Taking Nanotechnological Remediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment

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The NanoRem Sustainability and Markets Workshop

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Executive Summary

There has been an increased focus on sustainability in environmental remediation, which means that the decision making process should evaluate the environmental, economic and societal aspects of available options. Nanoremediation is an emerging remediation technology, with unique characteristics that can offer a number of benefits and improvements on existing process-based remediation. In order to build a cross-sectorial view of key sustainability issues related to nanoremediation, the NanoRem project arranged a “Sustainability and Markets” stakeholder workshop. The workshop gathered 36 participants from nine different countries, including land managers, consultants, technology contractors, planners, regulators and other experts, with various backgrounds and interests. The focus of the workshop was on developing an overview of the opinions of these stakeholders on:

(1) the sustainability of nanoremediation, and issues likely to influence perceptions of its sustainability, including ethical concerns,
(2) sustainability of nanoremediation compared to other remediation technologies and
(3) factors that push or pull the market development for the nanoremediation technology in the medium to longer term.

This report presents the approach used for the NanoRem Oslo workshop and its findings.

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1 Introduction

The problem of contaminated land is widespread and there is considerable demand for efficient remediation technologies. Contaminated land management is based on the identification and mitigation of unacceptable risks to humans and the wider environment. As part of the assessment of remediation technologies, there is an increasing recognition of the need to address sustainability considerations in the decision making process (Bardos *et al*., 2013). Although there is an ongoing debate on how to incorporate sustainability criteria into the evaluation of different remediation options and the remediation process itself, it is agreed that this should include economic, societal and environmental aspects (NICOLE and COMMON FORUM, 2013, Bartke and Schwarze, 2015). This means that any remediation project should consider which of the available remediation techniques would have the best net environmental, economic and social impact in dealing with a contamination problem (U. S. Sustainable Remediation Forum, 2009, EPA, 2008, Bardos *et al*., 2011, NICOLE, 2010).

Nanoremediation is an emerging technology that extends the range of available *in situ* remediation methods. This technique uses nanoparticles (defined as particles sized less than 100 nm) to transform contaminants into harmless forms (Karn *et al.*, 2009, Bardos *et al.*, 2014). The unique characteristics of nanoparticles can offer a number of benefits within some applications (Müller and Nowack, 2010), but at the same time concerns have been raised about uncertainties in particle behaviour and effects in the environment (Bardos *et al*., 2014).

NanoRem (*Taking Nanotechnological Remediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment*) is an EU-funded project[1] (www.nanorem.eu) that aims to ensure appropriate use of nanoremediation technology. The project focuses on facilitating practical, safe, economic and exploitable nanotechnology for *in situ* remediation. At the same time, NanoRem needs to understand the environmental risk-benefit of nanoremediation, market demand, overall sustainability and stakeholder perceptions. To do this, the project will support dialogue and engagement with various stakeholders in Europe in order to explore consensus about appropriate uses of nanoremediation.

One of the tasks in NanoRem work package 9, entitled "Dissemination, Dialogue with Stakeholders and Exploitation", is to collect "*specific usable information for risk assessment policy, market analysis and legal/ethical aspects, societal acceptance*" (NanoRem, 2012). These were to be achieved through, *inter alia*, project-oriented workshops.

The NanoRem workshop on Sustainability and Markets was one of the stakeholder-engagement activities and was held in Oslo 3rd-4th of December 2014. The workshop gathered a variety of expert and professional stakeholders from research, regulation and industry. This report presents the approach used for the NanoRem Oslo workshop and its findings. It is summarised from a number of contemporaneous workshop records, which have been kept as a confidential project archive.

[1] NanoRem is funded through the European Commission's Seventh Framework Programme, grant agreement no: 309517

2 Workshop objectives, approach and methodology

2.1 Objectives

The aim of the workshop was to build a cross-sectorial view of key sustainability issues and ethical concerns as well as market development opportunities in the medium to longer term related to nanoremediation across a range of stakeholder opinions. The workshop focus was on developing a realistic understanding of the opinions of land managers, consultants, technology contractors, planners and regulators on:

1. the sustainability of nanoremediation and issues influencing perceptions of its sustainability;
2. sustainability of nanoremediation compared to other remediation technologies; and
3. factors that push or pull the market development for the nanoremediation technology.

The output and results are intended to inform the development of appropriate use strategies within the NanoRem project, and are not directly linked to the decision-making process with regard to the actual regulation or acceptance of nanoparticle use in remediation, in any specific jurisdiction.

2.2 Participants

The workshop gathered 36 participants from nine different countries (Austria, Belgium, Czech Republic, France, Germany, The Netherlands, Norway, Poland and United Kingdom) (Figure 1), with a split of 16 participants from the NanoRem project and 20 external participants. Two of the external participants are also members of the NanoRem Project Advisory Group (PAG). All stakeholders could be classified as "expert" or professional representatives, rather than local or laypeople from actual remediation sites. This is in line with the workshop objective of a generic evaluation of issues and factors affecting the sustainability and marketing of nanoremediation, as opposed to a specific remediation action. It is also in line with the project's contracted Description of Work[2].

Given the multidisciplinary nature of the NanoRem project, the 16 internal participants represented various stakeholder groups with different views, background and interests. They included researchers, scientists, consultants and industry representatives, from groups working on nanoparticle production, toxicological testing, analytical measurements, large-scale lab and field trials, as well as the group responsible for the dialogue with stakeholders, who were actively involved in the planning and organization of the workshop. Their participation was intended to 1) stimulate dialogue between internal and external stakeholders, 2) ensure that all views were represented and 3) answer questions about the progress of the project, its current status and results.

[2] "*Two elicitation workshops will be held to provide a project orientated workshop that also delivers specific usable information for risk assessment policy, market analysis and legal/ ethical aspects, societal acceptance …Delegates to these workshops (up to 25 external delegates per event) will be invited from the project advisory group, the consortium and external stakeholder groups and networks to generate outputs of shared and mutual interest*." NANOREM 2012. NanoRem - Taking Nanotechnological Remediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment. Description of Work.

The background of the 20 external participants varied and included regulators, contractors, remediation consultants and social scientists. Throughout the organisation process, there were several attempts to involve representatives of NGOs and 'problem owners' (i.e., remediation site owners), but with limited success.

The full list of participants and affiliations is given in Appendix A.

Figure 1: Participants of the Oslo workshop. (Photo: Hans-Peter Koschitzky)

2.3 Methodology

The workshop used interactive discussions in smaller groups, following The World Café™ style, in order to allow every participant to contribute their views.

The workshop was divided into three main sessions:

- Session 1 explored generic issues associated with the sustainability of nanoremediation as a technology,
- Session 2 was a mock sustainability assessment in the context of a specific (hypothetical) site,
- Session 3 assessed factors that influence the medium to longer-term market development.

