outputs:

1. An onsite field testing plan for techniques that promise to be replicable to other similarly contaminated sites, based on technology evaluations and bench scale test work.
2. Guidance and strategies for re-use of land by transferring state of the art knowledge and successful implementation from the UK, EU and North America, and adapting it to the local situation as circumstances dictate.
3. A policy brief for regional and national governments in Colombia. The brief will address Law 1658 of 2013, Colombia's commitment to the UN Minamata Convention (i.e. The Unique Plan of Mercury), the 2015 Paris Climate agreement, and Colombian accession to the OECD.

This is the report for Output 2: *Guidance and strategies for re-use of land by transferring state of the art knowledge and successful implementation from the UK, EU and North America, and adapting it to the local situation as circumstances dictate*. Among a wide range of technical resources, this report makes particular use of several international projects which are the product of previous research and evaluation costing several million GBP (pounds Sterling):

- FP7 HOMBRE project 2010-2014 (www.zerobrownfields.eu) and FP7 Greenland Project 2010-2014 (www.greenland-project.eu) whose outputs provided the basis for Sections 2 and 3 of this report (after updating and adaptation to the Colombian context), excluding the case studies.

- US EPA renewables tool: an "*Electronic Decision Tree"* can be used to determine the feasibility of a site to develop a renewable energy project, taking into account its use in contaminated or degraded sites (https://www.epa.gov/re-powering/re-powerings-electronic-decision-tree)
- SURF-UK 2009-present (www.claire.co..uk/surfuk) which provided much of the basis for Section 4.1 of this report;
- Land Trust outputs 2016 (http://thelandtrust.org.uk), in particular the report of a project carried out over 2016 which explored the sustainability of the development of Port Sunlight Riverside Park (UK). This project's outcomes were, shared *pro bono*, with the FCO work.



In addition, r3 UK has also been a partner in the China Prosperity Strategic Programme Fund (SPF) project on "Promoting Sino-UK collaboration on developing low carbon and sustainable methodologies for Brownfields and marginal land re-use in China" (project 16AG15). This project has strong synergies with this Output 2 guidance report, with its similar focus on low input remediation, low carbon and brownfields. The technical sources and content of this guidance report therefore have a very similar coverage to the China Project final report. As far as possible technical content is as consistent as possible to ensure that conflicting guidance in the public domain is avoided. However, there are some differences because the reports 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 strongly transnational approach to be developed, providing added value to this Colombia-focused assessment, and creating opportunity for more concerted and collaborative developments in the future.

## 1.4 Purpose

This report is designed to support national policy advisors as well as local project designers and decision-makers in: (1) identifying options for developing the greatest overall value from the "soft" (i.e. non-built) re-use of brownfield/contaminated land; (2) selecting appropriate low input remediation techniques for the management of contamination problems; and (3) providing a means of assessing the sustainability and overall value of any overall restoration strategies agreed. There are three parts to the report:

- A brownfield opportunity matrix (BOM), including the results of testing it at two case study locations in Colombia
- Detailed technical guidance
- Sustainability assessment and valuation approaches

The BOM has been tested by engagement with stakeholders at national, regional, and local levels using focus group meetings, including a mid-term project brokerage and information exchange workshop with selected stakeholders and with major Colombian government participants.

Information in detail is contained in two annexes, and recommended references:

**Annex 1. The Brownfield Opportunity Matrix (BOM):** This section contains information on the origin of the BOM and its adaptation to Colombia's conditions. Likewise, the user may find the instructions on how and when to use this tool. At the end of the Section, the user can find two practical examples for two studies cases defined.

**Annex 2. Detailed Technical Guidance Sections:** In this section, the reader will find a more detailed description technical discussions of gentle remediation and the use of brownfields for renewables, including some examples from Colombia; along with some international renewable energy case studies.

## 2. The Brownfield Opportunity Matrix (BOM)

The BOM is a simple matrix screening tool designed to help developers and decision-makers involved in brownfields to identify what services can result from soft reuse interventions for their site, how these interact and what the initial default design considerations might be

Brownfields re-use can be for hard re-uses such as for housing, business parks or infrastructure. Alternatively, there are also soft end uses, such as for green space or renewables such as biomass production. Food crops are of course another form of biomass. Soft re-uses are those where the soil remains unsealed and its functionality is either maintained or enhanced (Cundy, *et al.* 2013). Most attention tends to be paid to built re-use. However, built re-use is unlikely to be a viable proposition for land affected by mining in Colombia which could be remote from settlement or in areas of limited economic demand for hard re-use options. However, soft end uses can provide services from a restoration project. Depending on design, some examples of these “project services” are:

- Provision of open space such as parkland, for local communities, which brings benefits for well-being, health, leisure, social cohesion, economic uplift 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).
- Protection of water resources

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 required to do this.

Annex 1 describes the BOM and its use on more detail. It 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 large range of possible services from restoration of brownfield land for soft re-use.

The BOM is available, with a supporting package of stakeholder engagement support files, in English language (Bardos *et al.* 2016) and as a customised Colombian Spanish Language version, which was developed and translated during this FCO Colombia project. These tools are available from [http://www.r3environmental.com.co/es/descargas.html](http://www.r3environmental.com.co/es/descargas.html).

*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 (for example biofeedstocks)
- Greenhouse gas mitigation (carbon offset revenue?)
- Synergies with waste processing and re-use, leachate management
- Shielding / soundscaping
- 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*

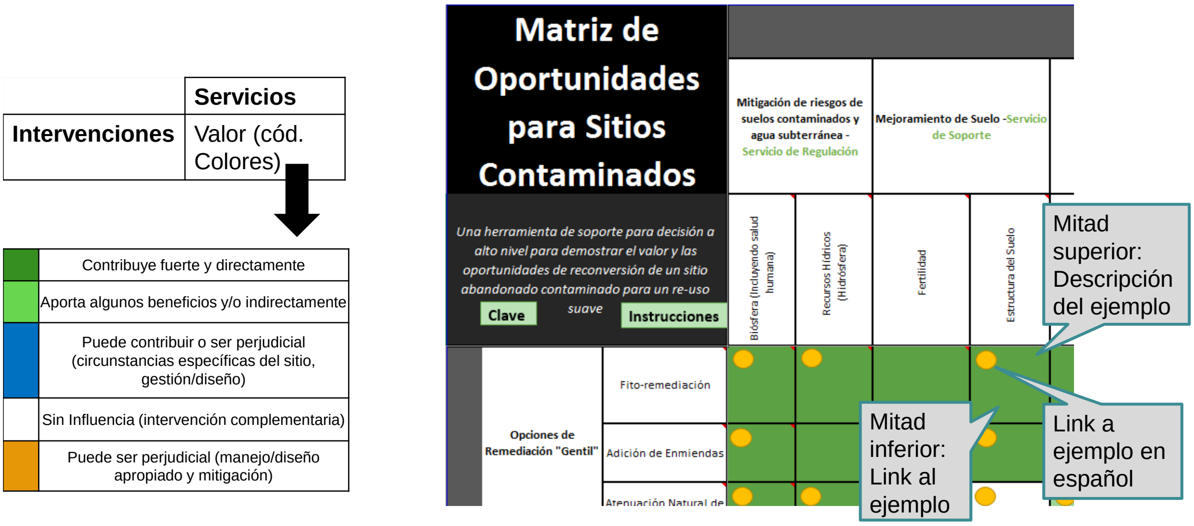


*Figure 2. View of the Simplified Spanish version of the BOM*

## 2.1 BOM and Stakeholder Engagement

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. The BOM shows how soft reuse interventions and services are connected. The matrix is intended to facilitate discussions between stakeholders, who might have different ideas about the desired outcomes for a site, to help them find a common approach. It is intended to support the visualisation of services and different forms of value connected to different stakeholders, synergies between these and finding a shared set of goals for a project and the optimal means of achieving these, for example, exploiting synergies to get the maximum services from the fewest interventions (Beumer *et al.* 2014).

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 Section 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.
5. Meeting a consensus across different interests or goals in services.

Box 2 lists a number of key principles for effective stakeholder engagement as a process.

*Box 2. Basic Principles for Stakeholder Engagement (Cundy et al., 2013)*

| |
|---|
| 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 |

# 3. Detailed Technical Guidance Sections

## 3.1 Risk Management Background



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. 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 (see in Figure 3). 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). Extensive guidance has been developed in several countries (Nathanail *et al.* 2013). More recently, with the advent of *sustainable remediation* concepts (see Section 4); the new model is *Sustainable Risk Based Land Management*. This approach encompasses years of experience from many countries. Countries relatively new to contaminated land management policies and frameworks can benefit from this learning and avoid considerable costs and many technical mistakes (Rizzo *et al.* 2016).

<u>Risk management</u> 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 as follows:

- At the level of the <u>source</u>; for example, as a source removal action
- At the level of the <u>pathway</u>; for example, managing the spreading of a groundwater plume, including by *monitored* natural attenuation
- At the level of the <u>receptor</u>; 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. prohibiting 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 *3* 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 other people, even for non-food crops, depending on how and where the biomass is utilised. This situation may (1) render biomass unsuitable for use, (2) suitable for use only in controlled facilities, such as waste to energy facilities, or (3) necessitate mitigation measures, such as the use of *in situ* stabilisation to reduce plant uptake.

