Crop-Based Systems for Sustainable Risk-Based Land Management for Economically Marginal Damaged Land

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The increasing need for biomass for energy and feedstocks, along with the need to divert organic methane generating wastes from landfills, may provide the economic leverage necessary to return this type of marginal land to functional and economic use and is strongly supported by policy at the European Union (EU) level. The use of land to produce biomass for energy production or feedstocks for manufacturing processes (such as plastics and biofuels) has, however, become increasingly contentious, with a number of environmental, economic, and social concerns raised. The REJUVENATE *project has developed a decision support framework to help land managers and other decision makers identify potential concerns related to sustainability and what types of biomass reuse for marginal land might be possible, given their particular circumstances. The decision-making framework takes a holistic approach to decision making rather than viewing biomass production simply as an adjunct of a planned phytoremediation project. The framework is serviceable in Germany, Sweden, and the United Kingdom. These countries have substantive differences in their land and biomass reuse circumstances. However, all can make use of the set of common principles of crop, site, value, and project risk management set out by REJUVENATE. This implies that the framework should have wider applicability across the EU. This article introduces the decision support framework. © 2011 Wiley Periodicals, Inc.*

INTRODUCTION

The use of land to produce biomass for energy production or feedstocks for manufacturing processes (such as plastics and biofuels) has become increasingly contentious, with a number of environmental, economic, and social concerns raised. Across Europe there are areas of land that have been damaged by past use. These include brownfields[1] and land affected by contamination. In a large number of situations this land is derelict or underutilized because its restoration is uneconomic or unsustainable using conventional methods. This economically stalled land is described as "marginal land" within this article.

There are estimated to be close to one million potential brownfield sites across the European Union (EU; Oliver et al., 2005). The European Environment Agency (EEA) has also collated information regarding the quantity of land contaminated by point sources in Europe. In August 2007, the EEA (EEA, 2007) estimated that 250,000 sites across Europe

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would require cleanup, with potentially polluting activities having occurred at nearly 3 million sites, and the number of sites was projected to increase. The EEA's report concluded that "although considerable efforts have been made already, it will take decades to clean up a legacy of contamination."

The extent of diffuse contamination is less well known as evidenced by the European Commission's (EC's) 2010 report, *European Environment State and Outlook on Soil* (EC, 2010), but appears to be a substantial problem. For example, across two small countries, Belgium and the Netherlands, diffuse metal contamination affects approximately 700 km^2 of land. Thousands of square kilometers of diffuse contamination are suspected in Eastern Europe (e.g., in Lithuania and Ukraine; EC, 2004). Significant areas of land in Belarus, Russia, Ukraine, and other countries are contaminated with ^{137}Cs, following the Chernobyl accident (Shevchuk & Gurachevskij, 2001). Oil seed rape production for biodiesel now takes place at a large scale in Belarus on this land, and is seen as a major opportunity to bring the land back into economic use (Wingate, 2008). Contamination of soils around military sites poses problems in the Baltic States, Czech Republic, and Hungary. For example, in Estonia, abandoned military bases cover about 1.8 percent of the country's land mass (EEA and UNEP, 2000).

"Although considerable efforts have been made already, it will take decades to clean up a legacy of contamination."

The increasing need for biomass for energy and feedstocks, along with the need to divert organic wastes from landfills where they generate methane, may provide the economic leverage necessary to return this marginal land to functional and economic use. This may be particularly advantageous where marginal land is present in significant amounts and cannot be readily used for development projects with buildings or food production. The production of biomass and the diversion of biowastes from landfills are supported strongly by policy at the EU level (EC, 2005, 2008). However, the use of land to produce biomass for feedstocks, fuels, and energy has become increasingly contentious in Europe and North America (e.g., OECD, 2007; Oxfam, 2007; Scharlemann & Laurence, 2008). Production on marginal land provides wider sustainability benefits related to land restoration (as illustrated in Exhibit 1) and the resumption of economic activities, and does not remove prime agricultural land from food production.

In addition, the need for soil restoration and soil improvement provides a potential market for composts and digestates produced from biowastes and other organic residues, and reduces the use of primary resources in the land management and crop production process. Some of these primary resources, such as mineral phosphate, are in increasingly short supply (Carpenter & Bennett, 2011). Combined recycling of organic matter and biomass production on marginal land may also have carbon sequestration benefits.

The *REJUVENATE* project (Bardos et al., 2010) has developed a decision support framework to help land managers and other decision makers identify what types of biomass reuse for marginal land might be possible, given their particular circumstances. The *REJUVENATE* project involved several countries—Sweden, Germany, UK, and the Netherlands—and a second phase project[2] is currently applying this framework to a number of case studies and testing its validity for a wider range of European countries (Andersson-Sköld et al., 2011; Bardos et al., 2010). The purpose of this article is to introduce the *REJUVENATE* decision support framework. This framework takes a holistic approach to decision making rather than viewing biomass production simply as an adjunct of a planned phytoremediation project.

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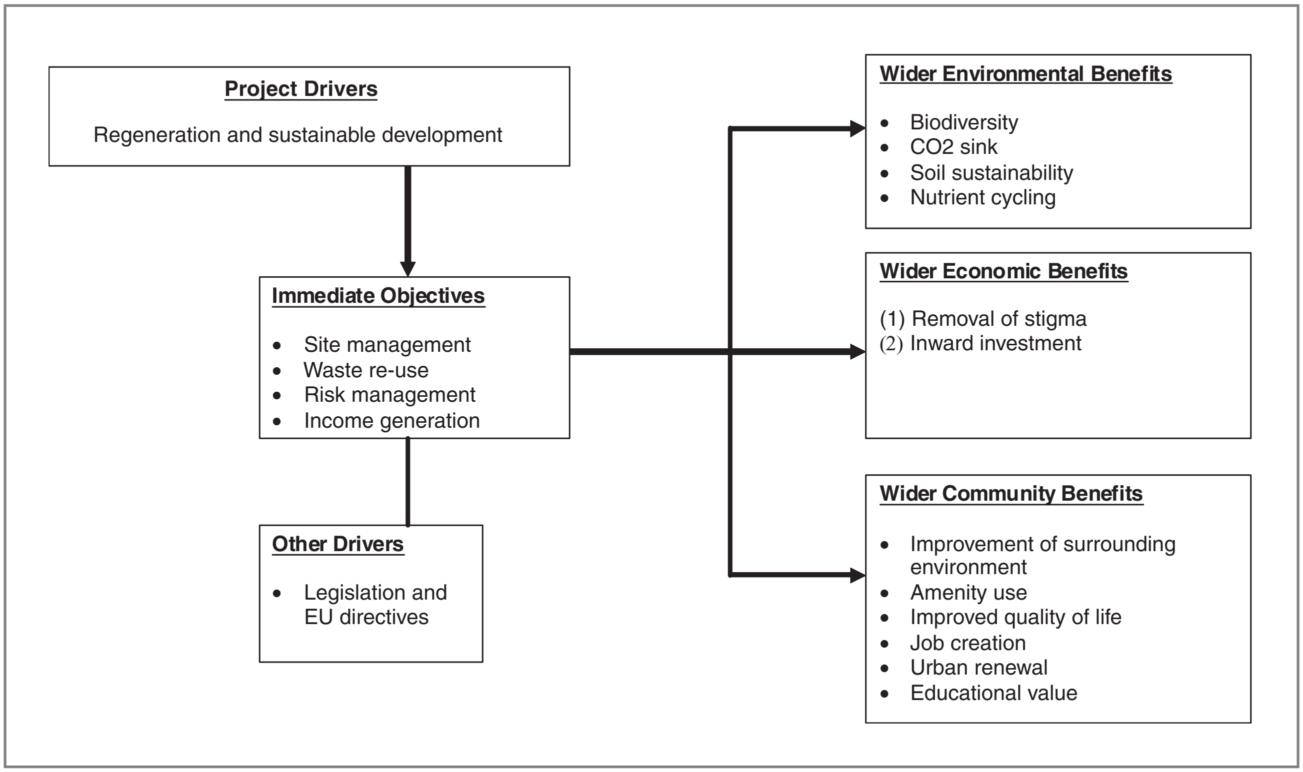

