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Sustainable Remediation: Which Approach Should I Use?

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ABSTRACT: Sustainability in remediation of contaminated sites is a recent concept that aims at having a holistic approach capable to assess the global impacts of remediation at the environmental, economic and social levels. A common definition and guidelines shared at international level are still lacking and various approaches and tools are used. A green remediation approach is usually based on: (1) the environmental footprint analysis (EFA), which can be performed with tools such as SEFA, SRT or SiteWise, or (2) a life cycle assessment (LCA), for which SimaPro is the most used tool, though not specific for cleanup purposes. A sustainable remediation process should also consider economic and social issues. As far as costs are concerned, the available tools include RACER and REC. No tools are available to quantify social benefit, which might include commercial, health or education services, increase in local occupation or real estate values.

INTRODUCTION

The concept of sustainable development has been defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). It is based on three fundamental concepts: (1) environmental protection; (2) the economic environment, defined as the ability to generate revenue and work to sustain the population; and (3) the social environment, in terms of the ability to bring about human well-being. Protection of the natural environment from the impacts that damage it is thus one of the main factors in sustainable development, but not the only one.

In recent years, the concept of sustainability has been applied in the remediation sector in the attempt to consider holistically all the impacts inherent in that field. Although remediation is, in and of itself, a tool to improve the quality of the environment, sustainable solutions can be identified that have lower overall environmental impacts, reasonable costs, and added value for society. Indeed, the traditional approach focuses on the internal aspects of projects, for example the remediation goals, the efficiency of the treatment systems, or local environmental impacts, but scant attention is paid to external aspects (Ellis et al., 2009), including the effects on the environment as a whole, as well as those on the economy or on society on a large scale (Bardos et al., 2011; Hou and Al-Tabbaa, 2014).

In 2006, an international organization was born in order to incorporate considerations on the potential social and economic impacts of remediation projects at the planning stage. The Sustainable Remediation Forum (SuRF) is a voluntary group of public and private sector entities that are active in the remediation sector. It aims to promote the concept of sustainability through (Albano et al., 2013):

- The identification and development of common guidelines and suitable tools;
- Involvement of all the various players in choosing the best remediation strategies and technologies; and
- Supporting the updating of environmental regulations in applying the concept of sustainability.

In Italy, sustainable remediation is defined as the "process designed to identify the best solution which maximizes benefits from environmental, economic and social points of view, through a balanced decision-making process which is shared by all stakeholders" (SuRF Italy, 2014). The incorporation of the concept of sustainability into remediation has, therefore, four main goals: (1) implementing land management based on risk analysis; (2) ensuring that the effects of the risk management are acceptable; (3) ensuring the involvement of stakeholders and the transparency of the decision-making processes; and (4) achieving balanced results in the three areas for sustainable development (Bardos et al., 2011).

At an international level, there are no guidelines or agreed methodologies for applying sustainability to remediation projects (Brinkhoff, 2011; Beames et al., 2014; Hou et al., 2014a); nonetheless, evaluation of the sustainability of a remediation project must be (Bardos et al., 2011):

- Consensual—The involvement of the stakeholders must be ensured from the very outset of the project;
- Transparent—In order that all interested parties fully understand it; transparency, together with the involvement of the stakeholders, increases the probability of reaching agreement between all parties, and as a result, of reaching robust and lasting decisions;
- Quantifiable—In order to allow the results of the remediation to be compared with the forecasts which informed the decision-making;
- Documented—All the assumptions and valuations must be clearly explained;
- Appropriate—So that the most robust decision can be reached with the application of the minimum necessary level of decision-making force; and
- Replicable—In order that the process may be reused for other sites.

APPROACHES

USEPA (2008) introduced the concept of green remediation, which it defined as the practice of taking all the environmental effects of a remediation into account and incorporating options into the process in order to maximize net environmental benefits. This type of approach is generally based on environmental footprint analysis (EFA), or life cycle analysis (LCA) of the whole remediation project.

EFA uses a restricted number of metrics to represent each of the fundamental environmental elements, which simplifies the analytical process. It calculates impacts for a reduced number of environmental categories and tends to take pre-defined parameters into consideration. The elements that are given the maximum weights are CO_2 emissions and the consumption of water and energy. This type of approach is thus not able to model all the possible environmental effects associated with a specific remediation project. It does not attempt to describe in detail all instances of natural resource utilization and all environmental outputs; nor does it include an impact assessment which converts the emissions into environmental effects, e.g. acidification, changes to the incidence of respiratory diseases, or human- and eco-toxicity.