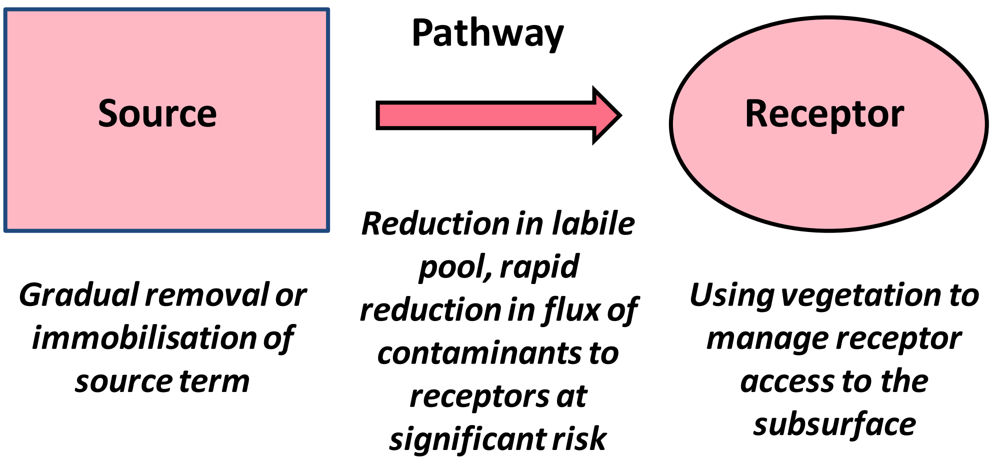


*Figure 3. A contaminant linkage, and different gentle remediation interventions at the level of source, pathway and receptor (taken from Cundy* et al. *2016).*

## 3.2 Gentle Remediation Options

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 trend 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 (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 Annex 2 contains technical guidance on a range of key GROs based on research, evaluation, and outputs from projects sponsored by the European Commission supplemented by information from the US EPA on phytotechnologies for remediation .

GROs encompass a number of technologies including:

- The use of plant, fungal and microbiological processes for removal, degradation or immobilisation of contaminants,
- In situ stabilization (using biological or chemical processes, for example sorption to biochar) or extraction of contaminants

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 bioavailable inorganic contaminants from a site (e.g. via phytoextraction), to remove or degrade organic contaminants (e.g. phytodegradation), protect water resources (e.g. rhizofiltration), or stabilise or immobilise contaminants in the subsurface (e.g. phytostabilisation, *in situ* immobilisation/phytoexclusion).

Intelligently applied GROs 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. Phytoremediation techniques involving *in situ* stabilisation of contaminants or gradual removal of the bioavailable or easily-extractable fraction of contaminants at a site can be durable solutions as long as land use and land management practice does not undergo substantive change. 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

## 3.3 Renewable Energy Generation Options

A range of techniques that allow generating renewable energy can potentially be deployed on brownfields, including biomass, photovoltaics, wind, and potentially geothermal / geological sources[1]. Renewable energy exploits sources that are carbon friendly and hence help mitigate global warming.  Renewable energy production allows 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 means of producing 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 green and renewable energy sector. 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.  Annex 2 also contains a detailed description of the several renewable energy options and the potential and pros and cons of using brownfields for production of renewable biomass and biofeedstocks.

[1] https://www.epa.gov/re-powering

## 4. Sustainability Assessment and Valuation

In the past decade or so, a risk-based approach to the management of historically contaminated land has developed, based on the prevention of unacceptable risks to human health and the environment, to ensure a site is 'fit for use'. More recently, interest has been shown in integrating sustainability as a decision-making criterion i.e. to select a remediation approach that achieves a balanced net benefit when considering wider environmental, economic and social impacts. Sustainable remediation has become an area of intense development across the world, with public and private sector organisations involved in a number of projects and networks intended to improve remediation practice and make it more sustainable. Sustainable remediation and sustainable brownfield regeneration are overlapping terms. Sustainable brownfield regeneration is defined as "the management, the rehabilitation and return to beneficial use of the brownfield land resource base in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations in environmentally non-degrading, economically viable, institutionally robust and social acceptable ways" (RESCUE Consortium 2005).

This interest in sustainable remediation is a global phenomenon (Rizzo *et al.* 2016). The various initiatives around the world have published a number of frameworks, standards, white papers, road maps and operative guidelines. While publications do differ in points of detail, overall there is a high degree of consistency across definitions and principles, which indicates a shared understanding of what sustainable remediation is both across countries and stakeholder groups. A Colombian Forum, SURF-Colombia is a part of this worldwide effort (http://surfcolombia.org/) and r3-Colombia has been a leading member of this work, as r3-UK has taken a leading in role in NICOLE and the UK sustainable remediation forum, SURF-UK, (www.claire.co.uk/surfuk).

Within the UK, the Sustainable Remediation Forum (SuRF-UK) have provided detailed guidance on how to carry out sustainability assessment for remediation projects (CL:AIRE, 2011), and a general description of sustainability assessment (in the context of remediation) has been adopted in the recently published ISO standard (ISO, 2016).

A key development at an EU level was when NICOLE and the COMMON FORUM published a joint position statement on "Risk-informed and Sustainable Remediation" in 2013 to promote the integration of risk-based and sustainable land management across Europe (NICOLE and Common Forum, 2013)

- NICOLE is a leading forum on contaminated land management in Europe, promoting co-operation between industry, academia and service providers on the development and application (www.nicole.org).
- The COMMON FORUM on Contaminated Land is a network of contaminated land policy makers, regulators and technical advisors from Environment Authorities in European Union member states and European Free Trade Association countries (www.commonforum.eu).

Four features are particularly important in sustainable remediation based decision-making: (1) sustainability assessment does not replace risk based decision making, this and a series of other broad underpinning principles have been summarised by SuRF-UK, see Table 1 below). (2) Sustainability covers a broad range of criteria. Table 2 lists the overarching categories of criteria considered by SuRF-UK, whose guidance on indicators is in widespread use (CL:AIRE). (3) A tiered approach to assessment should be taken, so that the simplest and easiest approach is always preferred and more complicated assessments are only used when simpler methods to not provide a clear cut answer, see Figure 4 (4) The effectiveness and acceptability of any sustainability assessment is critically dependent on engagement with a wide range of stakeholders involved in a project, although a *preliminary assessment* could be carried out initially by a small team to get an overall perspective, and provide a more concrete basis for the wider engagement of stakeholders.

In broad terms, there are three categories of assessment: qualitative, semi-quantitative and quantitative. However, all of them need to be adequately framed (i.e. prepared and defined) before execution. Hence there are three broad stages in any sustainability assessment: preparation, definition and execution, as shown in Figure 5. Depending on how stakeholders are engaged during the sustainability assessment there may be some iteration across these stages as the analysis is refined:

- *Preparation* - agreeing in advance how the sustainability assessment will be reported; who will be involved, and how communication will take place with other stakeholders.
- *Definition* - providing a clearly defined assessment procedure, considering: objectives, boundaries, scope, method and uncertainty.
- *Execution* - carrying out the assessment procedure defined with an appropriate level of dialogue and ensuring that the procedure, its findings and its underlying assumptions are clearly communicated to all relevant parties.

Using a site conceptual model of sustainability as a common thread through the different tiers of sustainability assessment towards quantitative valuation in financial terms can be very helpful. This is because often policy, funding and/or investment decisions need to be justified on the basis of a formal cost benefit analysis (CBA). The use of CBA can be highly contentious for a number of reasons. The valuation methodologies may not be seen as reliable. The process may not be seen as transparent, and, perhaps most importantly of all, the scope of assessment may be seen by many stakeholders as limited and not properly relevant to their interests (Bardos, et al., 2016). However, CBA underpins both policy decision making in many cases and of course investment decisions, for Public as well as Private Funds. A site conceptual model of sustainability is easier to agree at a *qualitative* level as a common or shared understanding across a range of actors, whatever their interests. Subsequent valuation (CBA) using the same shared model and also showing how specific valuation techniques have best fit to different aspects of this shared model in a transparent way provides CBA that is robust and consistent with sustainability assessment. It also means that even if some actors do not favour CBA it is at least clear to them how the CBA was derived, so that they can make their own representations.

