REJUVENATE: Crop Based Systems for Sustainable Risk Based Land Management for Economically Marginal Degraded Land

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Abstract:
The Rejuvenate project is a desk study carried out by four organisations from the United Kingdom, Sweden the Netherlands and Germany. Its goal is to highlight the potential opportunity for using marginal or degraded land, in particular brownfields and other previously developed or contaminated land, for producing biomass. This biomass could be used for energy, fuel production or as a feedstock. The use of marginal / degraded land may offer sustainability advantages in regions where it is present in significant amounts and cannot be readily used for built development. In addition, composts and other recycled organic matter may play an important role in the soil improvement and management necessary for the cultivation of these non-food crops.

INTRODUCTION

Rejuvenate's goal has been to highlight the potential opportunity for using marginal land, in particular brownfields and other previously developed or contaminated land, for producing biomass. (Marginal land is used as a term to include previously developed land, under-utilised land and land affected by diffuse contamination.) This biomass could be used for energy, fuel production or as a feedstock. The use of marginal / degraded land may offer sustainability advantages in regions where it is present in significant amounts and cannot be readily used for built development. In addition, composts and other recycled organic matter may play an important role in the soil improvement and management necessary for the cultivation of these non-food crops.

The specific aims of this project were to:

- explore the feasibility of a range of possible approaches to combining risk based land management (RBLM) with non-food crop land-uses and organic matter re-use as appropriate,
- identify a "matrix" of potential opportunities worthy of further development in the UK, Germany and Sweden and in a wider European context, and
- assess how verification of their performance might be carried out and identifying what requirements remain for future research, development and demonstration.

The project was a desk study carried out by partners from Germany, the UK, the Netherlands and Sweden and began in October 2008 and was completed in June 2009.

The project reports (Bardos *et al.* 2009, Polland *et al.* 2009) provide an overarching review of the opportunities for re-using marginal land for renewables. These renewables may be biofuels, biomass for energy or biofeedstocks (e.g. for plastics) or even natural fibres. Rejuvenate has developed an inclusive decision support approach, which is sensitive to the different national and regional contexts, caused by varying policy, regulatory and market drivers. A good example of these different contexts found in the current project is the interest in the UK of some small or medium sized enterprises (SMEs) in the integration of biomass use with on-site or local small scale waste management and energy solutions, compared with how the interest in Sweden has a greater focus on the sale of biomass off-site for energy conversion by big companies. However, Rejuvenate believes that the fundamental decision making process for bringing marginal land back into use for non-food crops is the same across Europe. The Rejuvenate team has identified the following key steps:

1. The identification of crop and use opportunities;
2. The management and improvement of soil and control of risks;
3. Understanding and maximising value and sustainability; and
4. The management of project risks such as technology status, due diligence and stakeholder perceptions.

BIOMASS ON MARGINAL LAND: SUSTAINABLE DEVELOPMENT AND CARBON MANAGEMENT OPPORTUNITIES

Large areas of brownfield land exist for which there is no economic case for restoration to conventional functional re-use and/or no realistic prospect for "hard" re-use[1]. Not only is there no economic driver, but even if there was, the levels of resource and energy use that would be needed to conventionally restore this land may not be environmentally sustainable either. Consequently local communities and landscapes remain affected by marginal land under varying levels of management. The use of this marginal land for growing biomass for energy and feedstock production could be an important means of unlocking development that is both environmentally and economically sustainable, and that also provides wider societal benefits.

It has been suggested that on a worldwide basis, energy production on abandoned agricultural land could supply up to 8% of world energy (Engelhaupt 2008). However, the use of land to produce any type of biomass for feedstocks, fuels and energy has become increasingly contentious in Europe and North America (BBC 2008, Moore 2008, Scharlemann and Laurence 2008). The use of marginal land, where food cultivation may not be appropriate, is an emerging opportunity in this biomass debate that can address some of the concerns about biomass production on agricultural or virgin / wilderness land.