The LCA methodology consists of an evaluation of the environmental impacts of an industrial process or product "from the cradle to the grave." When applied to the remediation sector, it affords the opportunity of studying a project in a more complete manner by incorporating the analysis into all the major phases (Favara et al., 2011; Hou et al., 2014b):

- Site survey and planning. The project planners identify the stakeholders and the local and regional questions which could be linked to the project;

- Selection of remediation technology. The technicians are able to compare a range of alternatives; in this phase the parameters and the opportunities for improving the available alternatives are also evaluated;
- Planning the project and building the plant. The technicians identify the available ways of optimizing the component parts of the selected technology and they assess construction techniques or new, low-impact materials;
- Operational phase, which may be regularly analyzed and assessed in order to identify available ways to reducing the impact of the remediation project under way;
- Monitoring and closing the operations. Decommissioning options are identified to reduce the impacts of dismantling the equipment, and restoring the site; and
- Post-remediation use of the site.

Based on past experience, LCA can be effective at a decision-making level, especially in the initial project-planning phase and for sites where multiple remediation technologies are legally, economically, and technically feasible. The LCA methodology is divided into nine phases, namely:

- Phase 1: Definition of the goals and scope of application;
- Phase 2: Definition of functional units;
- Phase 3: Definition of the boundaries for the system to be studied (in this context "system" is understood in the widest sense of the term with regards to the remediation system, and it also includes elements from outside the site);
- Phase 4: Definition of the project parameters;
- Phase 5: Compilation of a project inventory (analysis of materials and energy flows into and out of the system);
- Phase 6: Impact assessment;
- Phase 7: Sensitivity analysis and quantification of the uncertainty of the results;
- Phase 8: Interpretation of the inventory analysis and of the results; and
- Phase 9: Documentation and publication of the results.

These phases are flexible and can be adapted to each remediation project.

The question of whether to use an EFA or an LCA depends on many factors, including the complexity of the project, the number of input data available, the required outputs and the "perspectives" of the decision makers. Often stakeholders are only interested in a specific category of impacts, for example potential climate change outcomes; in this case, an analysis of the footprint could be more appropriate. However, an LCA may provide a better evaluation for a project implying significant use of chemicals and other materials, as well as a wide range of secondary processes (Favara et al., 2011).

In order to improve economic forecasts for remediation, a number of tools have been developed to aid analysts in cost estimation. The applicability of these tools is nevertheless limited because they assume to a large degree that a significant amount of the key elements for the analysis is known from the outset. One of the most recent calculation methods for remediation costs is based on the level and type of information available for the site. Based on this, three approaches are possible: site-specific, parameter-driven and based on experiences documented in the literature. The estimations of site-specific costs are considered to be the most reliable as they are often the most accurate and best reflect the real costs of the remediation, although they do require a large amount of information pertaining to the site. The estimates based on literature data tend to be used for sites where very few contamination data are available. Parameter-driven estimates come between these two methods and are based on the unit costs of different remediation technologies which can be selected according to certain site-specific characteristics (Ram et al., 2013).

The cost-benefit analysis comprises the evaluation of all costs and benefits connected to the various remediation options available. If a potential conflict between interested parties comes to light, or in the case of sites with multiple problems and a large number of possible remediation solutions, a multi-criteria analysis could be appropriate in addition to a cost-effectiveness analysis (Onwubuya et al., 2009).

In addition to the environmental and economic aspects discussed above, there are several complex social considerations linked to the involvement of the various stakeholders. In order to make remediation sustainable, stakeholder groups must be formed (public entities, property promoters, developers, remediation and environmental consultants, local inhabitants) and their involvement must be encouraged right from the start (Williams et al., 2007).

Social benefits and impacts can be measured by inputting specific results that can either be tangible, for example, the completion of a new park or the construction of a new road, or intangible, such as increasing local employment or property values (SuRF UK, 2010).

TOOLS

Several specific tools have been developed for calculating the EFAs of remediation projects, such as SEFA (Spreadsheets for Environmental Footprint Analysis), SRT (Sustainable Remediation Tool) and SiteWise.