A full scheme, with an illustrative case study, of how to carry out sustainability assessment, including the use of a conceptual site model of sustainability to refine and value outcomes, is provided in the report of a sister project to this one (Coulon *et al.* 2017)

*Table 1. SuRF-UK: Key principles associated with sustainable remediation (CL:AIRE, 2010)*

| Principle | Description |
|---|---|
| **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. 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. |

*Table 2. Overarching SuRF-UK Indicator Categories (CL:AIRE, 2010)*

| Environment | Social | Economic |
|---|---|---|
| Emissions to Air | Human health & safety | Direct economic costs & benefits |
| Soil and ground conditions | Ethics & equity | Indirect economic costs & benefits |

| Environment | Social | Economic |
|---|---|---|
| Groundwater & surface water | Neighbourhoods & locality | Employment & employment capital |
| Ecology | Communities & community involvement | Induced economic costs & benefits |
| Natural resources & waste | Uncertainty & evidence | Project lifespan & flexibility |

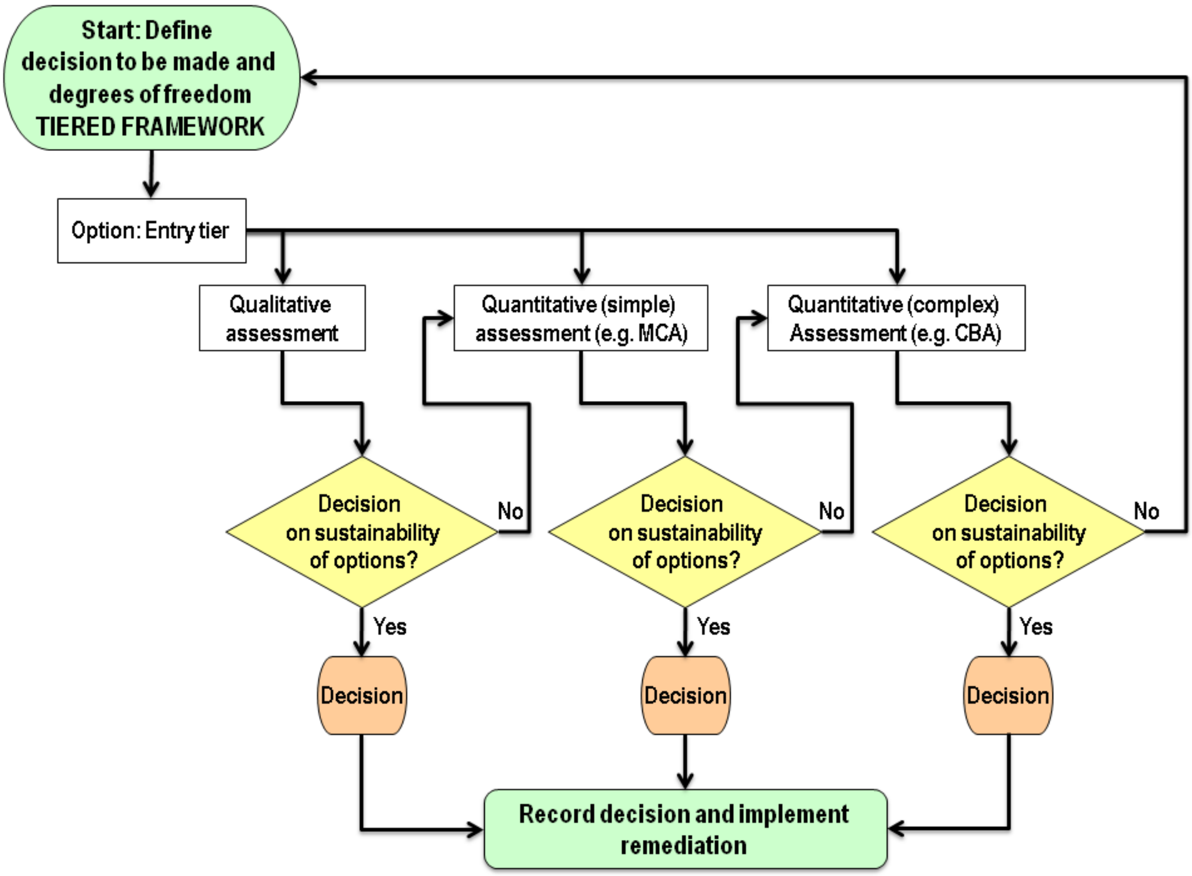


*Figure 4. A Tiered approach to sustainability assessment (CL:AIRE, 2011)*

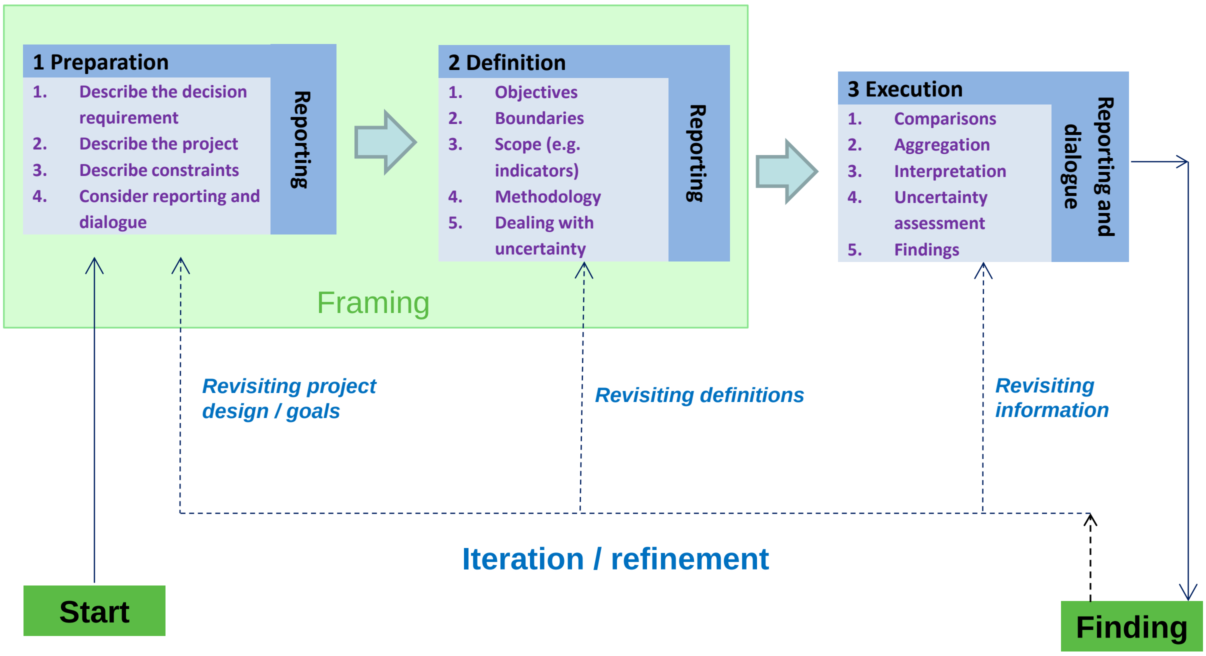


*Figure 5. A SuRF-UK Approach to Sustainability Assessment (CL:AIRE, 2014a)*

# 5. Concluding Remarks and Recommendations

Colombia has an enormous opportunity for the generation of renewable resources, such as energy from its land, for example from photovoltaic energy. Linking the safe re-use of mining brownfields (following application of low input “gentle” remediation techniques) with the generation of renewables presents a “virtuous” opportunity for land (re)use for several reasons.

- A variety of local energy market arrangements are possible: The approach is scalable--workable from community based projects to large projects with major mining companies.
- The income from renewables can help offset the cost of making the land safe, for example, from mobile mercury species.
- The use of this degraded land is a more sustainable approach to providing renewables than converting habitat or agricultural land over to renewables production.
- Colombia gets a lot of energy for free from the sun compared with many other countries in the developed world (e.g. the UK).
- There may also be opportunities for income from Carbon Offset under the Kyoto Protocol.
- Where not suitable for renewables, then consideration needs to be given to restoration as public open space for the societal benefits this can deliver.

This approach can also bring wider societal and economic benefits in Colombia. Income from renewables (and potentially also from carbon offset) can be recycled locally. Combining it with other land uses may also be very valuable, for example, with public parks or leisure. These might be combined, for instance, as a “mosaic” with renewable energy production to improve overall project acceptability and viability; as well as improving local support and hence project security.

This short guidance document provides an overview of the information needed to: (1) assess opportunities for the joint deployment of gentler remediation and renewables production on sites in Colombia, (2) understand the technical parameters of the approaches available, and (3) perform assessments of overall sustainability and link this to cost benefit analysis (CBA).

This guidance is supported both by supplementary information in the annexes following as well as in the references signposted from this guidance. Additional information is also downloadable from << http://www.r3environmental.com.co/es/descargas.html >>, including Spanish language versions of the opportunity guidance described herein and the other public outputs of this project:

- Output 1: Strategies for rehabilitating mercury- contaminated mining lands for renewable energy and other self-sustaining re-use strategies [*An onsite field testing plan for techniques that promise to be replicable to other similarly contaminated sites, based on technology evaluations and bench scale test work*]
- Output 3: A policy brief for regional and national governments in Colombia. [*A policy brief for regional and national governments in Colombia. The brief will address Law 1658 of 2013, Colombia’s commitment to the UN Minamata Convention (i.e. The Unique Plan of Mercury), the 2015 Paris Climate agreement, and Colombian accession to the OECD*]

This report is only the beginning of the story in Colombia to develop a strategy to deal with contaminated mining lands and reap the energy benefits of effective reuse. The next phase of work would be: (1) to conduct demonstration / exemplar projects in Colombia to provide national proof of concept trials, (2) to extend local skills and know-how, (3) to create opportunities for international collaboration between the UK and Colombia, and (4) to provide opportunity for technical refinements to this guidance to better suit local conditions in Colombia. Ideally, this guidance might also be updated in a subsequent project as experience grows with practical implementation of renewables with gentle remediation in Colombia.

The potential benefits of jointly applying gentle (low input) remediation along with the production of renewables does not exist in Colombia alone. A parallel FCO project has been investigating similar opportunities in China (http://cnukcontaminatedland.com/uk/downloads). A further opportunity exists to create collaborative, mutually beneficial demonstration / exemplar projects across several countries in different regions, including, for instance, Colombia, Peru, Mexico, Brazil, China, and India. These collaborative projects would develop a truly international cohort of remediation/renewables deployments based on the core expertise developed by this project and the project in China.

