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SUSTAINABLE REMEDIATION STRATEGIES: A MULTICRITERIA ANALYSIS TO SELECT AND COMPARE REMEDIATION TECHNIQUES IN A SUSTAINABILITY PERSPECTIVE

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Context: the OXYSOL project

The results presented in this paper come from research work conducted under the ongoing OXYSOL research project, funded by the French National Research Agency from 2008 to 2011.

The OXYSOL project aims to develop a new combination of in-situ soil treatment technologies for organic persistent pollutants such as PAHs. The project focuses on superficial soils (first meter) and is based on a combination of In Situ Chemical Oxidation (ISCO) technology and soil functions restoration processes. The final objective of this innovative technology is to enable the remediation of large brownfields areas, for which no real operational and cost effective technology currently exists.

Objectives and methodology

Within this project, a multicriteria analysis methodology integrating socio-economic and sustainable aspects was developed in order to assess the acceptability and the feasibility of this new remediation technique. One of the objectives was to provide the project partners with a way to compare and demonstrate the global performance of the new technique with more conventional techniques.

The main objective of the analysis was to identify all the parameters to be considered when choosing a remediation technology in a given context, taking into account the global performance of remediation scenarios. Those selected parameters should also help the project partners to gather information on this new remediation technology developed by the OXYSOL project in order for these partners to communicate and to disseminate scientific and technical information. Thus, it allowed to demonstrate technical, environmental, economical and social quantitative benefits of using innovative remediation technologies. Once these parameters were identified and organized within a specific assessment methodology, another objective was to validate them through real case studies.

This study was based on a multicriteria analysis (MCA) methodology. MCA is one of the decision-aid methods aiming at solving complex problems with contradictory goals. It enables decision-makers to

rank several solutions to a given problem, identifying the best one(s) according to a set of considered decision criteria. The criteria may be aggregated and weighted, and can be very heterogeneous in terms of nature or quality of required data: MCA is thus a very flexible and little binding methodology that can cope for instance with qualitative as well as quantitative criteria.
The weight of each criterion can be taken into account by MCA, at the criteria aggregation stage. The weighting system represents the decision maker's priorities ranking, and is inherently subjective. The intervention of a stakeholders panel is however a recommended step of MCA use (Kiker et al. 2005, Onwubuya et al. 2009), as a way to strengthen the MCA results legitimacy.

Results

- *A sustainability framework to compare remediation technologies*

The methodology was developed within a global framework taking into account sustainability principles. Remediation strategies and technologies were considered according to their abilities to address current sustainability challenges: global change (fossil fuels and natural resources depletion, climate change, biodiversity losses, etc.), human needs satisfaction and economic efficiency. This framework, by answering stakeholders' questions and expectations, strengthened remediation projects legitimacy and acceptability.

This framework relied on a definition of sustainable development as a balanced development ensuring human well-being, able to satisfy human needs while bringing an answer to global change and wealth allocation inequalities. Ensuring human well-being is to be understood as providing people capacity to satisfy their basic needs, referring to economists Max-Neef and Sen's works (Max-Neef 1991, Sen 1999 and 2003). These basic human needs are defined by Max-Neef, and have to be distinguished from desires. Max-Neef defines four existential human needs: being, having, doing, interacting, and nine basic axiological human needs (equally important except for the first one): subsistence (the only need outclassing the others), protection, affection, understanding, participation, idleness, creation, identity, freedom. In the context of soil remediation, the human well-being and basic needs to be considered are those related to the people impacted by the remediation project, especially the actual and future site users.

This framework was used as a basis to establish a clear relation between, on one hand, sustainability goals and principles, and on the other hand, objectives of a site remediation and redevelopment project. Human needs can thus be linked to site remediation and redevelopment sustainability components (see Fig. 1). Some of these components are mostly related to the redevelopment phase, such as the ones dealing with the balanced and fair wealth allocation dimension. As the redevelopment phase clearly influences remediation strategy (heavily determined by future site use), they were also taken into account in this framework.