SEFA (USEPA, 2012)**.** By supplying quantitative information, the application of the methodology can aid the team in identifying the best available technologies in the green remediation field. To aid the analysis from a quantitative point of view, a series of job folders have been developed for EPA that support the user in estimating the environmental footprint. USEPA uses this tool, but it is available to public or private entities working on a voluntary basis and wishing to evaluate the environmental impacts of a remediation.

In all, there are 21 environmental sustainability metrics suggested by the EPA, and they are grouped into five fundamental green remediation considerations: energy consumption by the treatment systems; air emissions; water consumption and impact on groundwater; impacts on the soil and ecosystems; and the consumption of materials and waste production (USEPA, 2008).

The methodology sets out a seven-phase process for the calculation of the environmental footprint:

- Step 1. Set goals and scope of analysis;
- Step 2. Gather remedy information;
- Step 3. Quantify onsite materials and waste metrics;
- Step 4. Quantify onsite water metrics;
- Step 5. Quantify energy and air metrics;
- Step 6. Qualitatively describe affected ecosystem services; and
- Step 7. Present results.

The results from this can help project designers in identifying the most significant contributors to the footprint and, thereby, develop different approaches for reducing them, which ultimately leads to a more sustainable remediation. The experience gained through case studies using EPA suggests that the most significant opportunities for the reduction of the footprint are often linked to using renewable energy sources; in general, the project designers are able to refer to Best Management Practices.

SRT (AFCEE, 2012)**.** This is a calculation tool developed in the United States on behalf of the Air Force Center for Engineering and the Environment by AECOM Environment and CH2M Hill. It consists of a series of Excel sheets and is structured into two analytical levels.

Level 1 is the simpler of the two. The calculations are based on assumptions that are widely used in the remediation sector. The use of this level is useful for analyses that are required over a short time frame, where detailed site-specific data are not available, or if a highly site-specific assessment is not required. Level 2, on the other hand, is designed for much more detailed calculations and allows the user to incorporate a greater number of site-specific factors into the analysis. Using the second level is recommended when site-specific data are available or when the evaluation of existing treatment systems is required or for projects already at the feasibility study stage.

SRT was conceived with three general objectives in mind: planning for future implementation of remediation technologies at a particular site, comparison between different remediation approaches based on sustainability parameters, and optimization of remediation projects that have already been started. This tool, therefore, allows the user to evaluate eight different groups of technologies at the same time (grouped by environmental category):

- Soil:
  - Excavation and disposal in landfill;
  - Soil Vapor Extraction;
  - Thermal treatments;
- Water table:
  - Pump & Treat;
  - Biodegradation;
  - Reactive permeable barriers;
  - In-situ chemical oxidation; and
  - Long-term monitoring - monitored natural attenuation.

After having carried out the calculations, SRT returns estimates for the following sustainability parameters; CO_2 emissions; emissions of other pollutants; costs; energy consumption; safety and the risk of accidents; and change in soil or groundwater use.

SiteWise (NAVFAC, 2011). This is a U.S. calculation tool developed jointly by Battelle, the U.S. Navy, and the U.S. Army Corps of Engineers to calculate the environmental footprint of remediation activities on contaminated sites, and it uses a series of Excel spreadsheets.

The assessment of the footprint is carried out by following a modular, building block approach, which subdivides each alternative into building blocks that simulate the remediation phases. The next step is to calculate the footprint for each building block. The different footprints are then added together to estimate the total for the project.

The required inputs are as follows:

- Information on the activities which have to take place;
- production and use of the materials required by the remediation activities;
- Information on the transport of the materials, equipment and personnel to and from the site;
- Equipment used, in order to calculate the fuel or electrical consumption and the emissions relating to them; and
- Waste management methods.

The footprint is calculated by multiplying the impact factors by the rate of use or consumption of materials, electricity or fuel during the remediation activities. SiteWise carries out the calculations based on emissions factors from reliable governmental and non-governmental sources. At the end of the calculation process, it generates the summary files containing the results by remediation option, which also permits comparative analysis between them.

The consequences that are currently not quantifiable by the model, for example, the effects on the community from a social or economic perspective, need to be evaluated using another methodology.