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# Annex 1: The Brownfield Opportunity Matrix (BOM), Adaptation for Colombia, Case Studies and Appraisal

This annex is 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[2] / contaminated land using the Brownfield Opportunity Matrix (BOM). The BOM is a simple matrix screening tool help 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: the "Brownfield Opportunity Matrix" (BOM). It follows on from a major European Commission research project funded under their Framework 7 programme: HOMBRE (Holistic Management of Brownfield Restoration (www.zerobrownfields.eu)

Brownfields re-use can be for hard re-uses such as for housing, business parks or infrastructure. Alternatively, there are also soft end uses, such as for green space, or renewables such as biomass production. Biomass may be produced for direct conversion to energy (for example, in a CHP[3] plant, or for AD), as a "biofeedstock" (for example a precursor for a bioplastic or biofuel) or for biochar production (potentially with energy recovery). Food crops are of course another form of biomass. Soft re-uses are those where the soil remains unsealed and its functionality is either maintained or enhanced (Cundy, *et al.* 2013). Most attention tends to be paid to built re-use. However, built re-use is seldom likely to be a viable proposition for land affected by mining in Colombia which could be remote from settlement or in areas of limited economic demand for hard re-use options. However, soft end uses can provide services from a restoration project. Depending on design, some examples of these "project services" are:

- Provision of open space such as parkland, for local communities, which brings benefits for well-being, health, leisure, social, cohesion, economic uplift, 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).
- Protection of water resources

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 required to do this.

[2] In this context, a brownfield describes degraded or previously used land that is not being redeveloped, for example, a former waste disposal site or former urban area
[3] Combined heat and power

## BOM description and origin

The BOM, first developed within 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. Table 3 provides a listing of the large range of possible services form restoration of brownfield land for soft re-use (Bardos *et al.* 2016)

The original BOM is available for download and use from HOMBRE's "Brownfield Navigator" page (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.

A Colombian Spanish Language version developed by this project is available from http://www.r3environmental.com.co/es/descargas.html ("Matriz de Oportunidades para Sitios Contaminados Abandonados")

*Table 3. Potential Services from Soft Re-uses of Brownfield Land*

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

The BOM is a simple tool which 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:

- Deep green: this 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 6 (below), 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.  The informational BOM is also available from http://bfn.deltares.nl/bfn/site/index.php/standard/bfn_home.  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 Colombia.  Although a detailed informational version in Spanish 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).

The BOM is organised using a hierarchy of categories of services and interventions, as listed in Table 4. The simple BOM provides some additional guidance in each green or blue coloured intersection cell 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 (see Figure 6).  In the Colombia 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.

*Table 4. The overarching services and interventions considered within the Brownfield opportunity matrix*

| **Services** | **Interventions** |
|---|---|
| • Soil Improvement<br>• Water Resource Improvement<br>• Provision of Green Infrastructure<br>• Risk Mitigation of Contaminated Soil and Groundwater<br>• Mitigation of Human Induced Climate Change (global warming)<br>• Socio-Economic Benefits | • Soil Management<br>• Water Management<br>• Implementing Green Infrastructure<br>• Gentle Remediation Options<br>• Other Remediation Options<br>• Renewables (energy, materials, biomass)<br>• Sustainable Land Planning and Development |

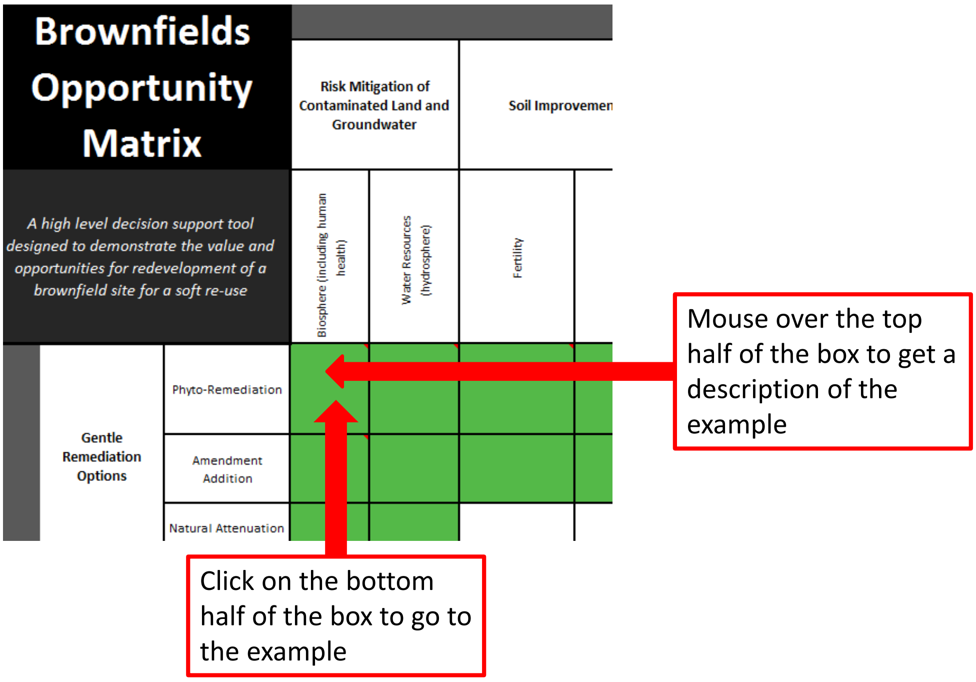



*Figure 6. View of the simplified Brownfield Opportunity Matrix.*

## Adaptation to Colombian context

The Colombian version of the BOM produced in this project includes translation and adaptation. Like the English language version, it has three parts: the case study example box for each interaction, the description of the example and the colour coding for each intersection. Figure 7 shows an explanation of the parts of the BOM and its location in the boxes.

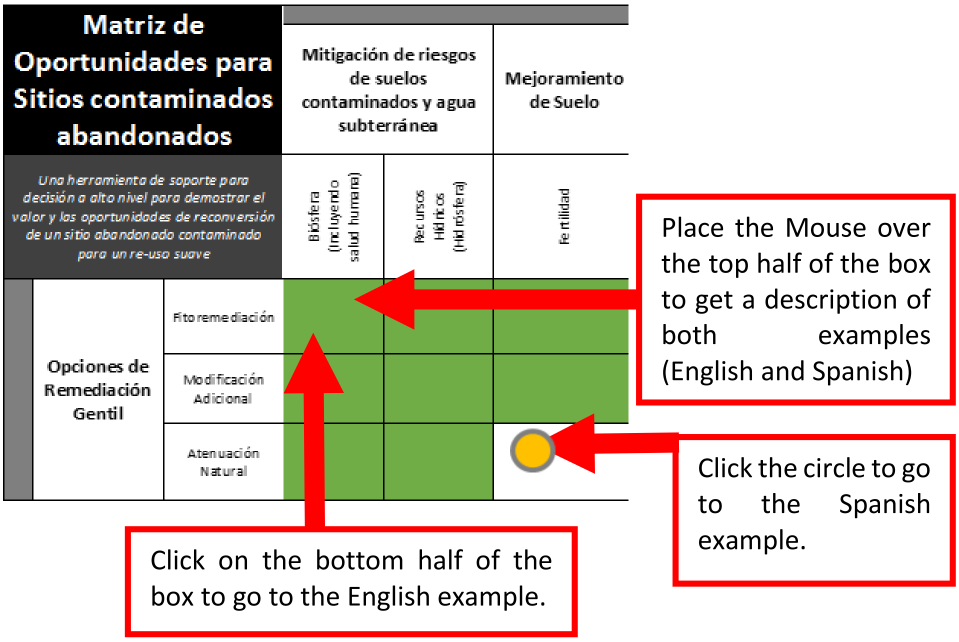



*Figure 7. View of the Simplified Spanish version of the BOM*

The first part (case study example box) consists of an adaptation of the case studies shown in every interaction box between interventions and services. Clicking the mouse on the yellow circle takes the user to a link that provides documents written in Spanish from different remediation interventions in Latin America, the Caribbean and Spain, which aim to guide the BOM user in the process of selecting the more appropriate low input remediation technique according to the services it provides in order to manage the contamination present.

In some instances, the case study of the link in the circle does not directly correspond to a case of successful implementation of remediation in Latin America, the Caribbean and Spain because some have not been found for such specific interactions. Instead, the link will direct the user to research articles, investigations of alternatives, reviews or laboratory studies involving the type of remediation that concerns to the cell. Nevertheless, the English examples are still mapped in the BOM so that they can guide the user as a supporting feature.

The description of each example is provided in the Excel box as a commentary divided into two parts: a comment about the English example, which is translated to Spanish and marked with the name of the commentator, followed by a brief description of the Spanish example (see Figure 8). This comment window is exposed only by placing the mouse over the top half of the box.