Exhibit 1. Example of a sustainability value proposition for non-food production on marginal land (Bardos et al., 2001)

PHYTOREMEDIATION OF CONTAMINATED LAND AND BIOMASS RECOVERY

The use of plants to manage soil contamination has long been recognized as a low-impact means of managing problems of land contamination (i.e., a relatively low cost approach that does not require the intensive use of energy or resources; Bardos & van Veen, 1996, Suthersan, 2002). In addition, as an *in situ* treatment it avoids excavation of soil that then must be transported to a landfill for disposal or treated *ex situ* (Marmiroli & McCutcheon, 2003). Phytoremediation methods (Nathanail et al., 2007) include:

- *Phytocontainment*: maintenance of a plant cover that prevents access to contaminants and limits their transmission by contaminant releases due to blowing dust
- *Phytodegradation*: the degradation of contaminants in the root zone directly by plant metabolism
- *Phytoextraction*: the removal of contaminants from soil into harvestable biomass
- *Phytostabilization*: reducing mobility of or immobilizing contaminants *in situ* as a result of root zone processes
- *Phytostimulation*: the degradation of contaminants by root zone microorganisms.
- *Phytovolatilization*: preventing the migration of dissolved volatile organic compounds through groundwater by their interception by tree roots and consequent volatilization via transpiration

In general, where biomass recovery has been researched or trialed as part of contaminated land management, it has been as part of a phytoextraction approach and, to a lesser extent, phytostabilization (Mench et al., 2010), typically for managing diffuse metal contamination across large areas. The most successful phytoremediation method depends on several site-specific factors, including geology/hydrogeology, hydrology, the contamination characteristics, and site grade. In addition, the land use and the planned use in short- and long-term perspectives are important factors in selecting the phytoremediation method (Andersson-Sköld et al., 2009).

Phytoremediation based on the degradation of organics aims to achieve complete mineralization of the organic pollutants, and has been trialed at field scale, although in a more limited way than for phytoextraction and phytostabilization (Mench et al., 2010). Its effectiveness is related to the degradability of the organic contaminants, which generally favors lower-molecular-weight, nonsubstituted compounds (Nathanail et al., 2007). Higher-molecular-weight compounds are only slowly degradable, although there is evidence that some can be irreversibly immobilized in soil, in particular, incorporation of polynuclear aromatic hydrocarbons into soil humic materials (Smith & Riddell-Black, 2007; Stegman et al., 1991).

A number of small- to large-scale phytoextraction trials have been completed or are underway (Mench et al., 2010). Other reviews include Biorenew Consortium (2002), Environment Agency (2002), French et al. (2007), Greger and Landberg (2003), Lord et al. (2007, 2008), U.S. Environmental Protection Agency (EPA; 1999), and Vangronsveld et al. (2009), mostly with willow *short rotation coppice* (SRC) on sites contaminated by potentially toxic elements (PTEs), including radionuclide contaminated sites (Dutton & Humphrys, 2005). Phytoextraction for PTEs may also result in accumulation of organic contaminants in the biomass (e.g., White et al., 2005).

In parallel with the development of phytoremediation techniques there have been developments in the strategies and decision making for contaminated land management (CLM). The two most significant of these are the widespread adoption of a risk-based approach for CLM and the emergence of sustainability considerations as a driving force in CLM option appraisals. The findings of the European *CLARINET* project in 2002 (Vegter et al., 2002) were the catalyst for increasing use of risk (e.g., to human health, water, and the wider environment) as the basis for CLM regulation and decision making, using the source-pathway-receptor paradigm (i.e., "pollutant linkage"), by regulators across the EU.[3] This has come to be known as Risk-Based Land Management (RBLM). More recently (and also as predicted by CLARINET) sustainability has also emerged as an important consideration in CLM. "Sustainable remediation" concepts are being developed by a number of forums worldwide[4] (Bardos et al., 2011a) considering how various indicators of environmental, economic, and social benefits and impacts can be used in decision-making.

While these developments might be expected to be positive in terms of encouraging the uptake of phytoremediation, given its low-impact characteristics, there are some significant challenges in using phytoextraction for risk management and biomass production on PTE contaminated sites. Phytoextraction is relatively slow, and is not particularly efficient at extracting metals. Hence, projected treatment times are on the order of decades (Environment Agency, 2002; Mench et al., 2010; Vangronsveld et al., 2009). Although "hyperaccumulators" offer the potential for higher levels of biomass accumulation of metals (Baker et al., 1994), there are few examples of species that can be

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used for practical CLM. Tong-Bin et al. (2007) describe the pilot scale use of *Pteris vittata* to remove arsenic at a site in China. Furthermore, phytoremediation can be applied only in conditions that can sustain plant growth, and the extraction effect is largely limited to the rooting depth of the plants (Environment Agency 2002; Huang et al., 1997; Marmiroli & McCutcheon, 2003; Suthersan, 2002; Vangronsveld et al., 2009).

Viewed from the perspective of RBLM, phytoextraction has been developed as a *source removal* intervention (i.e., its aim is removal of the source of contamination from the source-pathway-receptor linkage, thereby mitigating the risk). Its risk management performance may therefore be compromised in two ways. First, the source removal is slow and incomplete. Second, the creation of biomass enriched in PTE potentially creates a new linkage depending on how the biomass is managed. Furthermore, from a sustainability context, where harvested biomass contains elevated levels of metals, in many countries it would be designated as a "waste." This would mean that it could be used only in specialized facilities with appropriate licensing and permitting. This could greatly reduce its usefulness and value (Andersson-Sköld et al., 2009; Bardos et al., 2001; Haensler, 2003). Indeed, discussions with stakeholders in Germany, Sweden, and the UK undertaken by the REJUVENATE team indicate that concerns about contaminants in biomass, and how such biomass would be regulated, are hurdles to investment in biomass on marginal land. Consequently, the circumstances in which phytoextraction is practical for CLM will depend on the acceptability of long treatment times (decades) and any opportunities for use of biomass containing accumulated PTEs.

As an alternative, decoupling risk management from a strict dependency on source removal via biomass production, and also considering pathway management, might increase the range of possible biomass production uses of PTE-contaminated marginal land. A strategy of minimizing contaminant loadings in the biomass produced on marginal land, or using uncontaminated fractions of biomass, would maximize the range of uses for the biomass produced and hence its economic value. An ideal approach would be that the income from biomass production offsets or, possibly, even exceeds the ongoing CLM costs for the land. Hence, biomass production is simply a part of the envisioned future land use, with risk management being achieved by other means, such as the use of phytoremediation for pathway management through stabilization and containment rather than extraction. It is possible that several risk management strategies may be employed across a site producing biomass in an integrated way, some of which are mediated by plants, some of which are not, for example:

A strategy of minimizing contaminant loadings in the biomass produced on marginal land, or using uncontaminated fractions of biomass, would maximize the range of uses for the biomass produced and hence its economic value.

- Source management
  - Removal or treatment of "hotspots" using engineering approaches
  - Immobilization of contaminants by means of phytostabilization processes
- Use of *in situ* stabilization agents such as modified biochar (Anon, 2010), zerovalent iron (Cundy et al., 2008), or steel slag (Pichtel et al., 1994; Pinto et al., 1995), subject to the suitability of the amendment with regard to release of PTEs
- Pathway management
  - Generation of a "clean" surface soil horizon through the addition of restoration materials and biomass cultivation to reduce emissions to air and water

- Receptor management
  - Selection of plants that tend not to accumulate contaminants in their usable parts

The design and decision making for such a strategy will likely be highly site specific, depending on:

1. The selection of a suitable biomass opportunity
2. The soil improvement and risk management needed
3. Economic feasibility and sustainability
4. Implementation risks

Understanding these four sets of factors in a sequential way to optimize decision-making efforts defines the *REJUVENATE* decision support framework, described in the following.