Tools for LCA. The LCA methodology requires specific technical training and high levels of ability by its users. Commercial software packages such as SimaPro or Gabi are generally required, which brings the following strengths (NAVFAC, 2013):

- They are mature and reliable tools as a result of over 20 years of updates and they are able to support the production of models and reports to the ISO standards relating to LCA, and they have already been used in a large number of situations albeit only rarely in the environmental remediation field;
- They can retrieve contents from a range of databases, including from Ecoinvent, which is one of the most robust and comprehensive data sets on life cycle analysis;
- They can evaluate production processes or complex activities that could be included in the remediation project, but which are not yet included in the life cycle inventory database; and
- They give a final assessment of the impacts, which are not included in the EFA software.

RACER (Remedial Action Cost Engineering Requirements) (AECOM, 2010)**.** This system was developed by AECOM on behalf of the U.S. Air Force in order to provide environmental analyses and remediation cost analyses. It is a parametric system that is able to estimate the costs of projects involving large, complex sites requiring actions over several sequential phases.

REC (Risk Reduction, Environmental Merit and Costs) (Osborne and Schütte, 1997)**.** This system assists decision making in analyzing and evaluating possible remediation strategies for contaminated sites, and it allows users to compare results in terms of:

- Risk reduction for humans and the ecosystem;
- Environmental merits: this refers to the degree of positive environmental balance achieved by a remediation project. Projects prevent the spread of contamination and they increase the amount of uncontaminated soil and water, but they can be very resource intensive; for this reason the project's balance between benefits and environmental damage is analyzed; and
- Total costs for the remediation of the site, covering preparation, carrying out the clean-up activities, maintenance, and monitoring all the project phases.

REC can be used to find the point at which the three aforementioned elements are in balance, and it can identify the remediation option which achieves the highest level of risk reduction combined with most environmental merit and reasonable costs.

CONCLUSIONS

This paper has illustrated the state of the art in terms of methodologies and assessment tools applied to the sustainability of a remediation project.

Regarding the technical aspects, the main problem is the requirement to consolidate and standardize the methodologies and metrics used in analyzing remediation projects.

The main sector-specific tools currently available for analyzing the environmental footprint are all from the U.S., for example, SiteWise, SEFA, and SRT. The data included in the databases underlying these software packages are, therefore, primarily sourced from a U.S. context, and they have limited application for Italy.

From an economic perspective, universal methods and reference frameworks do not yet exist for the costing of projects, their implementation and management, and running remediation systems.

Finally, from a social perspective, the main issue to be addressed is the requirement for creating consensus on more sustainable solutions, by developing and implementing evaluation methodologies that allow the highlighting of the pros and cons of the different alternatives in a transparent and accurate manner.

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SUSTAINABLE REMEDIATION: WHICH APPROACH SHALL I USE?

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Introduction

Sustainable development

"meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987)

Applied in the remediation sector

- Environmental protection
- Reasonable costs
- Added value for society

* Remediation traditional approach focuses on the internal aspects of projects, but **scant attention is paid to external aspects**.

* At an international level, there are **no guidelines or agreed methodologies for applying sustainability** to remediation projects.

Introduction

The incorporation of the concept of sustainability into remediation has therefore four main goals:

- *implementing **soil management** based on **risk analysis**;*
- *ensuring that the **effects** of the risk management **are acceptable**;*
- *ensuring the **involvement of stakeholders** and the transparency of the decision-making processes;*
- *achieving **balanced results** in the three areas for sustainable development.*

Evaluation of the sustainability of a remediation project must be:

- consensual;
- transparent;
- quantifiable;
- documented;
- appropriate;
- replicable.

Approaches

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Green remediation *"the practice of taking all the environmental effects of a remediation into account, incorporating options into the process in order to maximize net environmental benefits"* USEPA (2008)

Environmental Footprint Analysis (EFA):

- Use restricted number of metrics

- Calculates impacts for environmental categories

- Take pre-defined parameters into consideration

Life Cycle Analysis (LCA):

Evaluation of impacts 'from the cradle to the grave'

- Site survey and planning,

- selection of remediation technology

- planning the project and building the plant,

-operational phase,

- monitoring and closing the operations,

post-remediation use of the site.

Use EFA or LCA depends on many factors including: **complexity** of the project, **number of input** data available, the **required outputs** and the **"perspectives"** of the decision-makers.