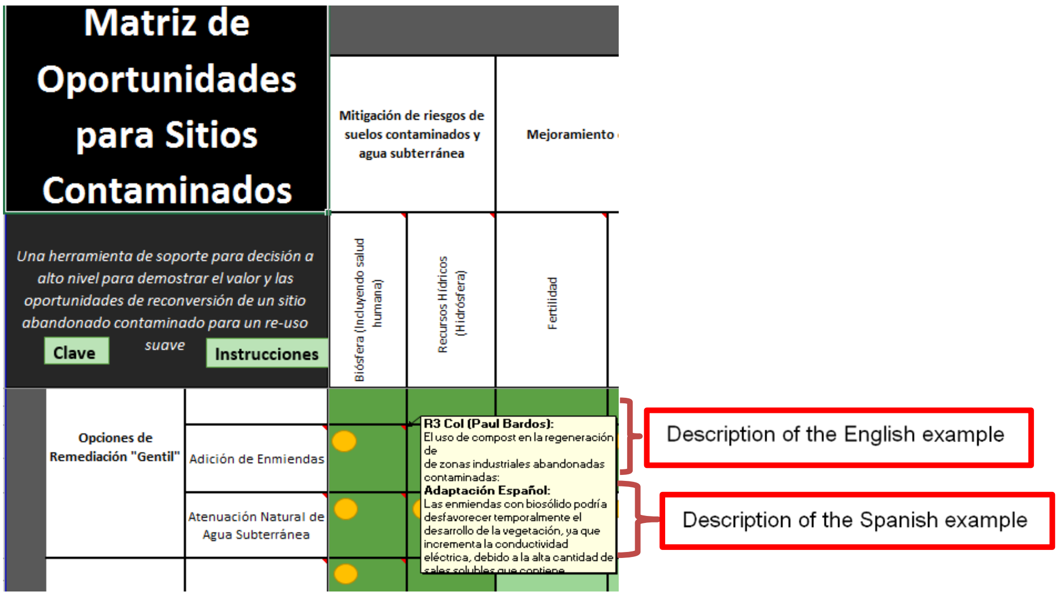



*Figure 8. Comment box with the brief description of the English and Spanish examples in the simplified Spanish version of the BOM.*

The third component of the matrix is the colour code, which is explained in the Key tab ("Clave" in Spanish) of the BOM. This part is what makes specific the applicability of the BOM to the two sites under study (Segovia and Tadó) since it is based on the outcomes of dialogue with stakeholders met in the site visits, including governmental entities, environmental and mining authorities and artisanal miners; so, the colour shown in each box indicates the possibilities to obtain a service from one intervention or a synergy between more than one, based on stakeholder opinions from each site.

This aims to support developers and stakeholders to identify conceivable services that could be obtained from the implementation of some soft re-use interventions, the interactions and the initial default design considerations.

## 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. The BOM shows how soft reuse interventions and services are connected. The matrix is intended for facilitate discussions between stakeholders, who might have different ideas about the desired outcomes for a site, to help them find a common approach. It is intended to support the visualisation of services and different forms of value there might be for different stakeholders, synergies between these and finding a shared set of goals for a project and the optimal means of achieving these, for example, exploiting synergies to get the maximum services from the fewest interventions (Beumer *et al.* 2014).

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 Section 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.
5. Meeting a consensus across different interests or goals in services.

Table 5 lists a number of key principles for effective stakeholder engagement as a process.

Figure 9 and Figure 10 show two example 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.

*Table 5. Basic Principles for Stakeholder Engagement (Cundy, et al., 2013)*

| |
|---|
| Identify and engage core and noncore stakeholders early in the process |
| Adopt a proactive not reactive approach to engagement |
| Engage stakeholders at all stages |
| 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 may need to be subjective and objective<br>Set out all assumptions and procedures for implementing and monitoring at the start of a project<br>Follow a logical, stepwise approach to engagement to avoid circular arguments and clearly address subjective issues |

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

1. Support initial identification or benchmarking of soft reuse options for brownfields at early stage.
2. Support exploratory discussions with interested stakeholders
3. Provide a structure to describe an initial design concept, in support for example of planning applications
4. 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.

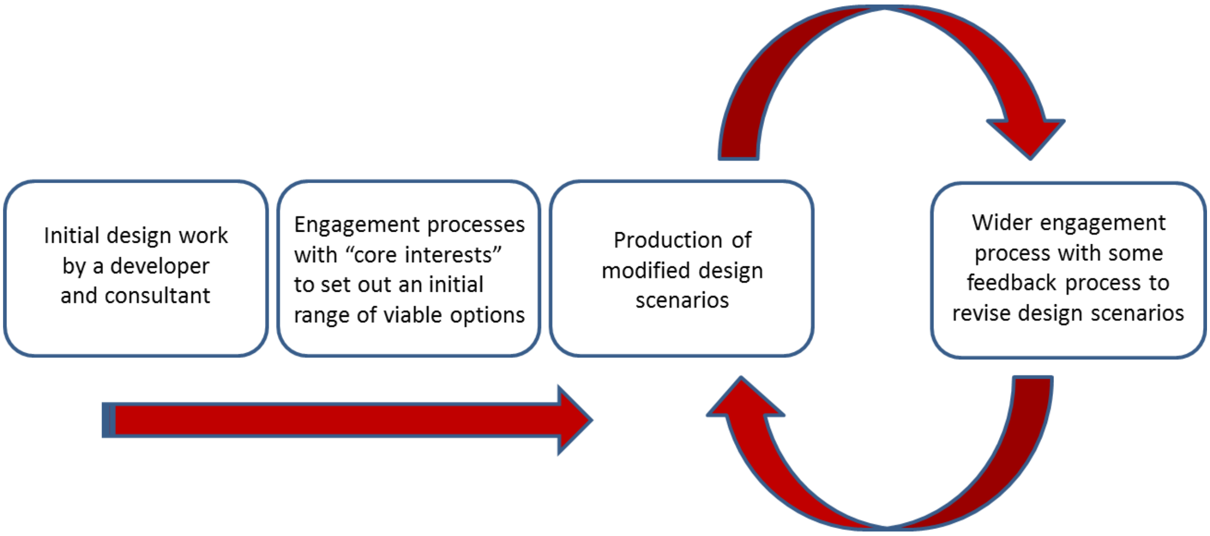



*Figure 9. An example "private" restoration project development design scenario (Cundy, et al., 2013).*

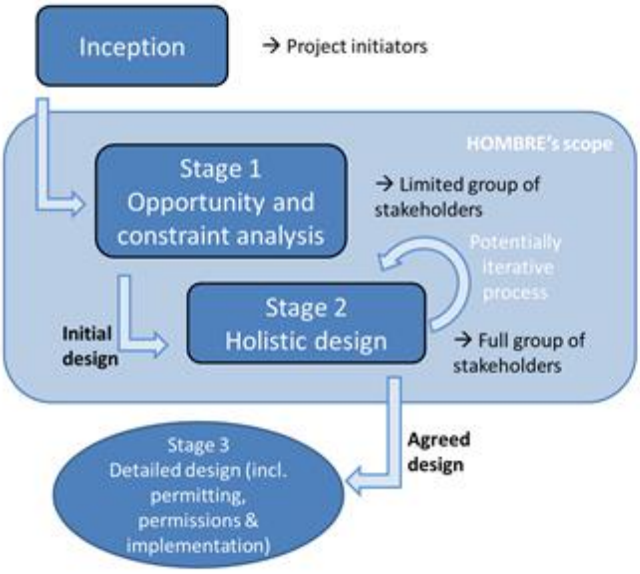
| | |
|---|---|
| <ul><li>Inception: a group of interested parties decides to take am project forward (for example via a public agency, or a community led NGO)</li><li>Stage 1: a limited group of stakeholders connected with the initialisation of a project develop their ideas and ambitions sufficiently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



*Figure 10. A coalition based project development process (Beumer et al. 2014)*

The BOM is seen as having several functions during project conceptualisation and early planning, as illustrated in Figure 11 and Figure 12, 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.

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, and 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.

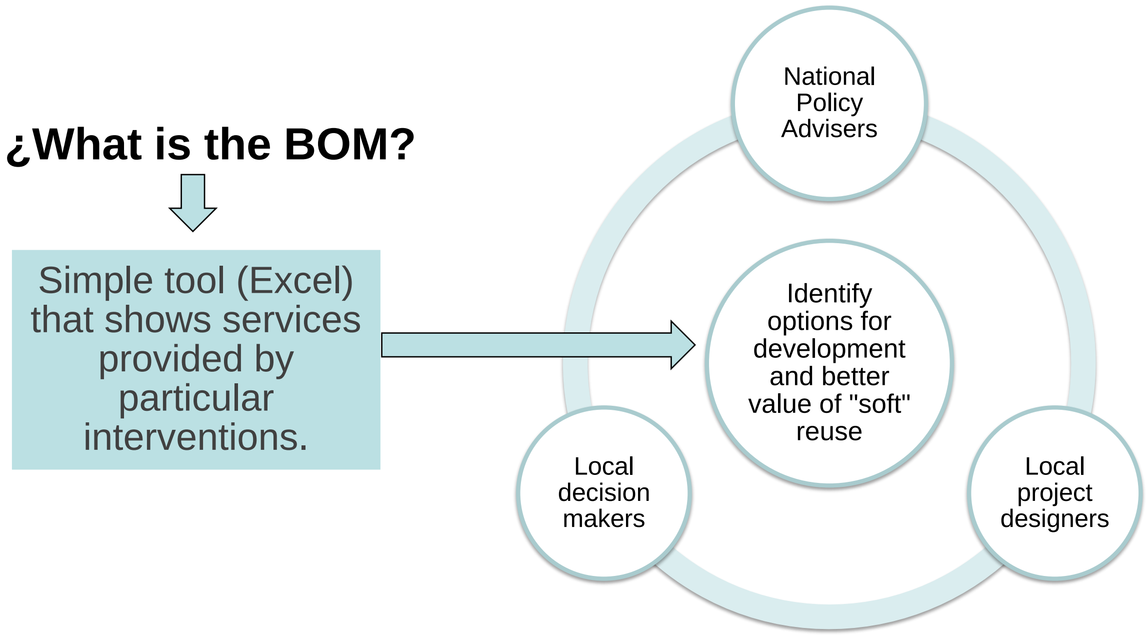



*Figure 11. Application of the BOM (© r3 Environmental Technology Colombia SAS 2016)*

To support these activities a number of components have been produced as a “stakeholder engagement package”, and are available in Spanish at: <[http://www.r3environmental.com.co/es/descargas.html (“Paquete de compromiso con las partes interesadas)](http://www.r3environmental.com.co/es/descargas.html)>

- Meeting agenda proforma
- The simple BOM
- A complete meeting slide deck
- Checklists (for services, interventions and forms of value)
- A meeting reporting template.
- A series of international stakeholder engagement resources to provide supplementary information and good practice guidance (see Table 6).