ORGANIC MATTER AS A RESOURCE FOR SOIL IMPROVEMENT ON MARGINAL LAND

Soils in a marginal land area may need to be made suitable for the crop cultivation (e.g., they need to be of adequate structure, depth, and fertility). Soil management also needs to take account of the impacts of site management, including the preparation for and maintenance of crop production. In some cases the marginal land will not have a functioning soil, in which case a series of "soil-forming" interventions will need to be implemented. Organic matter recycling to soil can support both the creation of initial conditions suitable for biomass production and the maintenance of the soil over the period of biomass production, whether it is for several years or decades. The performance developments for soil that can be supported, wholly or in part, by organic matter return include:

- Soil formation (Bending et al., 1999; Foot & Sinnett, 2006).
- Improvement of the physical structure and resilience of the soil to improve its chemical functioning, such as buffering and cation exchange capacity; and to improve its biological functioning, such as turnover and supply of plant nutrients (Foley & Cooperland, 2002, Golabi et al., 2007, Pagliai et al., 2004, Stukenholtz et al., 2002).
- Supply of plant nutrients such as N, P, K, Mg, and Ca, substituting for mineral fertilizers to reduce the use of primary resources and fossil fuel–based inputs (WRAP, 2008). For some biomass crops (e.g., willow) it may be possible to entirely substitute composts for mineral fertilizers because of their relatively low carbon requirements (Adegidi et al., 2003).

Organic matter return may also play a role in risk management of contaminants in the soil with immobilization onto added organic matter from composts and plant-mediated processes of contaminant stabilization in the subsurface (Ruttens et al., 2006a, 2006b). The effect of compost on trace element mobility appears to be highly case specific, as in some cases dissolved organic compounds and colloids from composts may increase the mobility of trace elements (McCarthy & Zachara, 1989; SU:BRIM, 2008).

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There is a wide range of potential organic matter amendments that could act as renewable sources of soil improvement and fertilizer. Of particular benefit is the potential for supporting the recycling of biowastes (i.e., organic wastes from municipal sources). These include sewage sludge (BIOPROS Consortium, 2006), source segregated wastes, such as garden and food wastes (WRAP and Environment Agency, 2009b), and "mechanical-biological-treatment" (MBT) facilities that produce compost-like outputs (CLO; Cameron et al., 2008). However, organic matter amendments themselves also can pose risks, depending on their source and composition, as follows:

- *Potential biological hazards.* Many plant pathogens are destroyed during the composting process, although some parasitic organisms may persist (Noble & Roberts 2003). Human and animal pathogens are likely to be rare or absent in properly made and matured composts, if produced in accordance with the Animal By-product Regulations (Department for Environment Food and Rural Affairs [Defra], 2008). Where large volumes of organic materials are used, mechanical agitation may create a localized risk of dispersal of bioaerosols (Environment Agency, 2009a).
- *Potential chemical hazards.* One concern is the possibility that increasing quantity of organic matter returning to the land may increase PTE loading in soil (Nicholson & Chambers, 2008). Levels of many PTEs, in particular, arsenic, cadmium, copper, lead, and especially zinc, tend to be elevated in CLO and sewage sludge compared with naturally occurring soils (Bardos, 2005; Defra, 2007; Environment Agency, 2009b). There are also concerns that CLOs and sewage sludge may contain persistent organic pollutants (POPs) at unacceptable levels, although not all authors agree that this is a cause for concern (Amlinger et al., 2004; Smith & Riddell-Black, 2007).
  The plant nutrient components of compost can also have negative impacts on ground and surface water if excessively applied (Defra, 2009) and the decomposition of the organic matter added may cause changes in soil pH and redox conditions (Inbar et al., 1990). Conversely, decomposition of organic matter added to soil may cause temporary immobilization of nitrogen, and reduction in its availability to plants, if the compost has a high carbon-to-nitrogen ratio (Rahn, 2000). The availability and transport of nitrogen to groundwater and surface water will need to be assessed and, if necessary, mitigated.
- *Potential physical hazards.* Depending on the substance in question, inert materials, such as stones, glass, metal, sharp items, and plastic, pose a variety of problems in compost and more particularly for CLOs; in particular, the visual appearance of soils treated with CLOs may be affected (Bardos, 2005). There is potential for harm to wildlife or domestic animals due to the presence of inert materials, for example, via the ingestion of plastics (Mays et al., 1973).

The severity of any impact is related to the composition of the organic matter added, the requirements of the soil, and its application and the sensitivity of the land, for example, its proximity to water resources and its capacity to buffer inputs such as nitrogen and phosphorous. Standards and quality protocols are widespread across Europe (e.g., TRI, 2009; WRAP et al., 2011) to minimize risks from biological and chemical contaminants in composts, and codes of practice are used to minimize impacts from inappropriate use, for example, to prevent excessive introduction of plant nutrients. However, the combination of issues presented by marginal lands, for example, soil contamination and requirements for water protection, the sensitivities of particular biomass crops, such as poplar, to rusts, or prevention of exposure of workers to dusts from organic matter stockpiles, suggests that a site-specific impact assessment is warranted before implementing phytoremediation projects.

DECISION-MAKING APPROACH

The most significant influencers of decisions, besides the party conducting the cleanup, are generally the local communities.

It seems difficult to determine simultaneously the approaches that will be taken to biomass production, soil management, and risk management as well as considering wider sustainability benefits and impacts and possible project risks. All of these considerations interact, so decisions cannot be taken in isolation of each other. One way of dealing with this dilemma is to take a project management approach, considering decisions that are easy to make and limiting on subsequent more difficult decisions, to make the overall planning more manageable.

Decision making should begin with an explicit statement by the project team of their objectives for the marginal land in question, including any constraints, for example: "The overall project objective is to secure a long-term economical solution for a sustainable transformation of a former coal mining site using as much land as possible for biomass production." Furthermore, successful master planning will depend on reaching a local consensus between a range of stakeholders, including those who will be the actual decision makers at the "core" of the project, and others with influential views but not directly involved in the decision making.

The most significant influencers of decisions, besides the party conducting the cleanup, are generally the local communities. Indeed, project managers may wish to bring local community representatives into the master-planning team at an early stage to ensure a good local buy-in. Other influencers may include nongovernmental organizations (NGOs) such as advocacy groups; the local media; and other organizations with a potential interest in the long-term use of the site (CL:AIRE, 2010).

Wider interests may add a significant sustainability benefit for projects. For example, in the UK, community-led restoration projects have been connected with creating educational opportunities and opportunities for sheltered employment, as well as the creation of leisure and amenity benefits (e.g., see projects listed at www.thelandtrust.org.uk). In the Netherlands, restoration projects have reconciled a broad range of wider recreational benefits (e.g., Dijcker et al., 2009).

A parallel project to REJUVENATE 1, called SUMATECS (Environment Agency, 2010), introduced the term "gentle remediation" as a means of removing or stabilizing/immobilizing contaminants in soil using plants, organisms, or soil amendments in a managed way while maintaining or improving the physical structure of the soil. The focus of gentle approaches is clearly to manage pollutant linkages while maintaining or improving soil functions, in particular, environmental regulation and productivity. The project identified a range of limitations with existing decision support tools for the appraisal of phytoremediation options for CLM (Onwubuya et al., 2009), but did not develop a tool itself.