Representatives of the NanoRem project acted as facilitators for the group discussions, but non-NanoRem participants were nominated by the groups as rapporteurs. In order to encourage open and free exchange of opinions, all discussions during the workshop were held under a variant of the Chatham House rule: namely, that only statements generated during the debate would be reported and not the identity of the speaker (i.e. "what was said not who said what"). The draft reports of the session results as well as the final workshop report were sent to participants for their comments prior to publication.

The participants were not asked to present themselves before the first discussion session, as this was intended to be a generic discussion about sustainability, without the influence of preconceptions resulting from the participants affiliation (i.e., in line with the original World Café™ spirit). However, introductions and affiliations were made prior to the next two sessions.

Session 1: Several plenary lectures were given at the beginning of this session, before the participants were split into groups for discussions. These presentations are available at http://www.nanorem.eu/Displaynews.aspx?ID=797. A detailed description of the approach, discussions and results is presented in Chapter 3.1.

Session 2 built upon the discussions within Session 1 and considered sustainability assessment in the context of a specific site and in comparison with other risk management options. A case study was presented at the beginning of the session. Afterwards, the delegates were split into groups and each group was asked to carry out a qualitative assessment of the selected remediation options, to identify criteria that are likely to be important and that differentiate between management options within the site context. The results of the discussions within this session are given in Chapter 3.2.

Session 3 aimed to use the cross-sectorial and transdisciplinary expertise gathered in the workshop to identify and assess the interaction of relevant factors that are likely to drive or inhibit market opportunities for the nanoremediation technology. The session built on the findings of preceding literature analysis and expert interviews, which generated an initial list of factors that are likely to influence the evolution of the nanoremediation market. In the session, participants were introduced to some background on the general market assessment idea utilizing the scenario technique (Gausemeier et al., 1998). Then they were divided into small groups based on their expertise, where they discussed and scored pairwise the perceived interdependencies of market factors. Groups then presented opinions and received feedbacks in the World Café™ format. The result of discussions within session 3 are summarized in Chapter 3.3

The report documents the discussions taking place during the course of the workshop, and questions and concerns raised during those discussions. It should be stressed that the information presented, reflects the opinions of the workshop participants, and in some cases their views on what other stakeholders' perceptions might be, and how these might influence issues. As such, the statements should not be taken as evidence-based.

The agenda of the workshop is given in Appendix B.

3 Workshop session reports

3.1 Session 1: Nanoremediation: hopes and fears from the sustainability perspective

Contaminated land management is based on the identification and mitigation of unacceptable risks to humans and the wider environment. The use of nanoparticles in remediation could offer new developments and benefits for remediation technology. But how sustainable is nanoremediation?

This session was intended to be a general brainstorming introduction, in order to investigate the range of generic "nanoremediation" sustainability issues related either directly to the technology or to the way the technology might be perceived to meet site-specific attributes of sustainability.

NanoRem consortium members gave several introductory lectures prior to the session: (1) Contaminated land management and risk assessment; (2) Nanoremediation and other in-situ remediation technologies; (3) The concept of sustainable remediation being applied in NanoRem; (4) Life cycle inventories of nanoparticle production. The presentations can be found at:
http://www.nanorem.eu/Displaynews.aspx?ID=797.

The participants were divided into five groups of 6-7 people, each with a facilitator from the NanoRem project, and asked to answer the following questions:

- What do you understand by sustainability and why is it important to you?
- How sustainable do you think nanoremediation could be and why? Consider environmental, economic and social aspects.
- What did you learn from this discussion? Did something surprise you? Challenge you?

The opening question was intended to stimulate a general discussion. For the second question, the participants were asked to write their own ideas for sustainability concerns and benefits of nanoremediation on Post-It notes. These were assembled according to the three elements of sustainable development - economy, society and environment (an example of a message board is given in Figure 2). This "raw data" served as the basis for further discussions within the groups (Figure 3). Each group considered all three elements of sustainability. When the participants were not sure if a certain issue was a benefit or a concern, or if it had the potential to go either way, the Post-it note was put in the middle. There were some minor differences in the way each group handled this task.

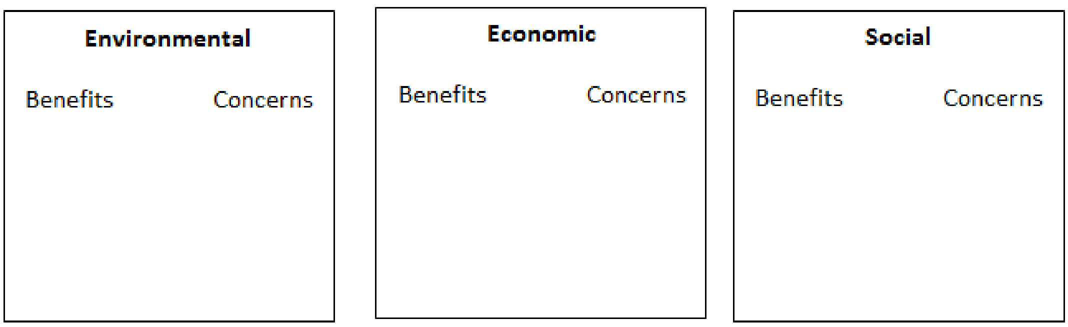


Figure 2: An example of message boards representing three aspects of sustainability, where participants could place their Post-it notes.

Figure 3: One of the groups during the discussion in Session 1. (Photo: Hans-Peter Koschitzky)

3.1.1 Question 1 - What do you understand by sustainability and why is it important to you?

In general, participants agreed on the three pillars, or elements, of sustainability – environmental, social and economic - and that assessment of risks and benefits should be balanced across these three categories. They recognized that sustainability needs to address more than economic cost and technical effectiveness and should be viewed with a longer and broader perspective. Sustainability should be considered beyond the immediate human impact, and should address long-term global impacts. The issues of resource use, risk and uncertainty were deemed to be particularly important as they have an effect on future generations.

It was hard to keep group discussions generic, as many participants wanted to discuss the NanoRem project itself, how nanoremediation compares to other remediation technologies and other specific details. However, this raised useful points for further discussion in the next round.

In one of the groups, questions on context and framing of the discussion were debated. The participants recognised that the question of sustainability would depend upon which part of the remediation process was under discussion: the application of remediation technology, the overarching process (with or without the process of nanoparticle production) or on the long-term goal of the remediation – to clean up the environment. In another group, a point was made that one might not actually want remediation to be sustainable if that would imply continuing sources of pollution; i.e., the successful development of remediation technologies should not be used to justify the future contamination of the environment. This underlines the importance of problem framing.

3.1.2 Question 2 - How sustainable do you think nanoremediation could be and why? Consider environmental, economic and social aspects.

Participants noted a number of potential benefits and concerns with nanoremediation[3] related to all three aspects. It was pointed out that a key issue for addressing sustainability will be how nanoremediation compares with alternative technologies. While a focused comparison with specific alternatives was not carried out during this session, the discussions raised a number of generic points that should be considered relevant for evaluation of nanoremediation sustainability.