Not only is marginal land a useful opportunity in many places for biomass production, but the substitution of non-renewable inputs (such as fertilisers) with renewable inputs (such as compost) further improves sustainability. Other organic materials in the area such as agricultural and forestry residues can be a supplementary source of biomass. Hence the

[1] www.cabernet.org.uk

combination of biomass cultivation and soil improvement could be an integral part of land rehabilitation and risk management in the long term. There may also be further benefits from this kind of land use, for example, providing: a self-funding land management regime, economic activity in deprived areas, a long term improvement in land values and environmental benefits such as carbon sequestration (substitution of fossil carbon resources, and "temporary" sequestration in managed soils). Similar ideas have been advanced in the UK by the "SUBR:IM" project[2] (CL:AIRE 2009).

There are two basic forms of carbon management benefit that may result from the use of marginal land for bio-renewables: emissions reduction, a permanent effect; and sequestration, a temporary effect.

Sequestration in soils and biomass is seen as temporary as it depends on the continuation of a particular land management regime. The extent to which a bio-renewable on marginal land will achieve sequestration depends on a series of carbon inputs and outputs, which in turn depend 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 (Kim *et al.* 2009). The potential for carbon sequestration for short rotation coppice (SRC) willow was found to be greatest where organic carbon in the soil had been depleted (Grogan and Mathews 2002).

Carbon impacts from biomass use of land may result from soil disturbance by cultivation and soil nitrogen metabolism. Disturbance of undisturbed soils, for example beneath pasture may lead to GHG release as soil organic matter is oxidised (Gibbs *et al.* 2008). However, marginal land may already be highly disturbed and have only low levels of pre-existing soil organic matter. Hence over time a net increase in soil organic matter is likely (as discussed above). Emissions of nitrous oxide (N_2O) from the nitrogen content of added organic matter may also reduce the overall GHG benefit (ADAS 2002).

Of course, set against the scale of agricultural land use overall, the marginal land bank may not seem large, but it can *offset* the use of some prime agricultural land. However, using it as a biomass resource is important for several reasons: the land bank may be very significant in particular localities and regions, and these are often areas with economic under-performance; it is an effective means of returning productivity to marginal land; that also brings wider sustainability benefits.

LAND BANKS

The Rejuvenate team has collected the land bank information that is available on marginal land, based on publicly available inventories in Germany, Sweden and the UK, and information collated by the European Environment Agency (EEA).

Germany: Brownfields information in Germany is typically compiled (if it is compiled) by individual lände for environmental and land use issues. Dransfeld *et al.* 2002 suggest that in Germany there are: 19,000 ha of industrial and 20,000 ha of infrastructure related

[2] http://www.subrim.org.uk

brownfields, 38,800 ha of Federal properties, and 50,000 ha of properties in conversion from military to civil use. Burmeier (1999) estimated that there were 127,800 ha of brownfield in Germany, while the Federal Environmental Protection Agency (UBA) has estimated that the area is 530,000 ha if military areas are also taken into account (Federal Environmental Protection Agency 2008).

Sweden: Regional MIFO[3] databases have been used to assess the extent of contaminated land in Sweden that could be used for arable purposes such as energy crops. The area of contaminated land that could be used for arable purposes has therefore been estimated on the basis of estimates of the usable area for sites in particular categories. On this basis the total potential arable area of contaminated sites in Sweden was estimated to be up to 778 km^2, about 0.2% of the land area of Sweden, out of a total area of contaminated sites that was estimated to be 2,936 km^2, which is about 0.7% of the land area of Sweden.

UK: In theory a wide range of nationally collated land bank information could be used to make a conjecture about the scale of marginal land bank in the UK, and its potential value in biomass production. However, the information available is very variable. A report for WRAP (2006) estimated that brownfield restoration area available for compost use in England is 3,000 ha. However, the estimate for the area available for community woodland in a single region of the England (Forestry Commission 2002), the Northwest is nearly nine times greater (at 26,385 ha) than this WRAP estimate, and also greater that an estimate of long term derelict land in England of 18,000 – 20,000 ha (Cameron *et al.* 2008). The usable land bank for biomass is dependent on site and market opportunities at a local / regional scale, and so "national" land bank estimates may have limited value in any case.