Site remediation and redevelopment sustainability components	Basic human needs
Global change control	
Fossil fuels consumption reduction to protect the remaining resources	subsistence, protection
Climate change effects control and mitigation	subsistence, protection
Ecosystems and biodiversity equilibrium, ecological services capacity production protection	subsistence, protection
Water resources protection (quantity and quality)	subsistence, protection
Soil quality protection	subsistence, protection
Human dimension	
Health protection	protection
Safety feeling, perceived risks acceptation	protection
Participation capacity	participation, understanding
Existence of opportunities and places for social and cultural life	participation, affection
Existence of opportunities and places for leisures and creativeness and knowledge development	idleness, creation
Places, history, traditions, social groups identification capacity	identity
Autonomy, rights equality, living according to personal choices capacity	liberty
Balanced and fair wealth allocation	
Employment, job opportunities	subsistence
Fair trade relations	subsistence
Goods and services access facilities	subsistence
Economic efficiency	
Economic efficiency and feasability : costs	subsistence, protection
Reasonable risk level (financial risks, acceptability risks, etc.)	subsistence, protection

Fig. 1: Sustainability framework for site remediation and redevelopment.

This framework was used as a basis to criteria organisation for the MCA methodology using the sustainability components as criteria categories (see Fig. 2). These categories include all basic parameters (technical, environmental, economical and social) used in remediation technologies assessment completed by parameters related to sustainable assessment. These parameters are classified according to the new framework.

Criteria categories	Criteria sub-categories
Anthropic impacts on biosphere (or global change) control	Fossil fuels consumption
	Climate change (GhG emissions)
	Biodiversity and ecosystems protection, natural resources consumption (incl. Water and soils)
	Water, air, soil pollution and waste production
Human well-being	Health risks control
	Nuisances control
	Risks perception and remediation strategy acceptation
	Identification to a place, an history, etc.
Economic efficiency	Direct costs
	Indirect costs
	Risks (economic consequences of hazards occurrences) and uncertainties

Fig. 2: Criteria organisation for the MCA methodology.

- *Criteria identification for the MCA methodology*

The next step in the MCA methodology definition was the identification of relevant criteria for remediation strategy selection and assessment. Two sets of criteria were defined:

- Selection criteria:
  Applied to a wide list of remediation techniques in a given context, they assess how compatible these techniques are with the site specificities. These criteria have the objectives to identify the techniques which could be used and to exclude inappropriate techniques. Thus,

they are called exclusion criteria. They are organized into compatibility criteria categories dealing with space, time, environment and human health issues, as well as constraints associated with future site use.

- Assessment criteria:
  Once the techniques which could potentially be used are identified, a second set of criteria is used: the assessment criteria, which rank the applicable techniques according to their global performance, i.e. according to their ability to control pollution-related risks but also according to their sustainability.
  These criteria are organised according to categories such as global change control, human well-being and economic efficiency, and associated sub-categories (see Fig. 2).
  It is important to stress that they perform a comparative assessment of the remediation techniques, and therefore are insufficient to assess the intrinsic performance or sustainability level of each remediation technique (RESCUE 2005; Nathanail et al 2002; Colombano et al. 2010).

Selection criteria were used to select remediation technologies which could be applied at the selected sites.

Thirty seven assessment criteria were defined and are discussed below.

These criteria are all qualitative or semi-qualitative: they are scored according to a 0 to 5 scale.
For each criterion, possible answers and corresponding scores are always specified. This helps the evaluator to select the right score and also aims at minimizing notation discrepancies between evaluators due to individual subjectivity.

The criteria can all be weighted, so as to take into account context specificities and decision-makers as well as stakeholders value scales. As criteria weights are highly dependant on site specificities (context, interacting actors and stakeholders, redevelopment project), there can be no universal weighting system. Therefore, the weighting system has to be specifically designed for each remediation project, by decision-makers and stakeholders. Involving stakeholders in the weighting system design (and in the criteria identification process itself) is a legitimacy and acknowledgement guarantee for the assessment results and for the remediation project itself (CLARINET, 2002).
A final score is calculated for each remediation technology assessed, using weighted arithmetical mean calculation. The higher the final score, the better the global performance of the assessed remediation technology is.

The criteria and the AMC methodology framework were then submitted for validation to the project partners in order to improve their exhaustivity, relevance and consistency. Each partner was consulted in order to validate or if necessary suggest modifications for the criteria and for the global MCA framework, using his own expertise.
This step provided validated criteria ready to be tested within a first real case study.

- *Case study: criteria testing*

The MCA methodology and the selected criteria were tested in February 2010 through a first case study provided by one of the OXYSOL project partners. This case study enabled to refine criteria and to validate the applicability of the method.

This case study is based on a 22ha contaminated site, formely used as a cokeworks. The industrial activity stopped around 1975. The contamination is mainly caused by organic pollutants (PAHs) but also inorganic compounds (Cr, Cu, Ni, Pb, Zn and As). Soil contamination covered approximately 45000 m² and was mainly located in superficial soil (first meter). Soil contaminant concentrations range from 500 to 7000 mg/kg. The local hydrogeological conditions as well as PAHs fate and transport characteristics prevent the off-site migration of the contamination in surface water or ground water.