Environmental - Participants noted a number of potential environmental benefits that might be attributed to nanoremediation. In general, common to other technologies, it is expected that the use of nanoremediation will result in a cleaner site and protection of the surface water. Nanoremediation at its current stage broadens the remediation technology toolkit and has potential to address both current problems like POPs as well as emerging contaminants.

Specific points listed included:

- It can possibly offer treatment of pollutants that have not yet been addressed by other technologies, or provide a faster treatment of current problems compared to existing technologies.
- That it is possibly more benign than its alternatives: for example in being less invasive and having a relatively low impact on site.
- That nanoremediation can act synergistically with natural attenuation and microbial processes in soils.
- A relatively low toxicity of the current materials used in nanoremediation, and lack of reported harmful by-products from the reaction of nanoparticles with the contaminant, or air emissions.
- A low mobility of the nanoparticles would limit their migration outside the treatment zone and reduce possibility of effects on the neighbouring areas.
- The small size of the nanoparticles could allow them to get closer to the contaminant resulting in improved clean-up.

Many of the environmental concerns were related to perceived potential intrinsic hazards of the nanoparticles themselves as well as uncertainties about production and application impacts. A general issue of unforeseen side effects (unknown unknowns) was raised during discussions in several groups. Specific points included:

- The possibility of air releases of particles during production and application, production of gases during the remediation process, and particles migrating and affecting the environment outside the treatment zone.
- Due to the high reactivity of nanoparticles, possible impacts on some site characteristics (e.g. microbial communities).

[3] Nanoremediation in this report refers to existing known technologies which are part of the NanoRem project

- Uncertainties as to whether nanoremediation process would generate any harmful by-products and their potential toxicity. If there was a potential impact on drinking water quality (e.g. due to site characteristics) this would be an important factor.
- Characterising nanoremediation as a less invasive technology will depend on, amongst others, factors such as the number of holes that would need to be drilled for the remediation project.
- Concerns about whether it would be possible (or necessary) to remove the nanoparticles from the site if something goes wrong.
- Uncertainties about the effectiveness within complex geology.

Finally, it was thought that nanoremediation could affect the ecosystem services of the area in both beneficial and detrimental ways.

Economic – Nanoremediation could be a faster and cheaper solution compared with other alternatives. There is also a possibility that this technology can offer a more efficient treatment of the contamination source.

Other positive issues raised in discussion:

- Iron ore, which is used in the nanoparticle production, is a widely available resource.
- The nanoremediation process is not dependent on the current site use and should pose relatively little disturbance to ongoing site activities. Although there may be short-term disturbances, for example, if there is a need for a dense network of injection wells.
- Being an innovative technology, it can create job and business opportunities in the development and production of nanoparticles.

On the other hand, there were a number of concerns about the efficiency and costs of nanoremediation. Specific issues included:

- As for many *in situ* remediation processes based on oxidation-reduction potential, there needs to be an oversupply of reagent (nanoparticles) deployed in the remediation process. If combined with high production costs, this can increase the price of the remediation project.
- There could be challenges in getting nanoparticles in contact with the contaminant, which would result in a need for reapplication and many injection points to achieve a full clean-up of the site.
- There are uncertainties as to whether this technology will be able to treat a wide range of contaminants.
- The relatively large number of uncertainties can create problems with insurance and financing of remediation projects. It is also important to define who would be held liable should the remediation fail.

Finally, nanoremediation can influence property costs on and around the remediation site, most likely leading to increased prices with a successful remediation. While this would tend to be regarded as a positive social consequence, there could also be negative social effects, depending on the situation of residents' and users.

Social - A number of the issues relevant for the economic evaluation will be have impacts on the social context

- Nanoremediation has the potential to be better, faster and work in a more efficient way.
- A new remediation technology tool may increase the number of brownfield sites cleaned up and regenerated.
- The remediation process can take place *in situ*, without drastic modification of land; the continued use of the site during remediation would avoid societal disruption.
- The development of new technology will create knowledge and, depending on the market size, job opportunities.
- The possible perceptions of nanotechnology resulting from its portrayal in science fiction were raised in this and a number of other discussions. While is sometimes presented as innovative, technologically advanced and beneficial, there are also examples of negative associations such as the book Prey (Crichton, 2003). As for many other technologies, the way nanotechnology is depicted in science fiction could have varying effects on public' views towards nanotechnology.

Some of the social concerns relate to uncertainties in the long-term consequences of the remediation, efficacy and longevity of the solution, and the fate of the nanoparticles in the environment.

- Nanoremediation has a specific application and should be considered within its niche.
- Public concerns about safety, the existing knowledge gaps, and the uncertainties in the environment and human health risks during the production and remediation process, might increase the unease with the technology.
- On site application processes might cause short-term disturbance to the local community (e.g. increased transport in the area close to the site).
- Development of nanoremediation technology might also trigger job losses within some sectors (e.g. in the competing fields of remediation technology).
- Issues of liability and what will happen in case of failure to treat the contamination are not yet clear.
- Specific regulations for nanoparticles are lacking and regulators are often not well acquainted with nanoremediation technology, which complicates the process of approval.

In general, there is a need for good case studies that will clearly demonstrate the benefits, safety and limitations of this technology, in order to address the concerns about the existing uncertainties with nanoremediation technology.

3.1.3 Question 3 - What did you learn from this discussion? Did something surprise you? Challenge you?

The discussions demonstrated that evaluation of sustainability evaluation requires a broad perspective. There was also a clear need for a better understanding of the relationships between environmental, social and economic aspects.

Many of the sustainability issues raised during the discussion were common to remediation in general and are not specific to nanoremediation.

Although several of the criteria mentioned had the potential to be seen as either a benefit or a concern, more of them were listed as concerns rather than benefits. This probably reflects the ongoing uncertainties and demands for more research (both technical and societal). Such research would improve understanding of the benefits and risks related to nanoremediation its comparison with the benefits and risks of alternative treatment options. However, one of the groups pointed out that the gaps in technical knowledge could be a potential for innovation and a positive driver for development of the technology.

The participants defined some specific challenges for nanoremediation if it should improve its sustainability rating: reduction of production costs, enhancing the mobility of the particles, and increasing the lifetime of the product in order to justify the production cost. Nanoremediation should look for possible synergies with other techniques. It is important to improve knowledge of the environmental fate of the particles and establish a method for control or tracking of the injected particles. Participants stated many times that a successful demonstration of remediation of a pollution source would make a big difference.

One of the groups was surprised that none of the arguments could be defined as a big advantage or seller for the nanoremediation technology. While the market niche for nanoremediation is not well established, it can still, be seen as a valuable supplemental technology.