EEA: In August 2007 the EEA (EEA 2007) concluded that soil contamination requiring clean up is present at approximately 250,000 sites in the EEA member countries. The data is very variable from country to country. They suggest: "Potentially polluting activities are estimated to have occurred at nearly 3 million sites (including the 250,000 sites already mentioned) and investigation is needed to establish whether remediation is required. If current investigation trends continue, the number of sites needing remediation will increase by 50% by 2025."

RISK MANAGEMENT AND BIOMASS PRODUCTION

A starting concept is that the risk management approach for the site is entirely based on phytoremediation, i.e. the use of plants to facilitate contaminant degradation, removal, containment or stabilisation of contaminants (Nathanail et al. 2007, SUMATECS Consortium 2008, US EPA 1999), and that therefore the biomass crop used would be the biomass produced by the phytoremediation plants.

However, from a risk management perspective these marginal land areas are large and may be complex. Opportunities for over-arching phytoremediation solutions might exist, but their practical feasibility is strongly dependent on site specific circumstances, so that a single phytoremediation based risk management approach may only be suitable for a limited number

[3] Methodology for the inventory work concerning contaminated areas in Sweden

of situations. For example, a former mining area will include zones with potentially acute problems demanding an immediate risk management response, with other areas with limited land uses by reason of topography, soil condition and/or levels of contamination. As a result, the biomass based re-use of marginal land should also encompass how biomass might be produced on marginal land where the risk based land management might be undertaken by a variety of means, and not depend solely on phytoremediation.

Phytoremediation is seen by some researchers as important advantages as a risk management tool, because it is low maintenance and relatively cheap, and has the potential to produce a fertile and usable soil (Suthersan, 2002). In addition, as an *in situ* treatment it avoids excavation of soil and disposal to landfill of soils or *ex situ* treatment residues (Marmiroli, 2003). The limitations of phytoremediation are that it is relatively slow, and can only be applied in conditions that can sustain plant growth, and the remediation effect is largely limited to the rooting depth of the plants (Suthersan, 2002, Marmiroli, 2003). Where plants have accumulated contaminants they may provide a source for contaminants to move through the food chain in the local ecology. 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.

In phyto-extraction, biomass removal is an explicit part of the risk management process. However, it is also possible that biomass production is simply a part of the envisaged future land use, with risk management being achieved by other means, or it may be one part of several risk management actions for example managing pathways by assisting with containment and stabilisation of contamination. It is possible that several risk management strategies may be employed across a site producing biomass, some of which are mediated by plants, some of which are not. This *decoupling* of biomass production from risk management would increase the range of possible biomass production uses of marginal land. For example, biomass types vary in the extent to which they accumulate contaminants such as potentially toxic elements. Combining biomass with stabilisation, phyto-stimulation and containment, and seeking biomass types that tend to exclude rather than accumulate contaminants seems more likely to yield usable biomass.

The technical components of a biomass on marginal land project include the biomass crop and its cultivation; the development and management of the soil on the land to be used for the biomass production; the management of any risks associated with the marginal land use for biomass; the utilisation of the biomass and sustainable development. These components will tend to be inter-linked and will have to be considered in an integrated way.

Biomass cultivation: From a cultivation point of view, the selection of a suitable crop will depend on local climatic conditions (which will vary from site to site even within a region) and the topography and size of the marginal land area. Climatic conditions may be seen as limiting, for example owing to temperature or levels of rainfall. Initial screening of biomass opportunities for economic viability is also strongly dependent on local conditions.

Soil and water management: Soil in a marginal land area may need to be made suitable for the crop cultivation, for example they need to be of adequate structure, depth and fertility. Soil and cultivation requirements will vary from crop to crop. Crop requirements for nutrients are conventionally supplied as mineral fertilisers; however compost or other recycled organic matter may substitute for mineral fertilisers to reduce the use of primary resources and fossil fuel based inputs (WRAP 2008). Soil management also needs to take account of the impacts of site management, including the preparation for and maintenance of crop production. These impacts can include compaction, oxidation of soil organic matter and soil losses. 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 carried out. A biomass crop will impact the water environment. For example, some biomass crops may have heavy water demands (Dominguez-Faus et al. 2009, Hall 2003) which may affect groundwater or surface water recharge, or indeed require water resources for irrigation. Biomass production may also impact groundwater and surface water by changing inputs of plant nutrients. Water balance and quality are important considerations in terms of environmental impact and overall sustainability.