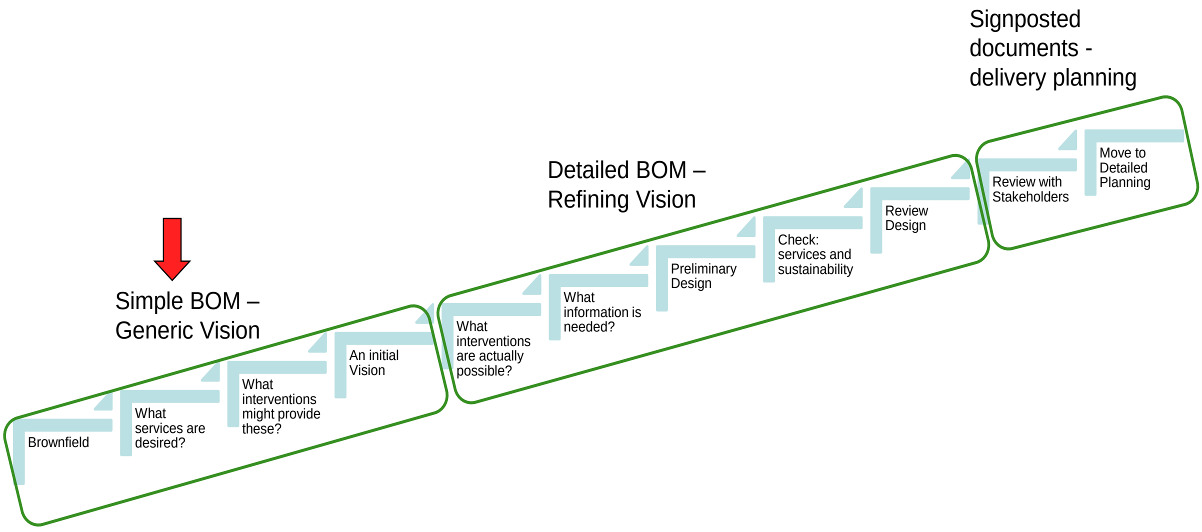



*Figure 12. Timing of the use of the BOM (© r3 Environmental Technology Colombia SAS, 2016)*

*Table 6. International Stakeholder Engagement Resources*

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

The BOM was customised using one of the sites selected for possible evaluation of gentle remediation using charcoal as a case study: the town of Segovia in Antioquia. In this area soil testing (carried out under the current FCO project) found the highest levels of mercury in soils and the presence of other heavy metals as lead[4]. The effectiveness of the BOM was evaluated on the basis of bilateral discussions with different interested parties with whom we could assess the use of the BOM in the context of Segovia's needs Discussions were held with

- Ministry of Environment and Sustainable Development of Colombia, Environmental and Sectorial Group and the Mining Group.
- Ministry of Mines and Energy of Colombia, Office of environmental issues and mining liabilities.
- Autonomous Regional Corporation of Antioquia, Corantioquia. Regional environmental authority.
- Secretary of Environment of Segovia. Local Environmental Authority.
- Manager of entables in Segovia.
- Community Leader of Segovia.

The methodology used with each stakeholder corresponds to the process described in section 2.3. The "stakeholder engagement package" was used as required, but modifications were made according to the characteristics of the scheduled meetings. Among the most relevant factors for its modification were the available time of the attendees to complete the exercise, and the level of knowledge of the subject of those engaged with.

From an initial version of the BOM submitted to a specific final version for Segovia, valuable contributions were received for the development of the process. During these discussions, we also came to understand the strengths, weaknesses, opportunities, and threats that would impact the future use of the BOM. These are summarised as a SWOT matrix in Figure 13.

[4] An onsite field testing plan for techniques that promise to be replicable to other similarly contaminated sites, based on technology evaluations and bench scale test work. (© r3 Environmental Technology Colombia SAS, 2016)

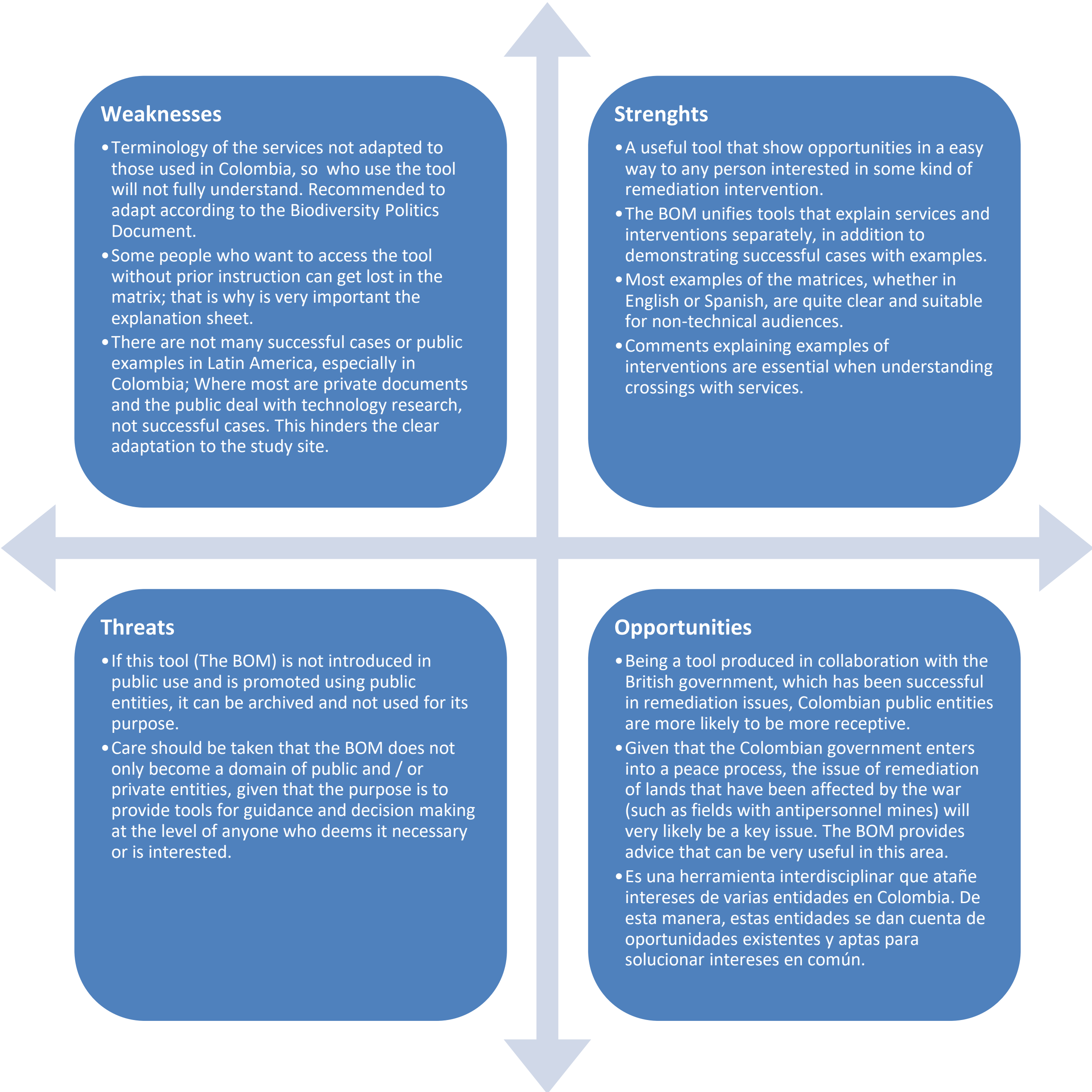



*Figure 13. SWOT Matrix of fact identified on bilateral discussions for the BOM*

# Annex 2 Detailed Technical Guidance Sections for Low Input (Gentle) Remediation and Production of Renewables on Brownfields

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, Bardos and Nathanail 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 3). 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.* 2013). 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 (Environmental Agency and Department for Environment, Food and Rural Affairs - Defra, 2004). More recently, with the advent of *sustainable remediation* concepts 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 relatively new to 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 14 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 other people, even for non-food crops, depending on how and where the biomass is utilised. This situation may (1) render biomass unsuitable for use, (2) suitable for use only in controlled facilities, such as waste to energy facilities, or (3) necessitate mitigation measures, such as the use of in situ stabilisation to reduce plant uptake (Anderson-Sköld *et al.* 2014; Jones *et al.* 2016).