The degree of consensus varied between the groups. In one of them, several people were outside their comfort zone in being asked to point out benefits or detriments in such a generic way without reference to a specific site or comparison with other types of remediation technologies. One participant felt very strongly that the wrong question was being asked and that already this first Café session[4] should have been orientated around a contaminated land management problem and the best means of tackling that problem.

Others felt that the broad potential benefits and concerns were already known at the proposal stage and that re-evaluating them in detail was actually detrimental because it could unduly increase worries about the technology. A similar concern about increasing worries about nanoremediation was put forward as a consensus point from another group.

A general consensus was that it was legitimate to explore the sustainability of nanoremediation, but that this should be made in the context of clear technical understanding of what nanoremediation is

[4] Participants had already been informed that Session 2 of the workshop would be based on a hypothetical case study from one of the NanoRem field trial sites

and what its advantages and limitations are. The fact that no substantive "new" generic issues were identified was a positive outcome, indicating that the boundaries of the NanoRem project had been well defined. It was also pointed out that the process of debate over the broad acceptability of nanoremediation was not greatly different to that taking place for other new technologies.

3.2 Session 2: Case study – Sustainability assessment

The aim of this session was to take the generic thinking developed during the World Café and to consider sustainability assessment in the context of a specific site and in comparison with other risk management options. The delegates were split into groups and each group was asked to carry out a qualitative assessment of selected remediation options to identify criteria that are likely to be important and that differentiate between management options within the site context.

3.2.1 Background to NanoRem sustainability assessment

One of the NanoRem tasks is to carry out a sustainability assessment using one or more of the existing sustainable remediation tools (e.g. NICOLE, SuRF-UK) and determining the most important impacts and benefits of practical remedial use of nanotechnology. As the sustainability considerations will be site- (and stakeholder-) specific, an assessment will be performed for more than one of the NanoRem field test sites.

The NanoRem approach to sustainability assessment follows the NICOLE Road Map (NICOLE, 2010) as the only Europe-wide framework and applies the SuRF-UK tools for qualitative assessment (CL:AIRE, 2010, CL:AIRE, 2011, CL:AIRE, 2014) within the Road Map. Both approaches are acknowledged as good practice in the COMMON FORUM and NICOLE Joint Statement on Risk-informed and Sustainable Remediation (NICOLE and COMMON FORUM, 2013). The sustainability assessment approach is illustrated below (Figure 4).

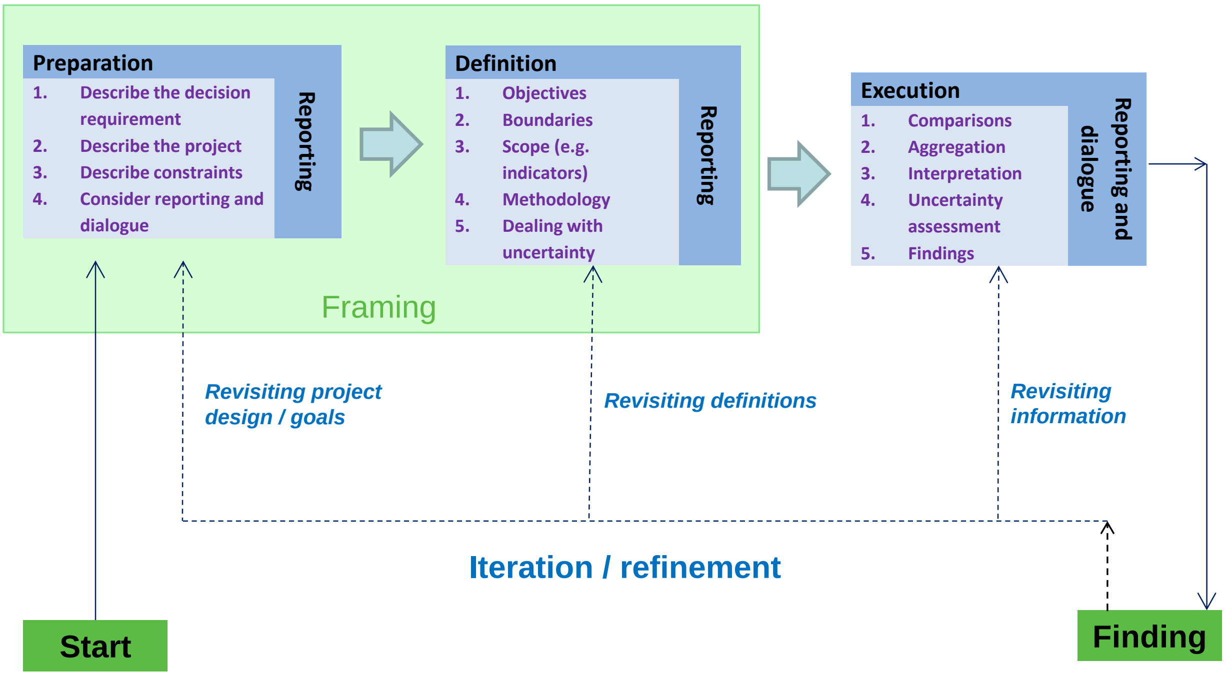


Figure 4: NanoRem sustainability assessment process steps (after CL:AIRE, 2014)

3.2.2 The Case Study

The site is based on one of the NanoRem field test sites for which a sustainability assessment has been framed but not carried out. However, the context was hypothetical in that NanoRem is not committing to a complete contaminated land management action at this site. The dominant purpose of the session was to gain feedback on the NanoRem sustainability assessment approach from the workshop delegates, rather than a peer review of the site management per se. The participants were provided with summary details for the site (Appendix C), including the site conceptual model (Table 1); the sustainability assessment framing and a list of key actors likely to be involved in the sustainability assessment.

The site is local council-owned with a groundwater plume contaminated with chlorinated ethenes. The site has residential neighbours and is used by a local football team and weekly market. The objective of this exercise was to assess the sustainability of nanoremediation against selected feasible management options using a qualitative approach outlined in the NanoRem sustainability assessment workbook. For the purpose of this exercise, the remediation objective is to ensure that the contaminated groundwater plume that crosses the site does not give rise to further pollution of groundwater or harm to human health.

Table 1: Conceptual model: sources, pathways and receptors

Source	Pathway	Receptor
Chlorinated ethenes	Migration in aquifer	Uncontaminated groundwater Water (irrigation) wells
Chlorinated ethenes	Use of contaminated groundwater during irrigation and ingestion of contaminated local vegetables and fruits	Residents
Chlorinated ethenes	Migration of vapours to indoor air and inhalation by residents.	Residents Workers and users of football field
Chlorinated ethenes	Migration of vapours to indoor air and inhalation by residents.	Workers and users of football field Market workers and users

The risk management options considered were:

- Baseline (limited receptor management- prohibition on use of irrigation wells, periodic monitoring);
- Pump and treat (removal of contaminated groundwater for treatment above ground);
- In situ enhanced bioremediation (treatment of contaminants in the ground by adding reagents to groundwater to create optimal conditions for biodegradation);
- In situ nanoremediation (treatment of contaminants in the ground by adding nanoparticles to promote abiotic treatment - dechlorination of the contaminants).