Risk management: The re-use of brownfields requires the identification, evaluation, and – where necessary – management of pollutant linkages as part of the development process. Use of a site conceptual model is recommended to support this risk assessment and management activity (Nathanail and Bardos 2004). Crop cultivation and soil improvement such as the addition of organic matter and cultivation may be necessary to support biomass production. However, these interventions may both control or create pollutant linkages. For example, the soil and crop management may also provide part of the management of pollutant linkages because added soil and vegetation prevent direct contact with on-site contamination and reduce dust blow as a pathway (AEA and r3 2004). The establishment of most crops will serve a risk pathway management function through containment, by covering and preventing dust blow off-site, which may be mitigating an important pollutant linkage to off-site receptors. The addition of organic matter and rooting habit of some crops may assist the generation of a new "clean" soil horizon and provide further containment and rooting zones may support enhanced microbial activity leading to contaminant degradation and immobilisation, for example the immobilisation of PAHs in humus. Cultivation and soil management may be combined with risk management interventions addition of sorbents to soil to provide in situ stabilisation of PTEs, using, for example, biochar or bone-meal (Hodson et al. 2000). Conversely, the use of the biomass produced on site, may potentially introduce new pathways by which site contaminants may reach receptors, for example increasing contaminant mobility by chelation with dissolved organic matter. These effects appear to be site and circumstance specific with a range of effects being reported (e.g. CL:AIRE 2008, Hartley et al. 2009, Nwachukwu and Pulford 2008), depending on site conditions such as the nature of the contamination, pH and redox conditions, soil texture and sorptive capacity and the impacts of plant roots. Risk assessment for biomass production therefore needs to be iterative, considering both the initial conditions of the site, and also the impacts of any changes brought about by biomass production, whether deliberate such as phyto-remediation, or consequential.

Biomass utilisation: Types of biomass that might be produced on marginal land will fall into one of these categories, depending on what can be produced: woody materials, e.g. wood chip from SRC, forestry residues, Miscanthus; grains, e.g. wheat, barley, oil seed rape; and straw and fibre, e.g. switch grass, straw, hay, fibre crops such as nettle or hemp. The principle fates of biomass are for energy or as a feedstock. Direct conversion to energy is typically to electricity and/or heat, but potentially also methane gas for distribution national networks (National Grid 2009); or via conversion to a fuel (e.g. Davies 2009). Biomass may also be used as a feedstock for some form of manufacturing process (e.g. HGCA 2009). Downstream manufacturing may be as raw materials for conventional manufacture, such as fine and bulk chemicals, bio plastics and oleo chemicals. Biomass conversion may also generate byproducts which may be used for energy recovery, as soil improvers or in some cases as agricultural animal feeds. Downstream processing can also include energy recovery and biochar production, which has generated great interest as a means of carbon sequestration (Lehmann and Joseph 2009).

Sustainable development: The overall sustainability of such schemes needs to be clearly demonstrated as part of the project preparatory process and linked to the sustainable development strategy for the particular locality the site is situated in. The rationale for growing biomass on marginal land is to provide environmental, economic and social benefits. Hence it is important that each of the components of the project (crop cultivation, soil management, risk based land management and biomass utilisation) can be shown to be sustainable, preferably individually as well as in combination.

ORGANIC MATTER RESOURCES

The benefits of compost use in soil are well established (EC 2003): they improve the carbon pool and organic matter content of soil, they supply valuable plant nutrients, they improve soil processes of fertility, they improve the condition of soil for plant growth for example by enhancing their ability to store and supply water and their structure and the resilience of that structure. Even for biomass crops that are conventionally regarded as “low input” such as SRC willow, organic amendments such as sewage sludge have been found to improve yields (e.g. Adegbidi *et al.* 2003), and is certainly important in the establishment of biomass crops on marginal land. The European Commission believes that enhancing organic matter input to arable soil on a long term managed basis may assist the offset of GHG emissions by sequestration of carbon in soil organic matter (Marmo 2008). Recyclable organic matter is produced in large quantities. In Germany some 1.4 million tonnes of sewage sludge and 8.5 million tonnes of green waste are produced annually. In Sweden approximately one million tonnes of sewage sludge is produced per year. In 2007 the total amount of biologically treated waste from households and the food industry in Sweden was about 870,000 tonnes. The most recent UK annual figures indicate 3.6 million tonnes of compost were produced from separately collected wastes, and 260,000 tonnes of CLO were produced. Around 1.8 million tonnes (dry weight) of sewage sludge were collected in 2008. Data sources are reviewed in detail in the Rejuvenate project Final report.