REJUVENATE developed a rationale for decision making that identifies how four interlinked broad stages can be used to refine choices for biomass on marginal land (Exhibit 2):

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Exhibit 2. Decision flow in the REJUVENATE framework

Stage	Substage	Rationale and Key Questions
1. Crop suitability		The functional use of the marginal land is for biomass production; this is only possible if there are one or more suitable crops that may be grown on-site.
	1.1: Range of crops meeting site objectives	What biomass crops can potentially meet project objectives? Site objectives may set boundaries, such as timescale, available area for biomass, linked land uses.
	1.2: Range of crops meeting local climate conditions	What biomass crops can potentially grow in local climate conditions? Consider temperature, rainfall, wind characteristics, hours of sun, days, and depth of frost.
	1.3: Range of crops that can be cultivated on the site's topography	What biomass crops can potentially be cultivated on the site topography? Consider elevation (above sea level), slope gradient, and facing direction.
	1.4: Available uses	Are there any feasible biomass utilization opportunities available? Consider heat and electricity, biofuel, and industrial feedstock utilization; proximity of potential users and scale of operation (minimum hectare requirements).
Output	*A list of feasible biomass crops able to grow under local and topographical conditions, which can fulfil the project team's objectives and for which viable end uses exist.*	
2. Site suitability		Once a list of feasible biomass crops has been determined, it is possible to identify those that could be grown on the site, and what soil and risk management interventions might be necessary.
	2.1: Determining soil management needs	Are the soil conditions suitable for the crops identified in Stage 1 or, if not, what amendments would be needed? Consider options for soil improvement and maintenance.
	2.2: Environmental risk management needs	What environmental and human health risks have been identified and what measures are required to mitigate the risks? Consider the risks associated with the condition of the site—the pollutant linkages (Environment Agency and Defra, 2004) and the remedial action needed to mitigate them, and risks associated with any soil amendments and activities (such as ploughing) used to improve the condition of the soil.
	2.3: Impact of interventions	What impacts may be associated with site management for biomass production? Consider the impact on water resources, the function of the soil, nutrient demand, biodiversity of the site (ADAS, 2002, Haughton et al., 2009), plant uptake, impact on the amenity, site workers, and site users (for example, noise, dust and bioaerosols, road transport) and emissions to air, water, and land from on-site utilization.
	2.4: On-site facilities	Is the site suitable for the necessary infrastructure and utilities to support on-site biomass conversion or utilization? Consider geotechnical conditions, road infrastructure and utilities (potential for on-site generation, water mains, or gray water recovery). What are the impacts associated with facility development? Consider the impact of construction activities and any measures needed to mitigate such impacts.

(*Continued*)

Exhibit 2. Continued

Stage	Substage	Rationale and Key Questions
Output	*A list of feasible biomass crops able to grow on the marginal land under consideration, their soil and risk management needs, and their environmental impacts, along with the on-site conversion strategies for those crops if these are to be considered.*	
3. Value		The possible combinations of biomass, soil management, and risk management interventions will be viable only if they deliver value—most importantly that they are financially secure, but also that they contribute to sustainable development.
	3.1: Financial feasibility	What biomass options are potentially financially feasible? Consider a comparison of direct costs against revenue-earning potential, for example, the potential for renewable energy schemes on-site, use of residues for soil improvement, linking the project to a carbon-offsetting initiatives, or recreational/educational opportunities.
	3.2: Financial viability	Are the options financially viable? Consider the detailed financial model to be used to assess financial viability that will take into account investment thresholds, such as rate of return and time to recover capital as set by investors.
	3.3: Sustainability appraisal	How sustainable are the viable options? Consider metrics to assess the environmental, economic, and social[5] costs and benefits of each viable option identified by the project team and other involved stakeholders (such as local authorities and local community interest groups).
Output	*Economically viable project concepts worthy of detailed appraisals, along with an initial sustainability assessment.*	
4. Project risk		A number of factors can derail a project, even one that is conceptually sound. It is important to consider these before detailed work and significant investment takes place.
	4.1: Stakeholder views	Have all appropriate stakeholders been consulted and necessary approvals, permits, and so on been obtained? During this stage, the project team offers their plans for detailed external comment and scrutiny. This stage includes seeking the necessary permits from planners and regulators, and engagement with the local community and other involved parties.
	4.2: Technology status	Is the selected option practicable? It is important to validate that any techniques to be used or amendments to be applied to the land are fit for the intended purpose and are available for the project over its life span. During this stage, biomass growth trials may be needed to demonstrate the proof of concept (for example, nutrient needs for growth and yield estimates) or efficacy of measures to mitigate impacts. This may include large-scale pilot trials on-site.
	4.3: Detailed diligence	Are all partners, systems, and markets reliable? A due-diligence assessment is needed to produce a detailed project plan. This should include an assessment of the reliability of investment capital, market prices, security of workforce, compliance with legislation, and consolidation of public or regional funding and tax incentives.
Output	*A firm project proposal, with confirmed organizational relationships, where project risks are known and mitigated where necessary, that is ready for detailed planning and implementation.*	

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1. *Crop suitability*. The output from this stage identifies a short list of biomass of crops that are able to grow in the local conditions and have a market outlet, preferably within the region. Each subsequent stage is likely to reduce the length of this list as a more refined solution is found.
2. *Site suitability*. The output from this stage identifies a shortened list of crops that could be grown on-site and specification of the management interventions needed to achieve this.
3. *Value*. The output from this stage identifies project options that are financially viable and sustainable.
4. *Project risk*. The output from this stage is a realistic appraisal of project risks and a mitigation strategy.

Exhibit 2 sets out the key questions that need to be addressed at each stage while the sequence and interlinking of these decisions is illustrated in Exhibit 3. Exhibit 3 uses a "traffic light" system to show when an approach is possible (green), when it is not (red), and when some kind of reevaluation of objectives is necessary (yellow). The REJUVENATE Report (Bardos et al., 2010) provides comprehensive supporting information for each stage for the UK, Sweden, and Germany.

Stage 1: Crop Suitability

The purpose of this stage is to select a list of feasible biomass crops based on local climate conditions, site topography, and utilization opportunities. The effects of future climate conditions need to be taken into consideration when assessing crop suitability. The output of Stage 1 is a list of feasible biomass crops that can fulfill the project objectives and for which an end-use exists. Alternatively, if no crops are feasible, then reasons for this finding can be recorded. It may be appropriate to revisit the original project objectives to widen the range of possible options.

Stage 2: Site Suitability

The purpose of this stage is to consider whether the site conditions are suitable for biomass crops in the Stage 1 list, or can be made suitable by specific intervention, such as remediation or the addition of soil amendments. If an on-site utilization facility is being considered, then the suitability of the site and infrastructure must also be considered. Furthermore, the impacts arising from any site management activities for risk and soil management and facility development need to be properly considered.

The output of Stage 2 is a shortened list of possible biomass crops that could be grown and identification of the management actions needed to achieve this. This also includes an assessment of the proposed site layout and infrastructure.

Stage 3: Value

The purpose of this stage is to evaluate the direct financial feasibility and wider (environmental, economic, and social) value of the project. The output of Stage 3 is an evaluation of the most economically viable option(s) for biomass production and an initial sustainability appraisal of the potentially viable options. A brief description of the