Assumptions made for the purpose of this exercise were that:

- Only management of the contaminant plume is considered;
- As no natural degradation is taking place, the baseline condition is not an option for this site, but forms a useful comparator;
- Nanoremediation and the other technology comparators are capable of achieving the remediation objectives. The objective is to assess how sustainable each option is considered to be, assessed against a range of wider environmental, social and economic factors.

For the sustainability assessment, project framing (preparation and definition) has been carried out and summary information was provided to delegates. The sustainability assessment used the SuRF UK indicator category sets (Figure 5) for assessment of each management approach against environmental, social and economic criteria.

Environment	Social	Economic
Emissions to Air	Human health & safety	Direct economic costs & benefits
Soil and ground conditions	Ethics & equality	Indirect economic costs & benefits
Groundwater & surface water	Neighbourhoods & locality	Employment & employment capital
Ecology	Communities & community involvement	Induced economic costs & benefits
Natural resources & waste	Uncertainty & evidence	Project lifespan & flexibility

Figure 5: SuRF UK Indicator category sets (after CL:AIRE 2011)

3.2.3 The Tasks

Six groups were set-up, each with mixed skill sets and at least one delegate with experience in contaminated land management and remediation. Each group was facilitated by a representative of the NanoRem project. Groups were given hints, but no clear direction, on how to report their findings, allowing discussions to evolve "unhindered".

Task 1: Each group was asked to discuss the sustainability of nanoremediation for this site against a baseline condition and another selected remediation technology (see Table 2) using the environmental, economic and social indicator categories sets. The assessment was qualitative. Each group was asked to identify the indicators that are likely to be important for this site, and those that may strongly differentiate between management options. Broad agreements and significant differences of opinion should be noted.

Task 2: Each group was asked to consider their assessment in more detail for one of the three indicator sets (see Table 2). The purpose of this exercise was to:

- Identify specific criteria within the indicator set that are likely to differentiate between the options compared;
- Identify any areas of strong agreement and disagreement between participants;

- Identify whether this level of detail has changed the opinion of the group.

Table 2: Management options and indicator sets considered by groups

Group	Task 1 comparator	Task 2 indicator category set
1	Baseline Pump and treat	Environment
2	Baseline Pump and treat	Social
3	Baseline Pump and treat	Economic
4	Baseline *In situ* bioremediation	Environment
5	Baseline *In situ* bioremediation	Social
6	Baseline *In situ* bioremediation	Economic

Task 3: individually, delegates were asked to subjectively rank the criteria assessed in Task 2 in order of importance. This information was assessed in order to observe any difference in opinion between skill sets.

3.2.4 General findings

Group discussions evolved in different ways, from considering the task in hand to debating either the technical basis for the case study or the interpretation and suitability of the indicator sets. Despite the different approaches taken by groups, broad consensus was reached in terms of the relative importance of indicator categories with particular regard to nanoremediation. A summary of group findings for all groups is shown in Table 3. This table and following text are derived mainly from an interpretation of the raw materials prepared by each group and from the recording of the plenary session (feedback from each group).

It is clear that the indicator categories considered as most important (high or variable high to moderate) for the case study were (in no particular order):

- **ENV 3** – Groundwater and surface water
- **ENV 5** – Natural resources and waste
- **ECON 1** – Direct economic costs and benefits
- **ECON 5** – Project lifespan and flexibility
- **SOC 1** – Human health and safety
- **SOC 4** – Community and community involvement
- **SOC 5** – Uncertainty and evidence

These findings were generally mirrored by the individual rankings carried out in Task 3.

It was generally agreed that there was little to differentiate between *in situ* bioremediation and nanoremediation apart from uncertainty and evidence (**SOC 5**) and this proved to be a key issue for all groups (see below). More differentiators can be identified between pump and treat and nanoremediation (see output from Group 3), with natural resources and waste (**ENV 5**) direct and indirect costs (**ECON 1 & 2**), project flexibility and lifespan (**ECON 5**), communities (**SOC 4**) and uncertainty and evidence (**SOC 5**) identified as high differentiators.

One key issue that arose from each group discussion was uncertainty. The delegates felt that there was insufficient information about nanoremediation (in terms of performance, cost, and deployment risks) to make a reasoned judgement against several of the indicators. This was particularly evident in Task 2 when indicator categories were subdivided into individual criteria and in the comparison with *in situ* bioremediation where methods of deployment were broadly similar. The biggest difference between the two technologies related to uncertainty and evidence.

Table 3: Summary of group findings

Indicator category	**Important?**	**Differentiator?**	**Consensus?**	**Comment**
ENVIRONMENT				
Emissions to air	Variable, high to not relevant	Variable, high to not relevant	Variable	Variability (within and between groups) due to interpretation – process emissions or inhalation pathway (latter should be considered under SOC 1).
Soil & ground conditions	Variable, high to low	Variable, high to low	Variable	Variability (within and between groups) mainly related to use of sports field (high) vs impact on soil function (low, due to depth of injection).
Groundwater & surface water	High	High to moderate	Yes	All groups considered groundwater to be a key factor.
Ecology	Variable, low to moderate	Variable, low to moderate	Yes	Response depended on whether groundwater ecology was considered important.
Natural resources & waste	Variable, high to moderate	Variable, high to moderate	Yes	Variability depended on which technologies were being compared - high importance and differentiator when comparing nanoremediation with pump and treat.
SOCIAL				

Indicator category	Important?	Differentiator?	Consensus?	Comment
Human health & safety	Variable, high to moderate	Low	Yes	Several groups discussed whether this should be included as H&S requirements will need to be met.
Ethics & equality	Low	Variable, low to moderate	Yes	Most groups felt that ethics and equality was not a key criterion for technology selection. Equality may be different for nanoremediation because of uncertainty.
Neighbourhoods & locality	Variable, high to moderate	Variable, low to moderate	Yes	Variability depended on which technologies were being compared.
Communities & community involvement	Variable, high to moderate	Variable, high to moderate	Yes	Considered important, especially for a new technology.
Uncertainty & evidence	Generally high	Variable, high to moderate	Yes	The costs and benefits of nanoremediation were considered too poorly understood to compare directly with established technologies.
ECONOMIC				
Direct economic costs & benefits	Variable, high to moderate	Variable, high to moderate	Yes	Difficult to determine for nanoremediation.
Indirect economic costs & benefits	Variable, high to low	Variable, high to low	Yes	Impact of uncertainty of indirect costs?
Employment & employment capital	Low	Low	Yes	Little opportunity.
Induced economic costs & benefits	Low	Low	Yes	Little opportunity.
Project lifespan & flexibility	Variable, high to moderate	Variable, high to moderate	Yes	Some groups considered these should be split

3.2.5 Summary findings from tasks 1 and 2

Group 1 – the group agreed to disagree on how the indicators should be rated. The group considered the importance of each indicator category and felt that the uncertainty, in terms of the site context, was too much and raised additional questions on site-specifics. For example, why bother treating the plume only and not the source, although it remains beyond the site boundary?