There is a wide range of potential organic matter inputs which could act as renewable sources of soil improvement and fertiliser. This includes: organic matter from municipal sources,

residues from arable agriculture and horticulture, residues from livestock, residues from forestry, treated soils and wastes such as gravel / sand extraction residues or "inert" wastes received at landfill sites and a range of industrial wastes such as food processing wastes and fermentation residues. The Rejuvenate Final Report focuses on organic matter from municipal sources: sewage sludge, source segregated wastes such as garden and food wastes, and mechanically processed mixed wastes produced at "mechanical-biological-treatment" facilities – MBT, sometimes known as "Compost Like Outputs" or CLOs, produced from municipal solid waste (MSW).

As well as the benefits of organic matter use, their inappropriate use may cause adverse impacts. Risks can be categorised as originating from biological, chemical and physical causes, for example plant or animal pathogens; potenyally toxic elements or persistemt orgamic pollutants, or litter such as glass and plastic. 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. Some forms of organic matter are seen as potentially having greater environmental risks than others, in particular CLOs (Environment Agency 2009).

Organic matter may also be a supplementary energy feedstock, for example, agricultural residues (like straw), forestry residues (like tree trimmings), commercial and industrial wastes (like waste paper / card) and municipal wastes, like wood, or refuse derived fuel, (e.g. AEA Energy and Environment 2008, Leible *et al.* 2007). From the standpoint of a biomass on marginal land project, integration of biomass with these other materials as a supplementary source of biomass may be an important means of increasing the energy capacity and scale of any related on-site bioconversion project, or indeed off-site export of biomass materials.

A DECISION MAKING FRAMEWORK FOR BIOMASS PRODUCTION ON MARGINAL LAND

The biomass production, soil management and risk management processes will take place simultaneously and interact. They will in turn place their own demands on the environment (for example soil and water impacts); and together will cross a range of regulatory domains. One way of dealing with this complexity is to decide a project management approach in stages, considering decisions that are easy to take and limiting on subsequent more difficult decisions, to make the overall planning more manageable. The overall Rejuvenate project's suggestion for a decision making approach follows in outline, and is available in more detail in the Rejuvenate Project final report and is summarised in Figure 1.

Stage 1: Crop suitability: primarily considers from a range of possible biomass crops which crops are able to grow and find a market in a region. Site topography is also considered at this stage for convenience. The output short list of biomass of crops that fit local conditions and have an outlet. Each subsequent stage is likely to reduce the length of this list as a more refined solution is found. This can be divided into substages:

- ***Stage 1.1: range of crops meeting site objectives.***

- ***Stage 1.2: range of crops meeting local climate conditions.***
- ***Stage 1.3: range of crops that can be cultivated on the sites topography.***
- ***Stage 1.4: available uses.***

The output of Stage 1 is therefore 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.

Stage 2 Site suitability and interventions: considers whether the site conditions are suitable for particular biomass crops in the short list and what the environmental risks of crop production might be. A site may be suitable already for some crops or can be made suitable by soil / risk management interventions. If an on-site conversion facility is being considered then the suitability of the site for this facility must also be considered and any necessary interventions (for example infrastructure 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 is a shortened list of crops that could be grown on-site and specification of the management interventions needed to achieve this.