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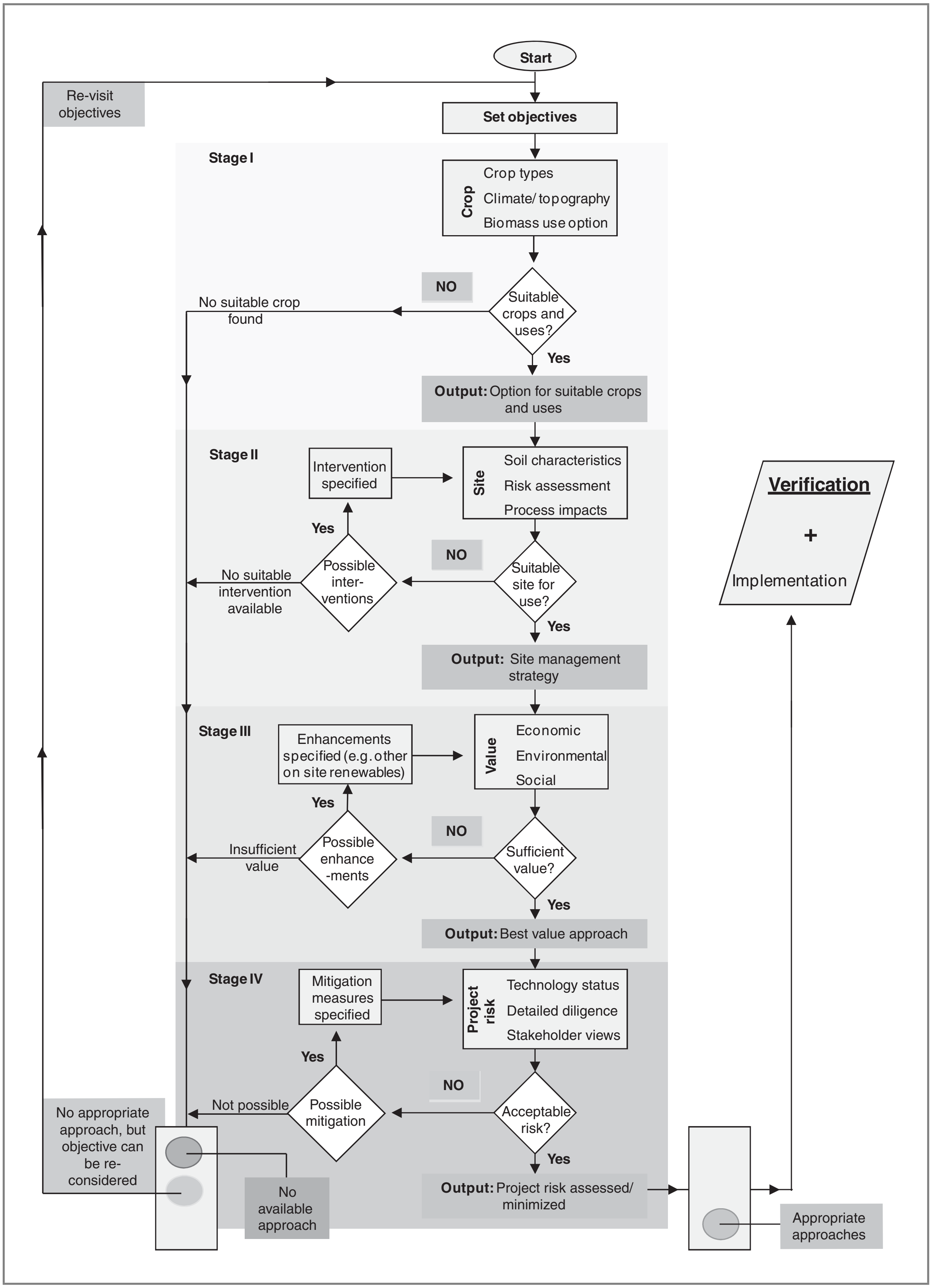

Exhibit 3. Project development for biomass on land

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procedure to assess financial viability for Stage 3 assessment is provided in the REJUVENATE final report (Bardos et al., 2010).

In the UK, the Sustainable Remediation Forum (SuRF-UK) has set out a framework for sustainable remediation that could be applied to biomass production projects (Bardos et al., 2011b, CL:AIRE, 2010).

Life-cycle assessment studies performed within REJUVENATE have shown major sustainable benefits, including reduction in emissions with impact on global and regional scale, use of resources, and even biodiversity, by cultivation on contaminated land compared to more traditional remediation alternatives (Suer et al., 2009). Interviews by key stakeholders, including energy producers and landowners, cultivating *Salix vinimalis* on contaminated sites indicated financial benefits and viability in Sweden (Andersson-Sköld et al., 2009).

The reuse of marginal land has several linkages with the climate change agenda. There are two basic forms of carbon management benefit that may result from the use of marginal land for bio-renewables:

1. *Emissions reduction:* a permanent effect resulting from the substitution of bio-energy for fossil carbon resources, and
2. *Sequestration:* a temporary effect resulting from changes in organic carbon levels in managed soils and the standing crop of biomass on-site.

Substitution of fossil fuel carbon by biomass in both energy and non-energy sectors is possible to a varying degree, depending on how the biomass is produced and the former land use of where it is produced (Crutzen et al., 2008; Environment Agency, 2009c, 2009d; von Blottnitz & Curran, 2007; Zah et al., 2007).

Sequestration of carbon decreases climate change through storage of carbon in soil organic matter. This may be increased through enhancing organic matter input to arable soil on a long-term-management basis (Marmo, 2008). In addition to organic matter input, sequestration also depends on the crop types selected; how they are cultivated, processed, and converted; and what inputs are needed for the management of the site and the system (Bolinder et al., 2007; Kim et al., 2009). The potential for carbon sequestration for short rotation coppice willow was found to be greatest where organic carbon in the soil is depleted (Grogan & Matthews, 2002), which is often the case for marginal land.

Stage 4: Project Risk

The purpose of this stage is to determine the viability of the project, taking into account the project opportunities identified at the end of Stage 3. Three broad considerations are important: technology status, detailed diligence (e.g., of financial partners and project partners), and developing a broad stakeholder consensus. The output of Stage 4 is an appraisal of the project risks and identification of an appropriate mitigation strategy.

This ends the decision-making procedure, at which point the project team will have a firm project concept and a detailed appraisal of project risks and viability, and the basis to continue to design and implementation.

Stage 5: Verification

The final step involves a verification of project performance against environmental, economic, and social goals (Bardos et al., 2010). The verification is based on the results of Stages 1 to 4 and accompanies the project from planning, via setup, to realization. When preparing the project verification plan, the project team needs to consider:

- The time period over which project goals should be verified. It may be useful to identify milestones rather than wait to assess performance at the end of the defined period.
- The assessment parameters for each of the three categories.
- The verification criteria, usually numerical values that were planned to be achieved in the defined period.

Improving the efficiency of the use of marginal land for biomass production will reduce the demand on prime agricultural land to be used for non-food production.

An example of a verification template is provided in the REJUVENATE final report (Bardos et al., 2010).

DISCUSSION

There are significant amounts of marginal land across Europe that are not in beneficial use, including brownfields sites, which are seen as "hard to develop," often for economic reasons. In addition, there are significant amounts of waste-derived organic matter that could be used for restoration, soil improvement, and as a fertilizer substitute. There is an increasing demand for land for biomass (for energy, fuel, and feedstock) and an increasing interest in carbon management opportunities. The conjunction of these needs and interests creates a new opportunity for sustainable development: use of marginal land for biomass production, which may also bring a wider range of benefits and also provide leverage to support the reuse of hard-to-develop sites. The conjunction of several drivers (land restoration, organic matter reuse, and biomass energy) as well as its wider sustainability benefits may make this land very attractive for "pioneering" biomass projects.

Biomass on marginal land projects may be important in localities and regions with a history of long-term land dereliction. Quality will be a determining factor from regulatory and market perspectives. Consequently, the uptake of contaminants into biomass should be limited.

Improving the efficiency of the use of marginal land for biomass production will reduce the demand on prime agricultural land to be used for non-food production. This is an important benefit of returning marginal land to non-food productive use, supported as far as possible by the use of recycled inputs, such as compost, and will contribute to improved food security and more sustainable agriculture. There may also be a wide range of additional sustainability benefits from the biomass reuse of marginal land, particularly at a local level.

The balance of benefits and impacts is highly site- and project-specific and related strongly to local circumstances. The wide-ranging possibilities for both benefits (and impacts) may not always be immediately obvious and may also show strong interrelationships; consequently, REJUVENATE has developed a stepwise decision support framework both to simplify issues by dealing with them in a logical sequence, and

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to provide a checklist to assist decision makers in taking a holistic view of their project proposals.

The decision-making framework (or decision support tool) developed by REJUVENATE is serviceable in Germany, Sweden, and the UK. These countries have substantive differences in their land and biomass reuse contexts. However, all can make use of the set of common principles of crop, site, value, and project risk management set out by REJUVENATE. This implies that this framework should have wider applicability across the EU.

The decision-support approach developed by REJUVENATE should be tested and refined against real demonstration projects, and also against its wider applicability in the EU, particularly for countries with large areas of marginal land. This is now taking place under a second phase of the project.

There would appear to be clear benefits from developing GIS-based approaches to the assessment of potential project opportunities, both from the perspective of individual project developers being able to access consolidated local information in support of their decision making, and also to provide local, regional, and national authorities with estimates of the scale of opportunities for marginal land management, organic matter reuse, and biomass production. At present, these broader assessments made on the basis of existing information do not withstand detailed scrutiny.

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NOTES

1. Brownfields are sites that have been affected by the former use of the site and surrounding land, are derelict or underused, may have real or perceived contamination problems, are mainly in developed urban areas, and require intervention to bring them back to beneficial use (Ferber et al., 2006).
2. http://projects.swedgeo.se/r2/wp-content/uploads/2010/09/Flyer-REJUVENATE.pdf.
3. See home page statement of the web page for the Common Forum on Contaminated Land in the European Union (www.commonforum.eu).