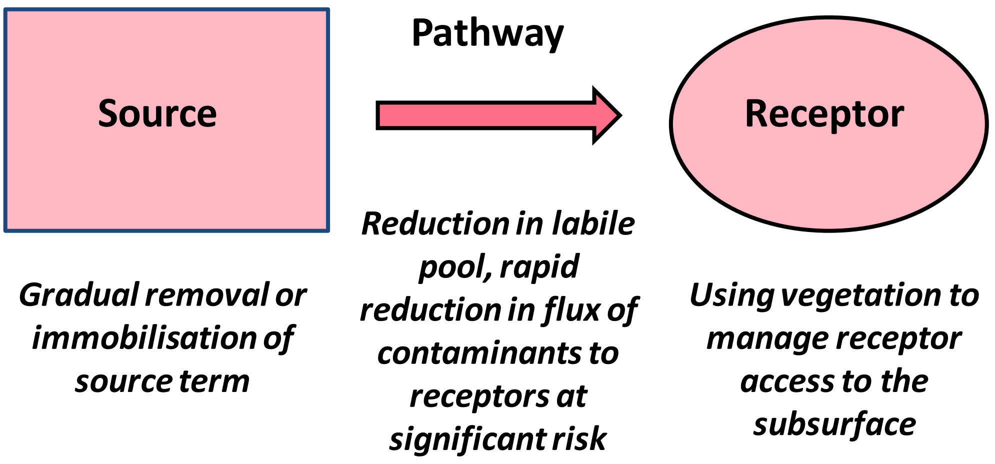



*Figure 14. A contaminant linkage, and different gentle remediation interventions at the level of source, pathway and receptor. (from Cundy et al 2016)*

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 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 (Cundy *et al.* 2013). 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 Section 2 (Cundy et al. 2015) supplemented by information from the US EPA (1990) 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, fungal microbiological processes for removal, degradation or immobilisation of contaminants, discussed in Section 3.1; and
- In situ stabilization (using biological or chemical processes, for example sorption to biochar) or extraction of contaminants, discussed in Section 3.2.

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.

GROs 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. phytodegradation), 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 GROs 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 Decision Support Tool (DST), in the form of a Microsoft Excel-based workbook. This is 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](http://www.greenland-project.eu).

Intelligently applied GROs 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).

## Gentle remediation - Phyto-Remediation

Phytoremediation is the direct use of living green plants for *in situ* risk reduction for contaminated soil, sludges, sediments 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 7.

Phytoremediation is thus a 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 GROs 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.

*Table 7. Phytoremediation Process Variants. From:(Nathanail et al. 2007)*

| | |
|---|---|
| ***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., 2016) |
| ***Phytovolatilization*** | 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 should primarily be deployed to gradually remove the labile (or bioavailable) pool of inorganic contaminants from a site (phytoextraction), remove or degrade organic contaminants (e.g. phytodegradation), 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 8

*Table 8. 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<br><br>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.<br><br>Phytoextraction can provides 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.<br><br>Phytodegradation, phytotransformation, and rhizodegradation can provide a long-term solution for a range of organic | Phytoextraction processes may take many years (decades), and some metals may be inaccessible or unavailable to the phyto-extraction process. Hence phytoextraction is limited in its suitability as a source management tool for removing bulk metals from soil<br><br>Very few types of hyper-accumulator are suitable for practical remediation use.<br><br>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.<br><br>May require cultivational measures, re-grading or decompaction, or other soil improvement measures to support adequate plant growth<br><br>Usually requires ongoing management and monitoring, e.g. fertilisation (which may be via |

| Advantages | Disadvantages |
|---|---|
| contaminants, including some recalcitrant forms such as PAHs | recyclates), to prevent pest damage, and/or recover biomass |
| Processes of phytocontainment, rhizofiltration and phytostabilisation can provide pathway management solutions for a broad range of organic and inorganic contaminants in parallel | 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. |
| Phytovolatilization may be an effective means of removing some volatile organic compounds from shallow groundwater | Phytovolatilization is the transfer of contaminants from matrix (groundwater) to another (air) and as such may raise regulatory objections |

Some studies in Colombia have used this technique of phytoremediation in different aspects, including:

- Remediation of contaminated soil with mercury using the guarumo (Cecropia peltata) trees (Vidal *et al.* 2010). In this study, the influence of the degree of contamination, the application of citric acid and growth time of Cecropia peltata, on the rate of removal of mercury in soil was determined.
- Phytoremediation in situ for the recovery of soils contaminated by heavy metals (lead and cadmium) and evaluation of selenium in the high furatena farm in the municipality of Utica (Cundinamarca) (Cordero, 2015; Serrano, 2006).
- Phytoremediation with artificial wetlands for the treatment of swine wastewater (Arias *et al.* 2010). The purpose of the project was to evaluate the effectiveness of wetlands to reduce the pollutant load, as economic systems of treatment for hog producers in Colombia.
- Phytoremediation of mercury-contaminated soils by Jatropha curcas (Marrugo *et al.* 2015). *Jatropha curcas* plants species were tested to evaluate their phytoremediation capacity in soils contaminated by different levels of mercury. The experimental treatments consisted of four levels of mercury concentrations in the soil - T0, T1, T5, and T10 (0, 1, 5, and 10 μg Hg per g soil, respectively). The total mercury content absorbed by the different plant tissues (roots, stems and leaves) was determined during four months of exposure.

## 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.* 2009).

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 biochar for the immobilisation of heavy metals and organic compounds (Ahmad, et al., 2014; Lehmann and Joseph, 2009), as discussed in more detail in the Output 1 Report[5]. 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[6].
- 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.

[5] An onsite field testing plan for techniques that promise to be replicable to other similarly contaminated sites, based on technology evaluations and bench scale test work. (© r3 Environmental Technology Colombia SAS, 2016)

[6] http://www.peroxychem.com/markets/environment/soil-and-groundwater/products/daramend-reagent

- Zeolites: there is a string 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 9.

*Table 9. 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.<br><br>Combinations such as compost and char can be used to achieve risk management and soil improvement services in parallel.<br><br>The use of chars / biochars may achieve (temporary) carbon sequestration in soils.<br><br>Amendments can restore soil quality by balancing pH, adding organic matter, increasing water holding capacity, re-establishing microbial communities, and alleviating compaction.<br><br>Compatible with many other interventions, including measures to achieve improved conservation, biodiversity (depending on the amendment selected).<br><br>Amendments can usually be deployed using readily available agricultural equipment.<br><br>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.<br><br>Validation and verification may be relatively complex, in particular to make the case of a long term protective effect to regulators.<br><br>Unlikely to be protective of human health where direct contact is a major exposure pathway.<br><br>Some amendments (e.g. composts and digestates or sewage sludge may be associated with nuisances from odour or bio aerosols. 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 bio aerosol and/or dust |

Some studies and projects in Colombia and South America that have used this technique of amendment addition in different aspects, including:

- Study of an alternative for loads remediation contaminants in soils, from agricultural activities (Segura, 2015). Agricultural sector is one of those used more agricultural inputs for controlling phytosanitary problems, the present work aims to expose a product of innovative technology, using advanced oxidation-reduction transforms potentially toxic elements in compounds or non-hazardous or less hazardous elements, reducing their solubility or toxicity; in addition to providing its disinfectant action with a broad spectrum of action on bacteria.

- Recovery of soils affected by salt in the department of Valle del Cauca using concentrated vinasse (Rojas, 2005). The addition of 200 m3/ha of concentrate vinasse in the saline-sodic soil reduced the exchangeable sodium concentration and the ESP (exchangeable sodium percent) to lower levels than the reference sodic soils. The electric conductivity was also reduced from 10, 28 up to 3,12 dS/m.
- Application of basic amendments on acid soils of the Pampa Region: effect on the soil exchange complex (Millan *et al.* 2010*).* The purpose of this study was to: a) evaluate the cation exchange capacity and the amount of basic nutrients present in some acid soils of the Pampa Region, b) evaluate the exchangeable Al3+ concentration, and c) assess the effect of different rates and types of alkaline amendments on the exchange complex.
- Characterization of compounds, lumbri composts and its potential use in soil amendments and production of crops (Torres *et al*. 2006).
- Strategies to reduce the absorption of mercury in rice (*Oryza sativa*) cultivated in contaminated soils (Urango and Marrugo 2015). The effect of two amendments on the absorption of Hg for rice (*Oryza sativa*) planted in a northern Colombia contaminated soil is evaluated. The techniques studied in this work are the application of lime and organic matter contaminated with Hg and subsequent planting of rice in each treatment soils.

## 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[7]. 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 3.4) 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 3.4) 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

[7] Industrial energy and non-food crops: business opportunities for farmers, https://www.gov.uk/guidance/industrial-energy-and-non-food-crops-business-opportunities-for-farmers

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 (*Wikipedia*[8])

Even food production may take place on brownfield sites[9], 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[10] [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, it 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 established and detailed guidance[11] is available from a number of sources (Cotton et al 2012; Willoughny *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).

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[8] https://en.wikipedia.org/wiki/Biorefinery

[9] US EPA Urban Agriculture & Improving Local, Sustainable Food Systems web site: http://www.epa.gov/brownfields/urbanag/

[10] CL: AIRE (UK) Definition of Waste: Code of Practice, http://www.claire.co.uk/projects-and-initiatives/dow-cop

[11] http://www.forestry.gov.uk/fr/infd-8a2lwj

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 form both agricultural and degraded land[12].