Seven remediation scenarios were tested in order to compare their performance at the site. They all imply different conventional soil remediation techniques (or combinations of techniques) and were selected on the basis of BRGM’s soil remediation technical expertise. One of these scenarios (scenario 7) was based on a conventional version of the process developed in the OXYSOL project: it involves a combination of a conventional in situ chemical oxidation (ISCO) with a soil functions restoration process. At this stage of the project, this process was not fully developed and all parameters were not fully known. Therefore expected characteristics of the performance of ISCO associated to soil function restoration were used.

A site redevelopment project, presented by the site-owner, was taken into account in the tested scenarios.

Based on selection criteria, the following remediation technologies scenarios were selected:

- Scenario 1: landfill cap
- Scenario 2: containment
- Scenario 3: thermal desorption ((on site)
- Scenario 4: thermal desorption (*ex situ*)
- Scenario 5: biopile (*ex situ*)
- Scenario 6: bioplie (on site)
- Scenario 7: combination of ISCO and a soil functions restoration process

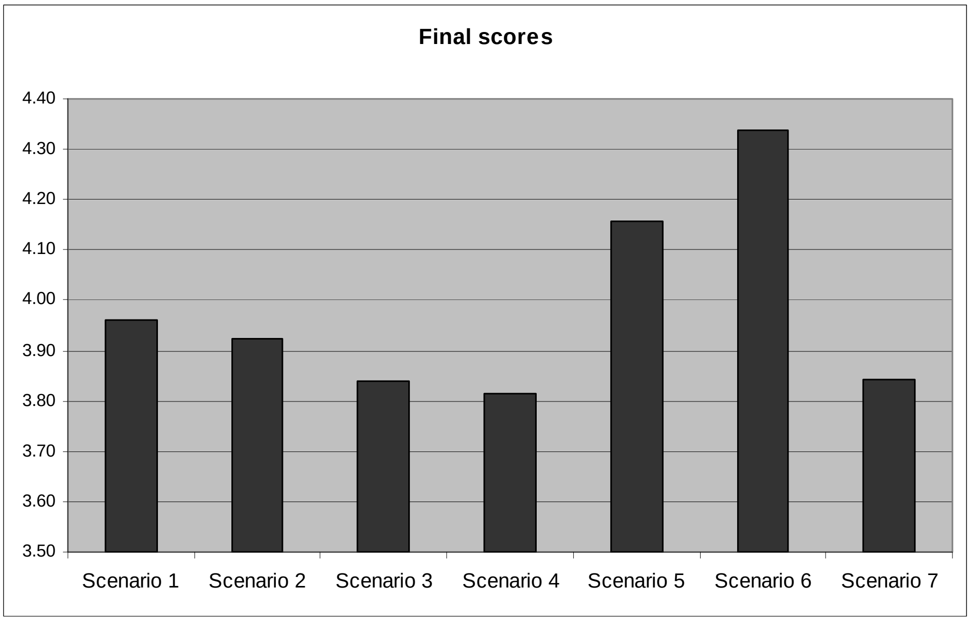
The MCA methodology was tested excluding weighting of parameters, except for an analysis of results sensitivity undertaken for the three criteria categories (global change control, human well-being and economic efficiency) for which weighting of criteria have been performed.

The results presented below (see Fig. 3 and Fig. 4) are not related to a specific weighting system: all criteria have the same weight inside a sub-category or a category of criteria, with categories being considered of equal importance.

	SCORE Sc. 1	SCORE Sc. 2	SCORE Sc. 3	SCORE Sc. 4	SCORE Sc. 5	SCORE Sc. 6	SCORE Sc. 7
A. Criteria for anthropic impacts on biosphere (or global change) control	**4.47**	**4.16**	**3.43**	**2.67**	**3.32**	**4.16**	**4.12**
A1. Fossil fuels consumption	5.00	4.50	3.25	1.50	3.00	4.50	4.88
A2. Climate change (GhG emissions)	5.00	4.50	3.00	2.25	3.50	4.38	4.88
A3. Biodiversity and ecosystems protection, natural resources consumption (incl. water and soils)	4.33	4.03	3.82	3.95	3.90	4.20	3.03
A4. Water, air, soil pollution and waste production	3.57	3.60	3.65	2.97	2.89	3.57	3.70
B. Criteria for human well-being	**3.58**	**3.70**	**4.00**	**4.13**	**4.36**	**4.31**	**3.73**
B1. Health risks control	3.25	3.25	3.50	3.50	4.00	4.00	3.00
B2. Nuisances control	4.20	3.95	3.35	3.60	3.70	3.75	4.05
B3. Risks perception and remediation strategy acceptation	1.88	2.60	4.15	4.40	4.75	4.50	2.88
B4. Identification to a place, an history, etc.	5.00	5.00	5.00	5.00	5.00	5.00	5.00
C. Criteria for economic efficiency	**3.82**	**3.91**	**4.09**	**4.65**	**4.79**	**4.54**	**3.68**
C1. Direct costs	3.33	3.58	2.50	4.33	4.75	3.83	1.67
C2. Indirect costs	4.00	4.00	4.83	4.67	4.67	4.83	4.83
C3. Risks (economic consequences of hazards occurrences) and uncertainties	4.14	4.14	4.94	4.95	4.95	4.94	4.54