4. Web-based seminars featuring presentations from these initiatives are available at www.cluin.org/consoil.
5. Sustainable development as defined by Brundtland (1987).

REFERENCES

Adas Consulting, Inc. (2002, August). Bioenergy crops and bioremediation–A review. Oxford, UK: Author.

Adegidi, H. G., Briggs, R. D., Volk, T. A., White, E. H., & Abrahamson, L. P. (2003). Effect of organic amendments and slow-release nitrogen fertilizer on biomass production and soil chemical characteristics. Biomass and Bioenergy, 25, 389–398.

Amlinger, F., Pollak, M., & Favoino, E. (2004). Heavy metals and organic compounds from wastes used as organic fertilisers. [Report ENV.A2/ETU/2001/024]. Rue de la Loi, Brussels, Belgium: European Commission. Retrieved from http://europa.eu.int/comm/environment/waste/compost/pdf/hm_finalreport.pdf

Andersson-Sköld, Y., Bardos, P., Crutu, G., Enell, A., Georgescu, P. D., Hoppenbrouwers, M., Track, T., Vanheusden, B., Wagelmans, M., & Witters, N. (2011, May 26–27). REJUVENATE: Biomass on marginal land: Land quality and land use information in the European Union, Keszthely, Hungary. Retrieved from http://landq2011.uni-pannon.hu/

Andersson-Sköld, Y., Blom, S., Enell, A., Haglund, K., Angelbratt, A., Rihm, T., Bardos, P. R., Track, T, Keuning, S. & Wik, O. (2009). Biofuel and other biomass based products from contaminated sites: Potentials and barriers from Swedish perspectives. Project 13702, Dnr 1-0711-0824 SGI SGI Varia 599, Sweden. Varia Statens geotekniska institut (SGI).

Anon (2010). EU developed economic strategy of Chernobyl extension/Byelorussian portal TUT.BY. News, Minsk, 2010. Retrieved from http://www.news.tut.by/170927.html (in Russian); and International projects for the purpose of negotiation of consequence of Chernobyl accident/Ministry of emergencies. Ukraine, Kiev, 2010. Retrieved from http://www.mns.gov.ua/content/chornobyl_international.html (in Russian)

Baker, A. J. M., McGrath, S. P., Sidoli, R. D., & Reeves, R. D. (1994). The possibility of in situ heavy metal decontamination of polluted soils using crops of metal-accumulating plants. Resources Conservation Recycling, 11, 41–49.

Bardos, R. P. (2005). Composting of mechanically segregated fractions of municipal solid waste: A review. Project carried out for SITA Environmental Trust. Gloucestershire, UK.

Bardos, R. P., Andersson-Sköld, A., Keuning, S., Polland, M., Suer, P., & Track, T. (2010). Crop based systems for sustainable risk based land management for economically marginal degraded land. Final Research Report. (REJUVENATE Project). Report for the European Commission's 6th Framework Programme project SNOWMAN (Contract No. ERAC-CT-2003-003219).

Bardos P., Bakker, L., Slenders, H., & Nathanail, P. (2011a). Sustainable remediation. In F.A. Swartjes (Ed.), Book on contaminated sites (pp. 889–948). Dordrecht, The Netherlands: Springer.

Bardos, R. P., Bone, B. D., Boyle, R., Ellis, D., Evans, F., Harries, N., & Smith, J.W.N. (2011b). Applying sustainable development principles to contaminated land management using the SuRF-UK framework. Remediation Journal, 21(3), 77–100.

Bardos, R. P., French, C., Lewis, A., Moffat, A., & Nortcliff, S. (2001). Marginal land restoration scoping study: Information review and feasibility study. [exSite Research Project Report 1]. Nottingham, UK: LQM Press.

Bardos, R. P., & van Veen, J. (1996). Longer term or extensive treatment technologies. Land Contamination & Reclamation, 4(1), 19–36.

Bending, N. A. D., McRae, S. G., & Moffat, A. J. (1999). Soil-forming materials: Their use in land reclamation. London: The Stationery Office.

BIOPROS Consortium. (2006). BIOPROS solutions for the safe application of wastewater and sludge for high efficient biomass production in Short-Rotation-Plantations. Collective Research Project D4: Report on ongoing research and gaps in SRP knowledge. Uppsala, Sweden: Swedish University of Agricultural Sciences. Retrieved from http://www.biopros.info/uploads/media/BIOPROS-D04.pdf

Biorenew Consortium. (2002). Bioremediation and economic renewal of industrially degraded land by biomass fuel crops. [Summary Report]. European Commission Environment Research Programme Contract No. ENV4-CT97-0610. Retrieved from http://publications.environment-agency.gov.uk/pdf/SP5-037-TR2-e-p.pdf

Bolinder, M. A., Janzen, A. A., Gregorich, E. G., Angers, D. A., & VandenBygaart, A. J. (2007). An approach for estimating net primary productivity and annual carbon input to soil for common agricultural crops in Canada. Agriculture Ecosystems & Environment, 118, 29–42.

Brundtland. G. H. (1987). Our common future. World Commission on Environment and Development. Oxford, UK: Oxford University Press. Retrieved from http://www4.oup.co.uk/isbn/0-19-282080-X

Cameron, R. W. F., Wheeler, R. S., Hadley, P. H., Bishop, H. O., Nortcliff, S., Chapman, A. S., Bardos, R. P., & Edwards, D. (2008). Market development of waste derived organic materials (WDOM). Report prepared for Grantscape by the University of Reading and r3 Environmental Technology Ltd. Retrieved from http://www.r3environmental.com

Carpenter, S. R., & Bennett, E. M. (2011). Reconsideration of the planetary boundary for phosphorus. Environmental Research Letters, 6.

CL:AIRE (2010). A framework for assessing the sustainability of soil and groundwater remediation. London, UK: CL:AIRE. Retrieved from www.claire.co.uk/surfuk

Crutzen, P. J., Mosier, A. R., Smith, K. A., & Winiwarter, W. (2008). N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospheric Chemistry and Physics, 8, 389–395. Retrieved from http://www.atmos-chem-phys.net/8/389/2008/acp-8-389-2008.pdf

Cundy, A., Hopkinson, L., & Whitby, R. L. D. (2008). Use of iron-based technologies in contaminated land and groundwater remediation: A review. Science of the Total Environment, 400, 42–53.

De Leij, F. A., Anna, M., Hutchings, T. R., & Wingate, J. R. (2009). Non-activated charcoals from living plant materials are useful as ion exchange agents for adsorbing cations from an environment, especially metal ions. Patent reference: PCT/GB2008/002612.

Department for Environment Food and Rural Affairs (Defra) (2007). Sources and impacts of past, current and future contamination of soil. Defra Science Report. London, UK: Author. Retrieved from http://randd.defra.gov.uk/Default.aspx?Menv=Menu+Module=More+Location=None+ProjectID=13317+FromSearch=Y+Publisher+1+SearchText=SP0547+SortString=ProjectCode+SortOrder=ASC+Paging=10#Description

Department for Environment Food and Rural Affairs (Defra) (2008). Animal by-products: Treatment in approved composting or biogas plants of animal by-products and catering waste—Q&A. Retrieved from http://www.defra.gov.uk/animalh/by-prods/wastefood/compost-qanda.htm

Department for Environment Food and Rural Affairs (Defra) (2009). Farming: Code of good agricultural practice. Norwich, UK: The Stationery Office. Retrieved from http://www.defra.gov.uk/farm/environment/cogap/pdf/cogap090202.pdf

Dijcker, R., Hendriks, W., Groenenberg, B. J., & Lacroix, B. (2009, November). Forest park(land)-integrated and risk based approach for management of contaminated sites. Paper C08 in Proceedings of the Conference on Green Remediation (K. Weber), Copenhagen. Retrieved from www.eugris.info/DisplayNewsItem2.asp?NewsID=667

Dutton, M. V., & Humphreys, P. N. (2005). Assessing the potential of short rotation coppice (Src) for cleanup of radionuclide contaminated sites. International Journal of Phytoremediation, 7(4), 279–293.