The pros and cons using brownfields for renewable biomass, biofeedstocks and secondary resources are summarised in Table 10.

*Table 10. 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<br>• 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<br>• May form part of a phytoremediation strategy to manage contaminated land risks<br>• May contribute to urban greening and city farm projects which have wider sustainability and community benefits<br>• Suitable for land unsuitable for building purposes for geotechnical reasons<br>• 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<br>• 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.<br>• May require cultivational measures, re-grading or decompaction, or other soil improvement measures to support adequate plant growth<br>• Usually requires ongoing management and monitoring, e.g. fertilisation (which may be via recyclates), to prevent pest damage, and/or recover biomass<br>• 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.<br>• Phytovolatilization is the transfer of contaminants from matrix (groundwater) to another (air) and as such may raise regulatory objections<br>• 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). |

Colombia has had a great development in the use of biomass for the generation of biofuels since the law 693 of 2001, however, it is not directly related to the regeneration of

[12] http://www.matrica.it/article.asp?id=26&ver=en#.VO35M_msXHV

contaminated sites. In 2011 Colombia's Mining and Energy Planning Unit (UPME) developed the Atlas of the Energy Potential of Residual Biomass in Colombia (UPME 2011). Also, the technological development has been in most important for ethanol production, they refer to processes of fermentation and hydrolysis of edible raw materials (sugar cane and maize), which at the global level are quite mature (UPME, 2009). Recent information of biomass can be found in "Vegetable residual biomass: technologies of transformation and current status" (Martinez, 2014).

## Renewable Energy Generation

A range of techniques that allow generating renewable energy can potentially be deployed on brownfields, including biomass, photovoltaics, wind, and potentially geothermal / geological sources[13]. Renewable energy exploits sources that are carbon friendly and hence help mitigate global warming. Renewable energy production allows 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 green and renewable energy sector (UK Energy Research Centre 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 $100m^2$ 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 efficiently buildings (i.e. choosing appropriate orientation of built elements towards the sun,

[13] https://www.epa.gov/re-powering

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 highly 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 mediums 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. Though in 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. Biogas is also generated in landfills containing degradable wastes[14]. 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, phytoextraction 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, the potential benefits from brownfield reconversion for biofuel generation offers multiples benefits and services for investment made. Finally, yet importantly, the production of biofuels from feedstock grown on former brownfields avoids both competition with agricultural land (i.e. crops for feedstock production) and reduces land consumption, thus contributing to mitigate GHG emissions and climate change.

The pros and cons using brownfields for different forms pf renewable energy production are summarised in Table 11.

*Table 11. 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 | • Economic benefits may not be sufficient to fully cover brownfield restoration costs (but can still provide a useful offset)<br>• Renewable energy supply typically requires long term use of a site (circa |

[14] https://www3.epa.gov/lmop/faq/landfill-gas.html

| Advantages | Disadvantages |
| --- | --- |
| • Renewable energy provides income in support of brownfields management and restoration<br>• 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)<br>• Compatibility with other forms of land use (e.g. crops, grazing animals, parkland are all feasible | 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.<br>• 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) |

Efforts in the US to identify the renewable energy potential of impaired lands and provide supporting resources for communities, landowners and developers have yielded impressive results. From a 2006 baseline of seven (7) projects with a total capacity of 7.5 MW, by 2016 190 renewable energy installations have been installed on contaminated lands, landfills, and mine sites, with a cumulative installed capacity of just over 1,172 megawatts (US EPA 2016). Furthermore, publicly available, stakeholder-reported information indicates that communities have saved millions of dollars in energy costs, created construction jobs, and received new property tax revenue as a result of reusing impaired sites for renewable energy. Two examples of renewable energy on mining lands in the US are:

- Chevron Questa Mine

Chevron, the potentially responsible party, coordinated with federal and local environmental ministries during clean-up planning, enabling construction of a 1-megawatt (MW) concentrated photovoltaic (CPV) solar facility over 20 acres of the site. The 175-panel facility has been operating since April 2011. Today, it is the largest facility of its kind in the United States. A local energy cooperative purchases the energy through a 20-year purchase agreement. The solar facility generates enough electricity to power about 300 homes.

- Avalon Solar Facility

In Southern Arizona, a public private partnership redeveloped ASARCO mine property for a utility-scale solar array. The project, called the Avalon Solar Facility will deliver 35 MW of clean energy for the local utility under a 20-year power purchase agreement.

## Renewable energy feasibility assessment case studies in Colombia

As part of this report's work we applied the *"Electronic Decision Tree"* is used to determine the feasibility of a site to develop a renewable energy project, taking into account its use in contaminated or degraded sites (https://www.epa.gov/re-powering/re-powerings-electronic-decision-tree). The decision tree tool is intended to engage non-experts in renewable energy to screen potentially contaminated or underutilized sites or landfills for whether they are good candidates for solar PV or wind projects. It is built so that more knowledgeable professionals can quickly navigate through the decision tree, and less experienced stakeholders can access additional information as they make their way through the questions. The tool is not intended to replace or substitute the need for a detailed site-specific assessment that would follow this kind of initial screening (US EPA 2016).

The tool addresses the following types of sites:

- Potentially contaminated sites
- Landfill (municipal solid waste, construction and demolition or similar unit)
- Underutilized (abandoned parcels, parking lots, buffer zones)
- Rooftop (solar PV only; commercial / industrial roofs)

It was used to help ascertain whether potential barriers to a solar or wind project exist at a site of interest, and the tool itself provides:

- A step-by-step walk through of key considerations for renewable energy development at the site;
- Suggested resources to help you answer screening questions to gauge the site's potential; and
- Reports summarizing your answers to the screening questions, initial findings regarding suitability and other comments about the site.

This project used this tool to evaluate the two pilot sites in Colombia, Segovia and Tadó. In order to make a correct comparative analysis, an additional site contaminated by pesticides in Cartagena City on Colombia's northern coast was selected because of the high level of radiation.

The tool was used in its entirely, although for some in some cases information inputs had to be made on the basis of assumptions because complete information was not available. It was also necessary to be aware that some American parameters used in the tool did not apply to Colombia. However, we used the tool both to provide a first approximation and 3 build capacity of Colombian-based organisations. Based on our experience the tool could also be used for other sites in Colombia and indeed throughout out Latin America.

### Results Segovia assessment

The site evaluated corresponds to "El Planchón Mine" in Segovia Antioquia. It is a currently exploited artisanal gold mine located at one of the most active municipalities in regards of this kind of economic activity but in an artisanal and illegal way. Solar resource at the site is greater or equal to 3,5 KWh/m2/day according to the Colombian Atlas of Wind and Solar energy.

Initial Findings from EPA Tool are satisfied criteria on general site characteristics, redevelopment considerations and load assessment and financial were obtain.

The area available for PV in the Segovia site is approximately 0,703 Ha or 1,7372 Acres (according to a rough estimate based on satellite images of Google Earth that do not have very good resolution in the area), and the perimeter is about 340 m. However, collecting information is needed to answer the skipped questions and return to the decision tree.

### Results Tadó Assessment

The site evaluated corresponds to an abandoned mine 8 years ago. This site has 116 acres approximately. The site is not free of land use or restrictions that would preclude the use of PV solar. It is located on environmentally sensitive or preservation areas, restrictions around airports nor sites of historical or cultural significance.

Previous studies have been developed, but they have not been continuous. Those previous studies were focused on phytoremediation but there is no enough data or results.

Initial findings from EPA tool is that the site need additional information to assess. One or more central questions has been skipped, there may not be enough information to make an initial judgment whether the site is a good candidate for renewable energy development or not. These findings do not replace or substitute the need for a detailed site specific assessment.

### Results Cartagena Assessment

In order to make a comparison with a site that has a much more viable record in the installation of renewable energy primarily focused on Solar energy took a property in Cartagena, north coast of Colombia.

The total land consists of around 44 Ha, of which approximately 20 Ha are available for PV systems installation. Currently the site is contaminated with pesticides and remediation process is already doing by environmental consultants. In the area of the initial site there is a security confinement that stores in a temporary and long term an estimated 22,726 m3 of containers with obsolete pesticide residues and soils contaminated with pesticides. Likewise, traces of heavy metals like Cadmium and Lead appear that do not correspond to the nature of the confined residues.

The results of the studies reported by the site’s owner in 2014 (and which continue to report on a regular basis according to the authorities' request) show that the confinement system has worked so far, according to design considerations. The owner is interested in the remediation due to the request of the environmental authorities since 1999. In fact, to date, on-site remediation efforts (Oxidation using alkaline solution of Sodium Persulfate) have been made by a consultant company. Additionally, the site’s owner has led a social work with the community which is mostly directed to give information about the site contamination and the remediation that is being done.

The solar radiation of the site is between 5 and 5,5 KWh/m2/day according to the Colombian Atlas of Wind and Solar energy; and the Wind Energy Density at 80 meters Height is between 343 – 512 W/$m^2$, according to that Atlas.

Also, initial Findings from EPA Tool showed satisfied criteria on general site characteristics, redevelopment considerations and load assessment and financial. The current cost is approximately 0,13 US$/KWh per the unit cost of providing the service of Electricaribe.

Feasible project arrangements according with EPA tool are sell power utility and sell power to off-site buyer or collection of buyers.