Approaches

In order to improve economic forecasts for remediation, three approaches are possible:

- site-specific → *most reliable; require a large amount of information*.
- parameter-driven →*selected according to site-specific characteristics.*
- based on experiences → *used for sites where very few data are available.*

Cost-Benefit Analysis:

- **comprises the evaluation of all costs and benefits connected to the remediation options.**
- **in case of sites with multiple problems a multi-criteria analysis could be appropriate**

In addition there are several complex **social considerations** linked to the **involvement** of the various **stakeholders** (*public entities, property promoters, developers, remediation and environmental consultants, local inhabitants*) and their involvement must be encouraged right from the start.

Tools

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Tool	Free	Environmental	Economic	Social
REC-Tool (Risk Reduction, Environmental Merit and Costs, 1998, Holland)	●	●	●	●
SAF (Sustainable Assessment Framework)		●	●	●
GolderSET-SRcn Sustainability Tool (2007 worldwide)		●	●	●
SiteWise™ GSR Tool		●	●	
CEEQUAL (UK)	●	●	●	●
SPeAR®(Sustainable Project Appraisal Routine, 2000, UK)		●	●	●
Sustainable Remediation Tool (SRT) (USA, Air Force Center for Engineering and the Environment)	●	●	●	●
Green Remediation Evaluation Matrix (GREM) (California Department of Toxic Substances Control)	●	●	●	●
Greener Cleanups: How to Maximize the Environmental Benefits of Site Remediation (Illinois EPA)	●	●		
AECOM Holistic Tool (AECOM)		●	●	
BalancE3™ (ARCADIS)		●	●	●
Sustainable Remediation Assessment and Methodology (CH2MHILL)		●	●	●
Sustainable Remediation Evaluation Tool (Haley & Aldrich, Inc)		●	●	●
Sustainability Impact Estimator (URS corporation)		●	●	●
MCEA Tool (Modified Cost- Effectiveness- Analysis, Excelbased Tool, 2012, Austria)	●	●	●	●
DESYRE (Decision Support sYstem for Rehabilitation of contaminated sites, Italy)	●	●	●	●
MMT – Megasite Management Toolsuite (Germany)	●	●	●	●
SimaPro (Prè Consultants)		●		

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RECONnet

SuRF Italy
Forum per la Sostenibilità applicata alle Bonifiche
Sustainable Remediation Forum

SEFA (**S**preadsheets for **E**nvironmental **F**ootprint **A**nalysis) (USEPA, 2012)

The application identifies the best available technologies in the green remediation field → To aid the analysis from a **quantitative point of view**, a series of job folders have been developed which support the user in estimating the environmental footprint.

21 environmental sustainability metrics are grouped into:

- energy consumption,
- air emissions,
- water consumption and impact on groundwater,
- impacts on the soil and ecosystems,
- consumption of materials and waste production.

Identify the most significant contributors to the footprint and develop different approaches for reducing them.

SRT (Sustainable Remediation Tool) (AFCEE, 2012)

Three general objectives:

- planning for future implementation of remediation technologies at a particular site,
- comparison between different remediation approaches based on sustainability parameters,
- optimisation of remediation projects which have already been started.

Identify the following sustainability parameters: CO_2 emissions; emissions of other pollutants; costs; energy consumption; safety and the risk of accidents; change in soil or groundwater use.

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SiteWise (Battelle - NAVFAC, 2011).

Calculate the environmental footprint of remediation activities on contaminated sites.

Alternatives are subdivides into building blocks which simulate the remediation phases → calculate the footprint for each building block.
The different footprints are then added together to estimate the total for the project.
The footprint is calculated by multiplying the impact factors by the rate of use or consumption of materials, electricity or fuel during the remediation activities.

At the end of the calculation process, it generates the summary files containing the results by remediation option, which also permits comparative analysis between them.

Tools

LCA methodology requires specific technical training and high levels of ability by its users.

Commercial software packages such as **SimaPro** or **Gabi** are generally required.

- Mature and reliable, but rarely used in the remediation field;
- Retrieve contents from a range of databases;
- Evaluate production processes or complex activities;
- Give a final assessment of the impacts.

RACER (**R**emedial **A**ction **C**ost **E**ngineering **R**equirements) (AECOM, 2010).