On the basis that the source has been dealt with, groundwater (**ENV 3**), and natural resources and waste (**ENV 5**) are the only environmental factors of high importance. Direct costs and benefits (**ECON**

1) are important, but induced costs and benefits (**ECON 4**) are not considered to be relevant for any management option. Different (remediation) choices behave in a similar way, but uncertainty and evidence (**SOC 5**) may be a very important issue – uncertainty related to baseline evidence as well as technology performance.

For nanoremediation, groundwater is considered to be the most important factor, but with many uncertainties associated with the stage of technology development. For pump and treat, natural resources and waste (energy use and waste arising) is the most important and largest differentiator between pump and treat and nanoremediation.

***In situ* bioremediation vs pump & treat**: all **ENV** indicators are fairly important, but two are of highest importance: groundwater & surface water (**ENV 3**) and natural resources and waste (**ENV 5**). For nanoremediation, **ENV 3** is the most important indicator (with uncertainties related to rebound and metabolites, secondary sources) and for pump & treat, **ENV 5** is the most important indicator (high energy, waste arising).

Group 2 – considered the importance of each indicator category and defined as a starting point that the source is remediated, otherwise there is no point in treating the plume. Ecology (**ENV 4**) is less important in the urban area, all other environmental indicators may be important. Direct costs and property value (**ECON 1 & 2**) are considered important, but residual risk and restriction on abstraction would continue to impact property values. Project flexibility and lifespan (**ECON 5**) are also important. Health and safety (**SOC 1**), and uncertainty and evidence (**SOC 5**) are very important. Communities and community involvement (**SOC 4**) was also considered to be important. **SOC** criteria are all related to time (how long will the remediation take) and impact on the residents (access to gardens for sampling and/or injection). It is difficult to determine the duration of the impacts of nanoremediation (single injection with periodic monitoring or multiple injections?) on local residents.

The most important indicators identified were considered to be:

- **ECON 1** – Direct economic costs and benefits
- **ECON 5** – Project lifespan and flexibility
- **SOC 5** – Uncertainty and evidence
- **SOC 1** – Human health and safety
- **ENV 3** – Groundwater and surface water

Nanoremediation may be an advantage if the plume can be dealt with in short timescale. However, time is a key factor – how long will it take to remediate and how long will impacts affect residents (including restricted use of irrigation water)? Impacts may be high (e.g. sampling in gardens) or low and there is uncertainty of performance, for example will single or multiple injections be needed?

Group 3 – considered the importance of each indicator category and their ability to differentiate between options. Strong agreements/disagreements were also reported.

Air (**ENV 1**), water (**ENV 3**) and natural resources and waste (**ENV 5**) are the most important and highest differentiating environmental indicators. Soil (**ENV 2**) may also be important if land use (football) is impacted, but there was disagreement over whether this was environmental or social category (**SOC 3**). There were mixed views on the importance of ecology (**ENV 4**), but ecology of the aquifer should be taken into account.

Direct costs (**ECON 1**) were considered to be very important, but the definition of the problem needs to be more detailed in order to differentiate. For example, if the source remains, how is it going to be managed in the future - by single or repeat injection? Indirect costs (**ECON 2**) are considered important, in particular local land values and reputation (of LA). Employment and employment capital (**ECON 3**) is not considered to be important in this context, but innovation may be a potential differentiator in favour of nanoremediation. The group considered little opportunity for gearing (induced costs and benefits, **ECON 4**) without dealing with the source first. Lifespan and flexibility (**ECON 5**) are considered important but difficult to assess without knowing more detail about the remedial design, e.g. configuration, number of wells, number of injections. It is difficult to determine the overall benefit of any option with the source remaining untreated. More detail on the scope of remediation would help the assessment.

Of the social indicator categories, both human health and safety (**SOC 1**), and uncertainty and evidence (**SOC 5**) were considered to be very important, followed by locality (**SOC 3**) and community involvement (**SOC 4**).

Group 4 –used role–play to gather the views of key actors and smileys to represent them. This group started to find that the story is simpler than the exercise gone through. The exercise merely verified the overarching principles. They considered remediation against the baseline and agreed a desire to do something; to do nothing was in nobody's interest.

However, there was general unease about the unfamiliar, with extra burdens of proof likely to be required (by the regulator) for new technology. The contractor also found it easier to work with established technology, as there will be fewer surprises.

***In situ* bioremediation vs nanoremediation:** The two technologies considered had a lot in common (injection, minimal waste etc.), but the greatest differentiator was the known shortcomings of *in situ* bioremediation against the unknown shortcomings of nanoremediation; the known problems against unknown aspirations.

The challenge of change and resistance to change were expressed by quotes from Niccolo Machiavelli "*Innovation makes enemies of all those who prospered under the old regime and only lukewarm support is forthcoming from all those who would prosper under the new*" and "*There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things*". (Why change and risk the unknown?)

Group 5 – different perspectives/interpretation led to much debate and confusion. It was considered that environmental indicator categories could not be prioritised without more knowledge on risks and uncertainties, for example, what is the impact on flora and fauna (risk or benefit)?

Direct costs and benefits (**ECON 1**) is the most important indicator, but project lifespan and flexibility (**ECON 5**) caused much debate – many different criteria; all considered important.

The social indicator categories caused much debate in terms of categorisation and why risks are dealt with differently (for example ecology vs health and safety). Because of concern over the uncertainty of nanoremediation, **SOC 5** (uncertainty and evidence) was considered to be most important, but is it really a social indicator? Communities and community involvement (**SOC 4**) was considered to be the next important driver.

As a general comment, it is considered that there is not enough cross-correlation between the indicator categories.

Group 6 – considered the sustainability of each option against the 15 indicator categories and aggregated the scores to conclude that, in terms of overall sustainability without applying weightings:

In situ bioremediation > nanoremediation > pump and treat > baseline.

Pump and treat and baseline were similarly ranked and difficult to differentiate (in terms of aggregated score). *In situ* bioremediation was a clear leader, but the score came down to certainty against uncertainty when compared to nanoremediation.

***In situ* bioremediation vs nanoremediation: Economic criteria**

Scoring is quite similar with little difference in direct costs; indirect costs are also similar, but may be more of a differentiator with other land uses (redevelopment). It was thought that weighting would possibly help to differentiate indirect costs; one key factor is that larger allowances are needed for nanoremediation to deal with uncertainty (risk of failure). Employment opportunities may exist for nanoremediation, but this is not significant enough to differentiate. Project lifespan & flexibility are considered to be the most important **ECON** category; familiarity with *in situ* bioremediation making it easier to change approach (flexibility).