Environment Agency. (2002). Bioremediation and economic renewal of industrially degraded land by biomass fuel crops (BIORENEW). [Summary report]. [R&D Project P5-037, Technical Report P5-037/TR2]. Bristol, UK: Environment Agency.

Environment Agency. (2009a). Review of methods to measure bioaerosols from composting sites. [Science report: SC040021/SR3].

Environment Agency. (2009b). A review of human health and environmental risks associated with the land application of mechanical-biological treatment outputs. [Science report: SC030144/SR2]. Bristol, UK: Environment Agency. Retrieved from http://publications.environment-agency.gov.uk/pdf/SCHO0609BQER-e-e.pdf

Environment Agency. (2009c). Biomass: Carbon sink or carbon sinner? [Summary report]. Environment Agency: Bristol, UK. Retrieved from http://www.environment-agency.gov.uk/business/sectors/32595.aspx

Environment Agency. (2009d). Minimising GHG emissions from biomass energy generation. Bristol, UK: Environment Agency.

Environment Agency. (2010). Technical summary of SUMATECS: Sustainable management of trace element contaminated soils. [Evidence report SC080023/R1]. Bristol, UK: Environment Agency. Retrieved from http://publications.environment-agency.gov.uk/pdf/SCHO1009BRCQ-e-e.pdf

European Commission. (2004). Reports of the technical working groups established under the thematic strategy for soil protection, volume IV: Contamination and land management. EUR 21319 EN/4.

European Commission. (2005). Biomass action plan, Brussels. COM(2005) 628 final.

European Commission. (2008). Green paper on the management of bio-waste in the European Union, Brussels. COM(2008) 811 final, {SEC(2008) 2936}.

European Commission Joint Research Centre Institute for Environment and Sustainability. (2010). The European environment state and outlook 2010, soil contribution to SOER 2010. Luxembourg: Publications Office of the European Union. Retrieved from http://eusoils.jrc.ec.europa.eu/SOER2010/Docs/Soil.pdf

European Environment Agency. (2007). Progress in management of contaminated sites (CSI 015): Assessment. Retrieved from http://themes.eea.europa.eu/IMS/IMS/ISpecs/ISpecification20041007131746/IAssessment1152619898983/view_content

European Environment Agency and United Nations Environment Programme (UNEP). (2000). Down to earth: Soil degradation and sustainable development in Europe: A challenge for the 21st century.

 Remediation DOI: 10.1002/rem

Environmental issue series No 16. Retrieved from http://www.unep.ch/roe/publications/assessment/03_soil%20_final4.pdf

Ferber, U., Grimski, D., Millar K., & Nathanail, P. (2006). Sustainable brownfield regeneration: CABERNET network report. The Concerted Action on Brownfield and Economic Regeneration Network (CABERNET). Nottingham, UK: CABERNET. Retrieved from http://www.cabernet.org.uk

Foley, B. J., & Cooperland, L. R. (2002). Paper mill residuals and compost effects on soil carbon and physical properties. Journal of Environmental Quality, 31, 2086–2095.

Foot, K. & Sinnett, D. (2006). Imported soil or soil-forming materials placement. Best Practice Guidance for Land Regeneration BPG Note 5. Farnham, UK: Forest Research.

French, C. J., Dickinson N. M., & Putwain, P. D. (2007). Woody biomass phytoremediation of contaminated brownfield land. Environmental Pollution, 141, 387–395.

Golabi, M. H., Denney M. J., & Iyekar C. (2007). Value of composted organic wastes as an alternative to synthetic fertilizers for soil quality improvement and increased yield. Compost Science & Utilization, 15, 267–271.

Greger, M., & Landberg, T. (2003, June 15–10). Improving removal of metals from soil by salix. In Seventh International Conference on the Biochemistry of Trace Elements, SLU, Uppsala, Stockholm.

Grogan, P., & Mathews, R. (2002). A modelling analysis of the potential for soil carbon sequestration under short rotation coppice willow plantations. Soil Use and Management, 18, 175–183.

Haensler, J. (2003). Phytoremediation schwermetallbelasteter Böden durch einjährige Pflanzen in Einzel- und Mischkultur. Retrieved from http://docserv.uni-duesseldorf.de/servlets/DerivateServlet/Derivate-2527/527.pdf

Haughton, A. J., Bond, A. J., Lovett, A. A., Dockerty, T., Sünnenberg, G., Clark, S. J., Bohan, D. A., Sage, R. B., Mallott, M. D., Mallott, V. E., Cunningham, M. D., Riche, A. B., Shield, I. F., Finch, J. W., Turner, M. M. & Karp, A. (2009). A novel, integrated approach to assessing social, economic and environmental implications of changing rural land-use: A case study of perennial biomass crops. Journal of Applied Ecology, 46, 315–322.

Huang, J. W., Chen, J., Berti, W. R., & Cunningham, S. D. (1997). Phytoremediation of lead-contaminated soils: Role of synthetic chelates in lead phytoextraction. Environmental Science & Technology, 31, 800–805.

Inbar, Y., Chen, Y., Hadar, Y., & Hoitink, H.A.J. (1990). New approaches to compost maturity. BioCycle, 31(12), 64–69.

Kim, H., Kim, S., & Dale, B. E. (2009). Biofuels, land use change, and GHG emissions: Some unexplored variables. Environmental Science & Technology, 43(3), 961–967.

Lord, R., Atkinson, J., Lane, A., Scurlock, J., & Street, G. (2008, March 9–12). Biomass, remediation, regeneration (BioReGen Life Project): Reusing brownfield sites for renewable energy crops. GeoCongress08, New Orleans, ASCE Geotechnical Special Publication. Reston, VA: American Society of Civil Engineers.

Lord, R., Atkinson, J., Scurlock, J., Lane, A., Rahman, P., Connolly, H., & Street, G. (2007, May 7–11). Biomass, remediation, regeneration (BioReGen Life Project): Reusing brownfield sites for renewable energy crops. Proceedings 15th European Biomass Conference & Exhibition (pp. 40–45), Berlin, Germany.

Marmiroli, N., & McCutcheon, S. C. (2003). Making phytoremediation a successful technology. In S. C. McCutcheon & J. L. Schnoor (Eds.), Phytoremediation: Transformation and control of contaminants (pp. 85–119). New York: John Wiley & Sons.

Marmo, L. (2008). EU strategies and policies on soil and waste management to offset greenhouse gas emissions. Waste Management, 28, 685–689.

Mays, D. A., Terman, G. L., & Duggan, J. C. (1973). Municipal compost: Effects on crop yields and soil properties. Journal of Environmental Quality, 2(1), 89–92.

McCarthy, J. F., & Zachara, J. M. (1989). Subsurface transport of contaminants: Mobile colloids in the subsurface environment may alter the transport of contaminants. Environmental Science & Technology, 23(5), 496–502.

Mench, M., Lepp, N., Bert, V., Schwitzgubel, J., Gawronski, S. W., Schroeder, P., & Vangronsveld, J. (2010). Successes and limitations of phytotechnologies at field scale: Outcomes, assessment and outlook from COST Action 859. Journal of Soils and Sediments, 10, 1039–1070.

Nathanail, J., Bardos, P., & Nathanail, P. (2007). Contaminated land management ready reference. London, UK: EPP Publications. Retrieved from www.readyreference.co.uk

Nicholson, F. A., & Chambers, B. J. (2008). Sources and impacts of past, current and future contamination of soil appendix 1: Heavy metals SP0547. Defra Science Directorate. London, UK: Department for Environment Food and Rural Affairs. Retrieved from http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=13317&FromSearch=Y&Publisher=1&SearchText=sp0547&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Noble R., & Roberts S. J. (2003). A review of the literature on eradication of plant pathogens and nematodes during composting, disease suppression and detection of plant pathogens in compost. Banbury, Oxon, UK: WRAP. Retrieved from www.wrap.org.uk

Oliver, L., Ferber, U., Grimski, D., Millar K., & Nathanail, P. (2005). The scale and nature of European brownfields. [EC FP5 CABERNET project paper]. Nottingham, UK: CABERNET. Retrieved from http://www.cabernet.org.uk

Onwubuya, K., Cundy, A., Puschenreiter, M., Kumpiene, J., Bone, B., Greaves, J., Teasdale, P., Mench, M., Tlustos, P., Mikhalovsky, S., Waite, S., Friesl-Hanl, W., Marschner, B., & Müller, I. (2009). Developing decision support tools for the selection of "gentle" remediation approaches. Science of the Total Environment, 407, 6132–6142.