It is a parametric system which is able to estimate the costs of projects involving large, complex sites requiring actions over several sequential phases.

Developed in order to provide **environmental analyses** and **remediation cost analyses**.

REC (**R**isk reduction, **E**nvironmental merit and **C**osts) (Osborne, 1997).

Analyzing and evaluating possible remediation strategies in terms of: **risk reduction** for humans and the ecosystem; **environmental merits**; **total costs** for the remediation of the site.

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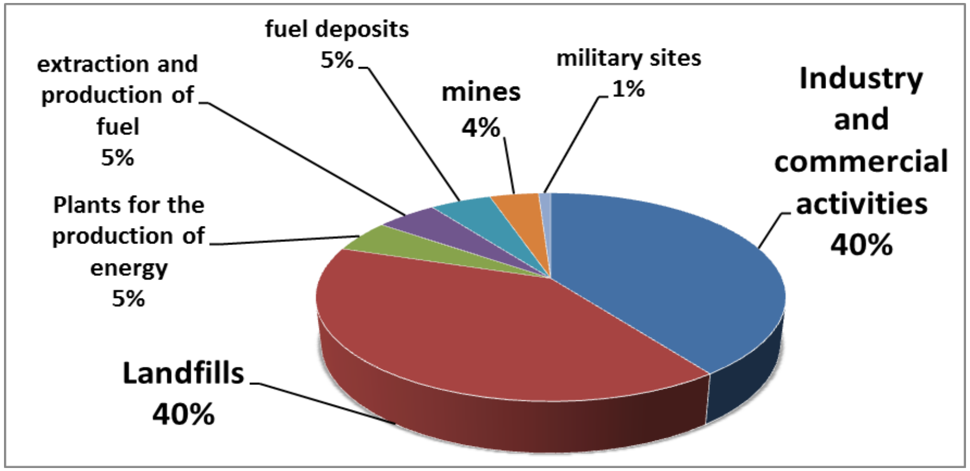
The **sustainability** is considered for the Italian remediation context for about **90% of the decision making**, with a particular attention to the selection of the technologies that are acceptable from an environmental perspective (green technologies, use of LCA and EFA approaches) and cost-benefit analysis.

Distribution of contaminated sites by type of source in Italy (ISPRA, 2013)



Contaminated sites: 4837
Sites with a complete remediation: 3088

...Nevertheless...

TOOLS ARE ONLY USED IN **40% OF DECISION-MAKING PROCESSES**. ORGANIZATIONS RELY MAINLY ON INTERNAL EXPERTISE AND EXTERNAL CONSULTANTS.

Italian context - cases

The main ENVIRONMENTAL ASPECTS are: the **impacts on soil and groundwater**, the **use of the land** and **natural resources**.
Among the SOCIAL ASPECTS, priorities are **human health**, the **safety of workers** and the **impact on local populations** while at the ECONOMIC LEVEL, the **direct and indirect costs** of remediation project and the **residual value of the area**.

Case	Author
Remediation of an industrial site	CH2M HILL
Remediation a store fuel	Eni
Net Environmental Benefit Analysis applied to a contaminated bay	Environ
Sustainability groundwater treatment plant	Golder Associates
Strategy for groundwater and soil remediation	Golder Associates
Environmental and socio-economic redevelopment of an Island	Intea

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Italian context – case 1

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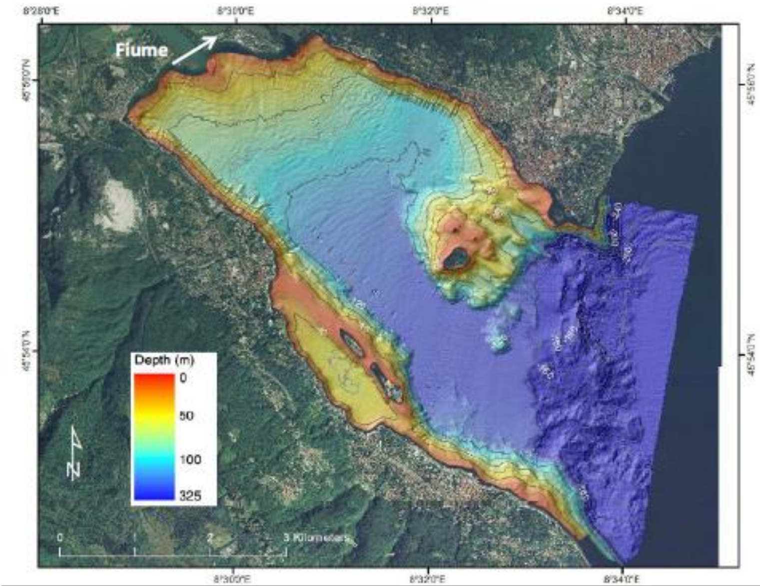
Case 1 – Italian lake bay