- ***Stage 2.1: range of crops that can be grown on the site.*** There are three possible outcomes from this consideration: that the soil is already suitable for a biomass crop, in which case perhaps only soil maintenance for the crop need be considered; that the soil can be made suitable for crop production by intervention, i.e. soil improvement and/or soil forming measures, or that the soil surface cannot be brought into a condition that is suitable for a particular crop type.
- ***Stage 2.2: environmental risk management.*** Where the site is suspected as being contaminated (or organic matter inputs may contain contaminants), risk assessment will be necessary. The effects of biomass production and use will need to be included in a conceptual site model that reviews all of the pollutant linkages that need to be considered for a site. Risk assessment may determine that some of these pollutant linkages are not significant, whereas others will require a risk management intervention. In some cases it may be determined that a particular biomass type cannot be grown on a site with acceptable risks.
- ***Stage 2.3: impact of interventions.*** Soil management and risk management interventions may themselves have environmental impacts. The purpose of this step is to ensure that the crop, soil and risk interventions on-site are compliant with wider environmental protection needs, for example considering the water environment and the local ecology.
- ***Stage 2.4: facility development.*** This stage is only necessary if on-site conversion of the biomass is envisaged. It considers the feasibility of the various on-site bioconversion alternatives avaialble.
- ***Stage 2.5: facility development impacts.*** This stage considers the impacts of the facility development on the marginal land and its surroundings.

The output of Stage 2 is therefore 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 this is to take place.

Stage 3 Value: there is a direct cost benefit equation as to whether the benefits of using a site for biomass are worth the investment needed, and also a wider sustainability consideration, for example aspects such as carbon sequestration or local community or biodiversity enhancement. It may be appropriate to include other interventions to increase overall project value, for example integrating other forms of renewable energy production with the site re-use, or combining biomass use with the re-use of agricultural residues.

- ***Stage 3.1: financial feasibility.*** The direct costs for each biomass option (including soil and other site management interventions and any on-site conversion) are compared with its revenue earning potential.
- ***Stage 3.2: financial viability.*** This stage develops a more detailed financial model and comparing it against investment thresholds set for the project, such as requirements for return on capital set by investors and other funders.
- ***Stage 3.3: Sustainability appraisal.*** This stage uses q sustainability appraisal based on a series of indicators of sustainability representative of economic, environmental and social factors identified as important by the project team and the other stakeholders involved in the project. In the UK the Sustainable Remediation Forum (SURF-UK) has set out a framework for "sustainable remediation" which can guide this SA process[4].

The output of Stage 3 is therefore one or may be two economically viable project concepts worthy of detailed appraisals, along with an initial sustainability assessment of them.

Stage 4 Project risk: once a firm project concept has been elaborated whose value is attractive to its developers, the project planning needs to ensure as far as possible its viability before any major investment takes place. Three broad considerations are important: technology status, detailed diligence (e.g. of financial partners and project partners) and developing abroad stakeholder consensus. The output is a realistic appraisal of project risks and a mitigation strategy.

- ***Step 4.1: Technology status***.
- ***Step 4.2: Detailed diligence***
- ***Step 4.3: Stakeholder views***.

The output of Stage 4 is therefore a firm project concept where project risks are known, and mitigated where necessary, that is ready for detailed planning and implementation.