Fig. 3: Case study results: criteria scores by categories, for each tested remediation scenario, all criteria having the same weight.

Criteria scores were calculated and summarised by criteria sub-categories and categories, for each tested remediation scenario (see Fig. 3 and Fig. 4).



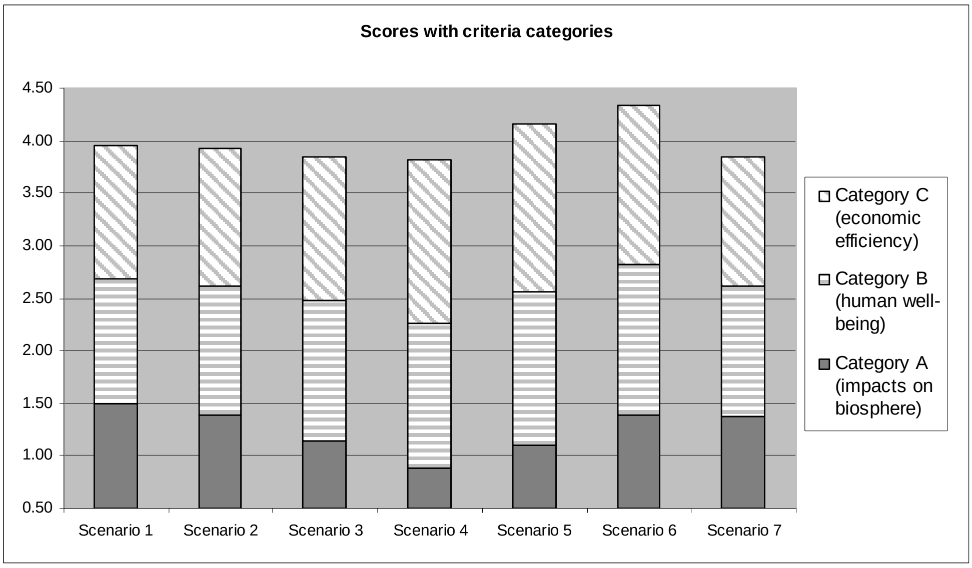


Fig. 4: Case study results: graphical comparison of the global and by criteria categories performance of the selected remediation scenarios, all criteria having the same weight.

Discussion and conclusion

For this case study, criteria were tested without weighting system. However, in real life situation, decision-makers or stakeholders involved in a site remediation project would certainly consider some criteria or categories of criteria more important than others. This could lead to change the results, especially the scenarios hierarchy. Consequently, the ranking of scenarios obtained here (and in any case) has to be examined very carefully. As for any decision-making situation, results obtained with a decision support system are only a support for decision: they should be discussed and analysed carefully before any decision (observing them or not) is taken.

Stakeholders can consider the results differently according to their interests. For this case study for instance, a strong emphasis put on the economic efficiency category would lead to different results than the ones obtained with a strong emphasis put on the biosphere protection category (see Fig. 5 and Fig. 6).