Key differentiators – indirect costs and project lifespan & flexibility, but more information is needed to make the distinction between *in situ* bioremediation and nanoremediation clearer.

3.2.6 Summary findings from Task 3

Each delegate was asked to rank the importance of each of the indicator categories discussed in task 2. The findings are shown in Table 4. There was strong recognition that such ranking will be site/problem-specific. On that basis, the individual assessments generally reflect the importance attributed during group discussions.

Of the environmental indicators, groundwater then natural resources and waste were considered to be of greatest importance, followed by emissions to air. Two contaminated land specialists considered ecology to be fairly important. Human health and safety, uncertainty and evidence, and communities and community involvement were considered to be the most important social indicators, although there were some comments that neither human health and safety or uncertainty and evidence were appropriate social indicators. Direct economic costs and benefits, indirect economic costs and benefits, and project lifespan and flexibility were considered to be the most important economic criteria. Some comments were made that each of these indicators should be split.

Table 4: Summary of individual rankings

Indicator category	Landowner (problem-holder)	Consultant/ contractor	Regulator	Other
ENVIRONMENT				
Emissions to air		3, 3	1	2

Soil & ground conditions		2, 2	1	1
Groundwater & surface water		5, 5	5	2, 5
Ecology		1, 1	1	4, 3
Natural resources & waste		4, 4	4	4
SOCIAL				
Human health & safety		5, 5		3, 5
Ethics & equality		1, 2		1
Neighbourhoods & locality		3, 1		1, 2
Communities & community in-volvement		2, 3, 4		3
Uncertainty & evi-dence		4, 4, 5		5, 4
ECONOMIC				
Direct economic costs & benefits	5	5, 5	5	5
Indirect economic costs & benefits	4	5, 4	3	3
Employment & employment capi-tal	1	1, 1	4	1
Induced economic costs & benefits	2	1, 1	1	2
Project lifespan & flexibility	3	5, 3	2	4

5 = highest importance, 1 = lowest importance (when several are considered not important scored as 1)

3.2.7 Overall summary of sustainability assessment case study

The case study exercise showed good consensus between groups on which indicator categories are considered to be of most importance in appraising management options for the site. The most important indicator categories for the case study were:

- ENV 3 – Groundwater and surface water
- ENV 5 – Natural resources and waste
- ECON 1 – Direct economic costs and benefits
- ECON 5 – Project lifespan and flexibility

- SOC 1 – Human health and safety
- SOC 4 – Community and community involvement
- SOC 5 – Uncertainty and evidence

However, this may not be the same for other sites and technologies. The use of a category to differentiate between options depended on the options. For example, **ENV 5** strongly differentiated between nanoremediation and pump & treat (energy use, waste arising); whereas **ECON 5** and **SOC 5** strongly differentiated between nanoremediation and *in situ* bioremediation.

In general, there were no surprises, and the exercise reinforced the significance of uncertainty; not just in response to the category **SOC 5** Uncertainty and Evidence, but also across each category. A number of findings have helped to shape how retrospective sustainability assessments will be carried out for NanoRem field trial sites.

Project framing – the case study was based on summary information from one of the NanoRem field trial sites. Most groups felt that insufficient information was presented, for example on the remediation strategy, and the presence of a contaminant source area beyond the site boundary caused much debate beyond the remit of considering plume management only.

Nanoremediation – was not rejected as a remediation option by any group, but:

Uncertainty –over its cost and performance constrained the groups' ability to compare nanoremediation against established technologies. Uncertainty was identified as a key differentiator when comparing nanoremediation with established technologies.

The NanoRem project aims to address some of the uncertainties through upscaling from laboratory to field scale, in order to validate cost, performance and fate and transport findings. It is proposed that sustainability assessments will be carried out for NanoRem field test sites after trial injection, and information from the trial will be presented to the stakeholder group as part of the introduction to the sustainability assessment. This will help to reduce the uncertainty associated with nanoremediation on a site-specific basis and lead to a more balanced comparison with established technologies.

Indicator categories – although there was much discussion over interpretation of the indicator categories, we consider the categories to be fit for purpose as the only peer-reviewed tool currently available for qualitative assessment. No new categories were suggested by workshop delegates, so it is considered that the indicator categories are sufficiently inclusive.

However, the indicator category tables will be clarified for use by NanoRem, and individual example criteria framed as questions rather than statements. Fewer example criteria will be listed. At this stage indicator categories will not be moved (for example, as suggested for **SOC1**) or spilt (for example, as suggested for **ECON5**) as the current framework has been subjected to peer review. The clarification should make the tables clearer to use and reduce the variation in interpretation observed for some criteria during the workshop.

3.3 Session 3 - Market development

One aim of the NanoRem project is to determine "value propositions[5]" for its remediation approach. The objective is to identify the opportunities for exploitation and routes for better regulation by understanding the market system and the uncertainties eminent to its development. This understanding is achieved through a step-wise approach, which includes a series of dialogues with key practitioners, academics and stakeholders ("key informants") from across the EU. As part of the process, the last session of the NanoRem Oslo workshop exploited the cross-sectorial and transdisciplinary expertise of participants to evaluate factors that are likely to drive or inhibit the development of the nanoremediation market. The aim of the session was to identify and assess the interdependencies of relevant factors in order to base the deduction of market opportunities on a more realistic understanding of the perceptions of senior experts and concerned parties in the field.

3.3.1 Session background and preparation

The session was based on preliminary findings of literature analysis and expert interviews. These identified a series of external determinants from economy, technology development, politics and society that affect the market for contaminated land remediation in general and the potential evolution of medium to longer-term development of nanoremediation in particular. The assessment of market opportunities needs to take account of the uncertainties and complexities of assessing a risky and partly uncertain future. New institutional economics has highlighted the meaning of norms and (informal) rules for understanding the effectiveness of institutional settings and the emergence of governance over time (Geels, 2002, North, 1990, Ostrom, 2005, Williamson, 1985). NanoRem has applied a "scenario" approach to give insights into the diversity of factors that potentially influence the future development of the nanoremediation market system - including its institutional setting.

The Oslo workshop contributed to the assessment of market opportunities as part of an explorative and transdisciplinary scenario approach (which is described in further detail in (Bardos *et al.*, 2015). Participants were introduced to some background on the general idea of the scenario rationale and technique, pointing out that scenarios are not probabilistic forecasts of the future but can be defined as "internally consistent stories about ways that a specific system might evolve in the future" (March *et al*., 2012). Scenarios have been applied to uncover and examine the complexity of an emerging system – here the nanoremediation market. Scenarios help to understand (i) what the push and pull factors for developments into the future are, (ii) what the extent of their impact is, and (iii) how they are interdependent. These insights allow for a systemisation of these factors and the uncertainties related to them. For example, regulation might be a decisive driver, but if policymaking is uncertain, it becomes an ambiguous element and potential inhibitor. Discussing the influence of factors in scenario storylines can support the identification of alternative development trajectories. This should enable exploitation strategies for enterprises and business to be identified, as well as improve the future regulation by policy makers.