Organisation for Economic Cooperation and Development (OECD) Round Table on Sustainable Development. (2007, September 11–12). In R. Doornbosch, & R. Steenblik (Eds.), Biofuels: Is the cure worse than the disease? SG/SD/RT (2007) 3. Paris, France: Author.

Oxfam International. (2007). Bio-fuelling poverty: Why the EU renewable fuel target may be disastrous for poor people. [Oxfam Briefing Note 1, Oxfam]. Retrieved from http://www.oxfam.org/en/node/217

Pagliai, M., Vignozzi, N., & Pellegrini, S. (2004). Soil structure and the effect of management practices. Soil & Tillage Research, 7, 131–143.

Pichtel, J. R., Dick, W. A., & Sutton, P. (1994). Comparison of amendments and management practices for long-term reclamation of abandoned mine lands. Journal of Environmental Quality, 23(4), 766–772.

Pinto, M., Rodriguez, M., Besga, G., Balcazar, N., & Lopez, F. A. (1995). Effects of Linz-Donowitz (L-D) slag on soil properties and pasture production in the Basque country (Northern Spain). New Zealand Journal of Agricultural Research, 38, 143–155.

Rahn, C. R. (2000). Management Strategies to reduce nitrogen losses from field vegetable crops. ISHS Conference: Towards an Ecologically Sound Fertilisation in Field Vegetable Production, Wageningen, Netherlands.

Ruttens, A., Colpaert, J. V., Mench, M., Boisson, J., Carleer, R., & Vangronsveld, J. (2006a). Phyto-stabilization of a metal contaminated sandy soil. I: Influence of compost and/or inorganic metal immobilizing soil amendments on phytotoxicity and plant availability of metals. Environmental Pollution, 144, 524–532.

Ruttens, A., Colpaert, J. V., Mench, M., Boisson, J., Carleer, R., & Vangronsveld, J. (2006b). Phyto-stabilization of a metal contaminated sandy soil. II: Influence of compost and/or inorganic metal immobilizing soil amendments on metal leaching. Environmental Pollution, 144, 533–539.

Scharlemann, J. P. W., & Laurence, W. F. (2008). How green are biofuels? Science, 319, 43–44.

Shevchuk, V. E., & Gurachevskij, V. L. (Eds.). (2001). Fifteen years after Chernobyl catastrophe: Consequences in the Republic of Belarus and their overcoming. Committee on the Problems of the Consequences of the Accident at the Chernobyl NPP, Republic of Belarus National Report, Minsk, Belarus.

Smith, S. R., & Riddell-Black, D. (2007). Sources and impacts of past, current and future contamination of soil. Appendix 2: Organic contaminants SP0547. Defra Science Directorate. London, UK: Department for Environment Food and Rural Affairs. Retrieved from http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=13317&FromSearch=Y&Publisher=1&SearchText=sp0547&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Stegmann, R., Lotter, S., & Heerenklage, J. (1991). Biological treatment of oil contaminated soils in a bioreactor. In R.E. Hinchee & R. Olfenbuttel (Eds.), On-site bioreclamation processes for xenobiotic and hydrocarbon treatment (pp. 188–208). Oxford, UK: Butterworth-Heinemann.

Stukenholtz, P. D., Koenig R. T., Hole D. J., & Miller, B. E. (2002). Partitioning the nutrient and nonnutrient contributions of compost to dryland-organic wheat. Compost Science & Utilization, 10, 238–243.

SU:BRIM Project. (2008). The use of compost in the regeneration of brownfield land SUB 10. London, UK: CL:AIRE. Retrieved from www.claire.co.uk

Suer, P., Andersson-Sköld, Y., Blom, S., Bardos, P. R., Track, T., & Polland, M. (2009). Environmental impact assessment of biofuel production on contaminated land: Swedish conditions in selected case studies. Project 13702, Dnr 1-0711-0824, SGI Varia 600, Sweden. Varia Statens geotekniska institut (SGI) 600.

Suthersan, S. S. (2002). Natural and enhanced remediation systems. Boca Raton, FL: Lewis Publishers.

Technical Research Institute of Sweden. (2009). Certifications rules for compost SPCR 152. BORÅS, Sweden, Author.

Tong-Bin, C., Xiao-Yong, L., Ze-Chun, H., Mei, L., Wen-Xue, L., Liang-Yu, M., Zhi-Zhuang, A., Chao-Yang, W., Xi-Yuan-Xi, X., & Hua, X. (2007). Phytoremediation of arsenic-contaminated soil in China. In N. Willey (Ed.), Biotechnology v23: Phytoremediation: Methods and reviews (pp. 393–402). Totawa, NJ: Humana Press.

United States Environmental Protection Agency. (1999). Phytotechnology for metal-contaminated surface soils. Tech Trends, August Issue No. 34, EPA 542-N-99-005.

Vangronsveld, J., Meers, E., Van Slycken S., Meiresonne, L., Adriaensen K., Witters, N., Thewys T., Boulet, J., Weyens, N., van der Lelie, D., Dejonghe, W., Carleer, R., Mench, M., & Ruttens, A. (2009). Metal accumulation in plants with added economical value grown on metal contaminated soils: Sustainable use of these soils for bioenergy production and possibilities for phytoextraction. Extended abstracts of the 10th ICOBTE Congress in Chihuahua (Mexico).

Vegter, J., Lowe J., & Kasamas, H. Eds. (2002). Sustainable management of contaminated land: An overview. [Report]. Austrian Federal Environment Agency, on behalf of CLARINET: Wien, Austria. Retrieved from http://www.commonforum.eu/publications_clarinet.asp

von Blottnitz, H., & Curran, M. A. (2007). A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. Journal of Cleaner Production, 15(7), 607–619.

Waste and Resources Action Programme (WRAP). (2008). Using compost in agriculture and field horticulture compost information package 1. Branbury, UK: Author. Retrieved from http://www.wrap.org.uk/downloads/AgCIP1.5d67c431.306.pdf

Waste and Resources Action Programme (WRAP) and Environment Agency. (2009, March). The potential for biofuel crop production on a former coal washing site in Kinglassie, Fife. [Project code: OBF002]. Banbury, UK: Author. Retrieved from http://www.wrap.org.co.uk

Waste and Resources Action Programme (WRAP), British Standards Institution and Association for Organics Recycling. (2011). PAS100:2011: Specification for composted materials. Banbury, UK: Author. Retrieved from http://www.wrap.org.co.uk

White, J. C., Parrish, Z. D., Isleyen, M., Gent, P. N., Iannucci-Berger, W., Eitzer, B. D. & Mattina, M. J. I. (2005). Uptake of weathered p,p'-DDE by plant species effective at accumulating soil elements. Microchemical Journal, 81, 148–155.

Wingate, J. R. (2008). Development of novel charcoals for the sorption and transformation of heavy metals in contaminated land. Ph.D. Thesis, University of Surrey.

Witters, N., Van Slycken, S., Ruttens, A., Adriaensen, K., Meers, E., Meiresonne, L., Vangronsveld, J., Tack, F.M.G., Thewys, T., & Laes, E. (2009). Short rotation coppice of willow for phytoremediation of a metal-contaminated agricultural area: A sustainability assessment. BioEnergy Research, 2, 144–152.

Zah, R., Böni, H., Gauch, M., Hischier, R., Lehmann, M., & Wäger, P., (2007). Life cycle assessment of energy products: Environmental impact assessment of biofuels executive summary. St Gallen, Switzerland: Empa.

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