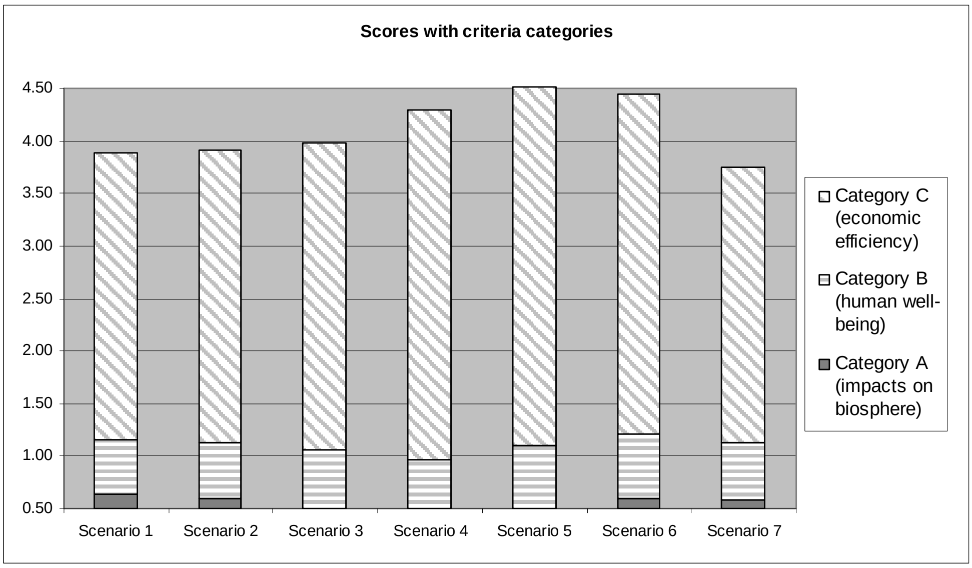


Fig. 5: Case study results: graphical comparison of the performance of the selected remediation scenarios, with a strong emphasis on the economic efficiency criteria category.

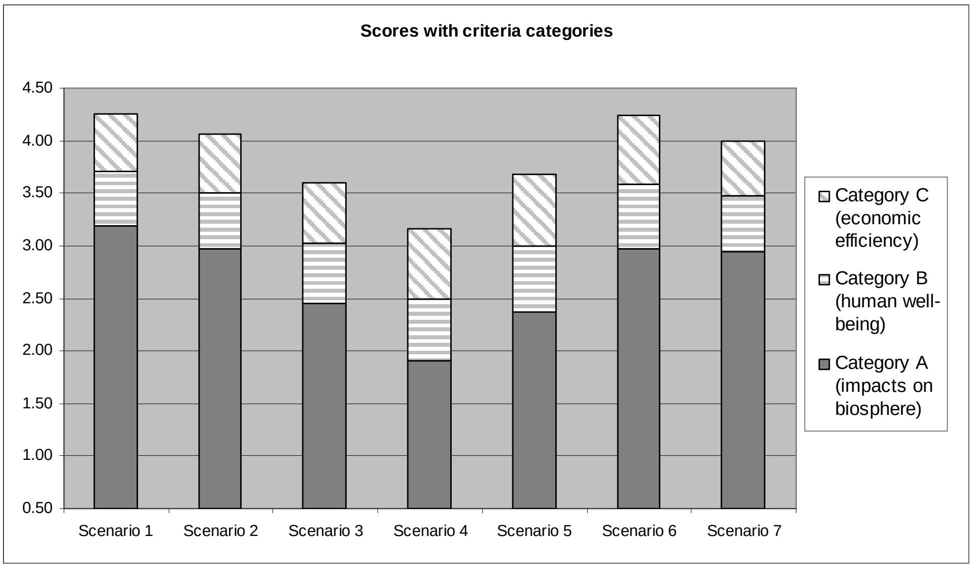


Fig. 6: Case study results: graphical comparison of the performance of the selected remediation scenarios, with a strong emphasis on the biosphere protection criteria category.

Preliminary results of the MCA and of the sensitivity analysis showed that the scoring of the various scenario tested enabled to broadly assess which scenario was the most suited to remediate the site. Scenario 6 had the best score for the MCA undertaken without criteria weighting and for the MCA weighting strongly the biosphere protection criteria. Scenario 5 had the best score for the MCA weighting strongly the economic efficiency criteria. However, these results should be considered as preliminary results and should be used with caution for the two following reasons:

- Scoring obtained for scenario 1 to 7 were of similar range and as a consequence do not demonstrate a significant difference in scenario ranking.
- Preliminary results of scenario 7 deal with the assessment of a very conventional version of the innovative process developed in the OXYSOL project. Therefore, the ranking of scenario 7 does not reflect the real ranking of final version of the OXYSOL project.

While developing the case study, some difficulties were encountered for data collection. As a consequence, criteria identification/definition was improved, through slight reformulation and medication, in order to better match real-life situations.

This methodology provides a successful basic assessment of the applicability and of the global performance of the conventional version ISCO / soil functions restoration process. However, as the combined ISCO / soil functions restoration process will be further developed up to the end of the OXYSOL project (mid-2011), the MCA methodology will be further developed and this final version of the OXYSOL remediation process will be assessed on other case studies.

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