Evaluation process with "**Net Environmental Benefit Analysis - NEBA**":
- **Monitoring of Natural Recovery** (MNR);
- **Monitoring of Natural Recovery** (MNR) with measures to improve habitat;
- **Dredging** of sediments throughout the Bay Area (2317 ha);
- **Capping** the bay.



Aspects evaluated	**Evidence derived from the analysis process**
The analysis allow to measure ecological and anthropic benefits for each option. - **quantify the losses and gains of ecological services** through the "Habitat Equivalency Analysis"; - quantify the losses and gains of anthropogenic services through "days visitor-user"; - evaluate the **changes in ecological and health risk**; - **Reduction of toxicity**, mobility or volume of contaminated sediments; - Feasibility; Cost and duration of the options; - Acceptance by the Authority and Acceptance by the local community.	**MNR project, with measures to improve habitat**, is the only option that **brings environmental benefits in the ecosystem without producing any negative impact**. The capping and dredging would not lead to any benefit and lead to a substantial deterioration in both ecological and human services, producing also a significant increase in the ecological risk and health.

Italian context – case 2

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Case 2 – Italian industrial site

Different kinds of remediation technologies implemented in order to take account the **different requirements** of the site:

- In **indoor and outdoor areas** (where contaminants characterized by reduced mobility) → installing **waterproof cover systems** and a **water harvesting system**.
- In areas characterized by **high levels of contamination** → **excavation** of contaminated matrix.
- In the areas where remediation technologies intrusive were not feasible (**production areas**) → **SVE System**.

The evaluation of remediation alternatives in terms of the criteria of sustainability was made during the preliminary. Sustainable approach use is **Multi Criteria Analysis**

Aspects evaluated	Evidence derived from the analysis process
- **human health protection**; - Effectiveness of the intervention in the short and long term; - Cost-benefit analysis; - **Acceptability** (stakeholders); - In situ non-intrusive technologies for the production area, excavation for other areas.; - Reducing the use of natural resources; - Reduction of waste generation.	Minimize the production of waste in landfills where not authorized. Respected regulatory objectives and specific environmental requirements without interfering with the production activities of the site. **The social and economic impacts have been minimized and the remediation objectives have been achieved**.

Italian context – case 3

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Case 3 – Italian residential/public use site

Planned remediation: **hydraulic barrier (P&T)**

Evaluation of different remediation alternatives with **SRT** (Sustainable Remediation Tool)

	Pump & treat	Bioremediation	Monitoring of Natural Recovery
Duration	**10 year**	**3 year**	**20 year**
Wells	**1 (pumping) 5 (monitoring)**	**30 (injection) 6 (monitoring)**	**12 (monitoring)**
Other	Submerged pump	Dosage of compounds with release of oxygen	

Tecnology	Emission				Energy
	t_{CO2}	t_{NOx}	t_{SOx}	t_{PM10}	GJ
P&T	596	3,47	6,34	1,21	10.500
Bioremediation	52	0,149	0,077	0,011	750
MNA	43	0,087	0,035	0,0061	640

Conclusions

TECHNICAL ASPECTS → Consolidate and standardize the methodologies used. The main sector-specific tools are all from the US. The data included in the databases underlying these software packages are therefore primarily sourced from a US context, and they have limited **application for Italy**.

ECONOMIC PERSPECTIVE → universal methods and reference frameworks do not yet exist for the costing of projects, their implementation and management, and running remediation systems.

SOCIAL PERSPECTIVE → creating consensus on more sustainable solutions, by **developing and implementing evaluation methodologies** which allow the highlighting of the pros and cons of the different alternatives.

THANK YOU FOR YOUR ATTENTION!