[4] www.claire.co.uk/surfuk

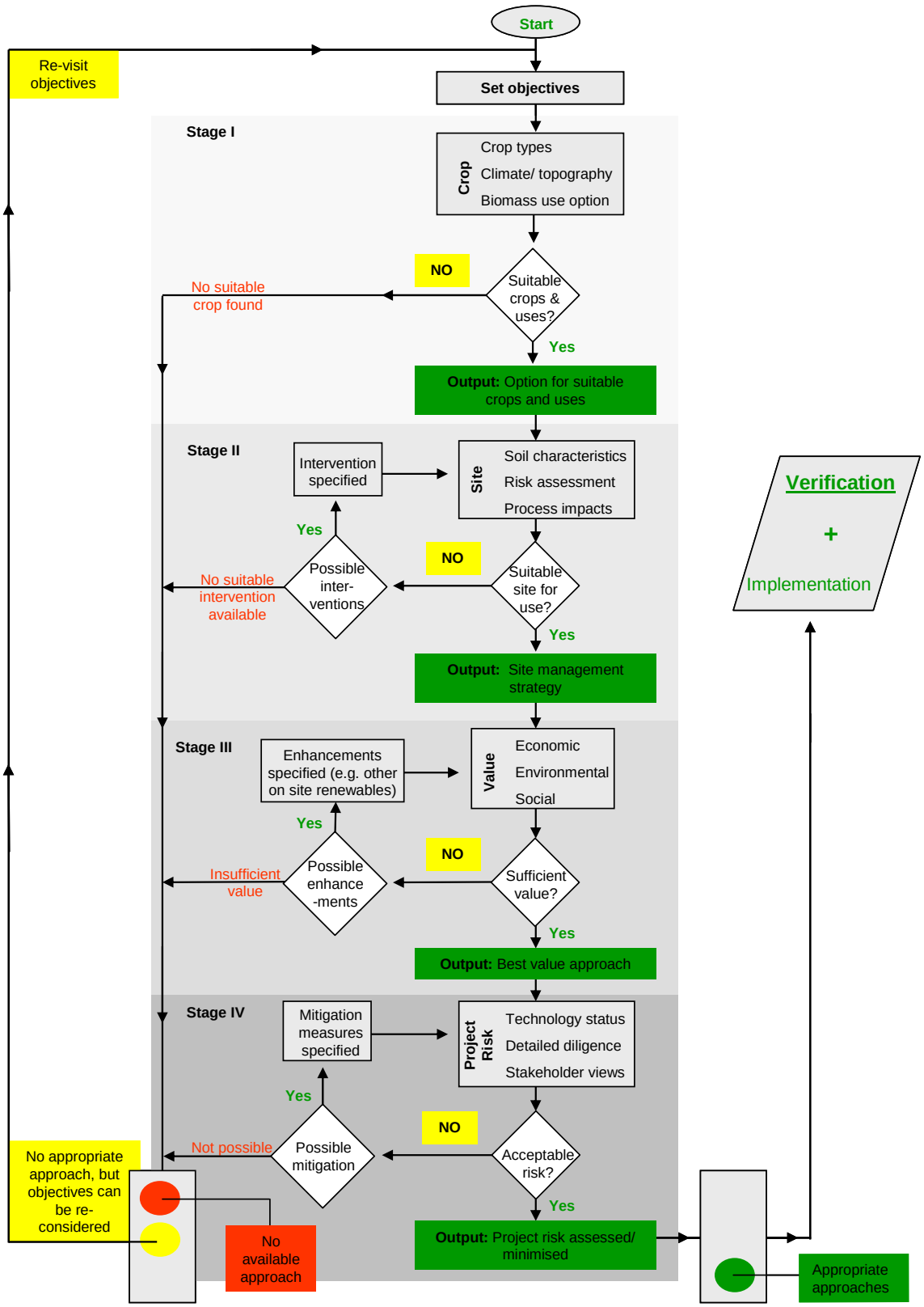

Figure 1 Overall Rejuvenate decision support flowchart

PROJECT VERIFICATION

Verification is the process by which stakeholders can be assured that the project has met its planned objectives. It will need to consider both the specific environmental project goals agreed with regulators and the project economic goals needed to achieve suitable economic performance. It will also need to consider the wider sustainable development performance of the project, in particular if sustainability goals have been agreed as a part of any public investment in the project. A verification plan will need three broad components: verification goals which are the values (e.g. financial, environmental, productivity) that were planned to be achieved in a defined period, what that defined period is within which particular project goals must be met and an agreed period over which verification is to be carried out, and the parameters which will be measured to assess compliances with verification goals.

CONCLUSIONS

The use of marginal land for biomass production may provide leverage to support the re-use of "hard to re-use" marginal land. The conjunction of several drivers (land restoration, organic matter re-use 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.

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 re-use 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.

At a European level (and indeed within national jurisdictions) the findings of Rejuvenate indicate that there are data gaps which a range of demonstration projects of biomass re-use of marginal land could help to fill, to take into account different regional, economic and technological aspects, and to robustly test the decision making framework presented in this report.

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- r3 environmental technology ltd – r3 (lead partner) www.r3environmental.com
- DECHEMA e.V., Germany www.dechema.de
- Swedish Geotechnical Institute - SGI, www.swedgeo.se
- Bioclear, the Netherlands, www.bioclear.nl