[5] the overall promise of value to be delivered

Scenario design and analysis differ, but usually comprise a stepwise approach (Figure 6) including:

1. conducting a present situation analysis to define the scenario base (in this case the market for nanoremediation), via
2. systematising factors that drive or inhibit the development to
3. understand and filter the key factors and their potential progression into the future to
4. elaborate consistent stories about ways the system might evolve in the future to
5. deduce and conclude on strategies.

The Oslo NanoRem workshop focused on the second step of systematising the push and pull factors determining the market development.

Figure 6: Steps in scenario analysis. Source: Modified from Gausemeier *et al*. (1998)

Preliminary research – the present situation analysis – had identified 22 potentially influencing factors after several iterations with expert involvement. These 22 factors were sent to the workshop participants in advance of the meeting with a request to identify the perceived importance of each factor for the development of the market. Based on the feedback of 20 participants, an average score was calculated for each factor. The 22 factors were grouped into different categories (technology, policy, communication, economy, society and megatrends). The results of the scoring are given below.

Considering the European Union in 2025, the importance of factors regarding their potential to influence the nanoremediation market was gauged using the scale:

(0) = *Negligible relevance* – the factor is not an important driver or inhibitor;
(1) = *Minor relevance* – the factor might have a limited but not so important effect;
(2) = *Considerable relevance* – the factor is likely to have a notable (indirect) effect;
(3) = *Key relevance* – this factor is most certainly among those of utmost importance to push or pull the nanoremediation market development.

Top important factors as rated by experts to likely influence the market development (≥2.00):

1. Innovation on treatment of known contaminants with NP 2.48 *Technology*
2. Regulation of nanoparticles 2.45 *Policy*
3. Validated information on NP application potential 2.40 *Communication*
4. Costs of competitive technologies 2.35 *Economy*
5. Standardisation for nanoparticles 2.20 *Policy*
6. Innovations along NPs production chain 2.18 *Technology*
7. Environment (especially soil) protection policies 2.10 *Policy*
8. Synergies with other technologies 2.05 *Technology*
9. Public stakeholder dialogue 2.00 *Communication*

Less important factors (>1.50 and <2.00)

10. NP treatment of emerging contaminants	1.95	*Technology*
11. Public perception of NPs in general	1.93	*Society*
12. Science-Policy-Interface	1.93	*Communication*
13. Technology and research policies	1.75	*Policy*
14. Growing number of nanoparticles suppliers	1.73	*Economy*
15. Real estate market development	1.68	*Economy*
16. Innovation attitude	1.60	*Society*
17. Environmental awareness	1.55	*Society*

Minor relevant factors (≤1.50)

18. EU economic development	1.50	*Economy*
19. Globalization	1.20	*Megatrend*
20. Industrial and military land use	1.00	*Society*
21. Climate change	0.70	*Megatrend*
22. Demographic change	0.60	*Megatrend*

No "key factor" achieved a score of greater than 2.50, indicating that no factor alone is of utmost importance to push or pull the European nanoremediation market's development by 2025. The top set of important factors contained a variety of different categories, with the exception of "*Mega-trends*", which were found to have only minor relevance together with factors from "Economy" and "Society". Thus, it appears that the driving factors of the nanoremediation market are diverse, i.e. development depends not only on technology, but also on political (dis)incentives, societal preferences or the attitude of the industry.

The results of this exercise were presented to workshop participants at the start of the session. The presentation can be found at http://www.nanorem.eu/Displaynews.aspx?ID=797. For the following discussions, the experts were assigned to various groups according to the overarching categories (technology, policy, communication, economy, society and megatrends). For example, factors assigned as "technology" were discussed by a group of experts who had experience related to design, ecotoxicology and risk assessment as well as pilot testing of nanoparticles. Only the top 17 factors were discussed by participants.

3.3.2 Nanoremediation market factor interactions for the EU till 2025

In order to clarify the interdependencies of the identified to factors, participants were asked to assess the relevance of the development of one factor on the development of another factor – and so forth in order to obtain pairwise assessments for the full list of factors. Participants were divided into smaller groups that were aligned to factor categories reflecting their expertise, and each group was assigned two facilitators. The five groups were:

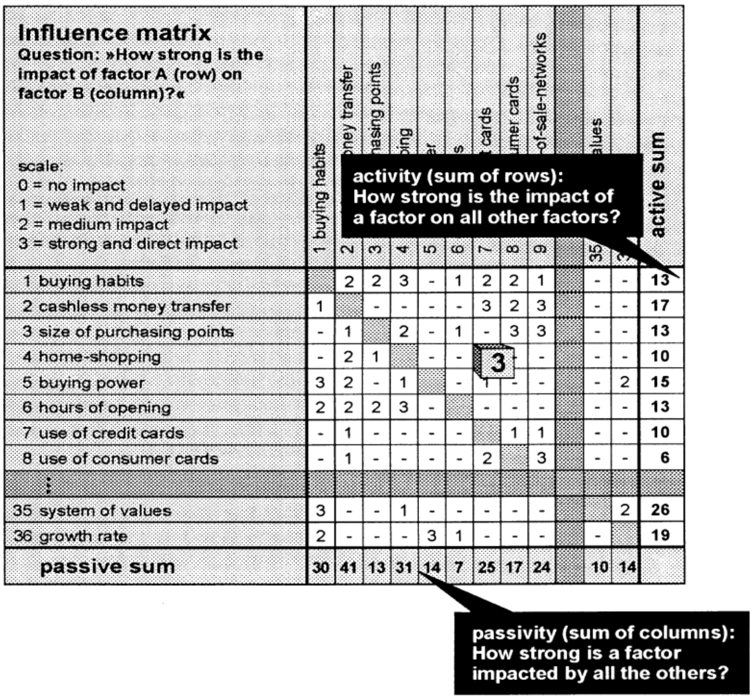
- group 1: Technology,
- group 2: Regulation / Policy making,
- group 3: Economy,
- group 4: Communication, and
- group 5: Society.

For each group a poster with an empty influence matrix was provided showing a short list of factors from the respective field of a group's expertise in the rows on the vertical axis (4 - 5 specific factors) and the full list of factors in the columns on the horizontal axis. Figure 7 gives an example of a typical influence matrix outline. In the first phase, participants were asked to review and provide opinions, comments and suggestions about their specific group of factors. Next, they were asked to identify and discuss the interrelations of the development of each of their factors in the rows on the full list of factors i.e. to discuss pairwise the influence of development of a factor from the vertical axis on the development of a factor from the horizontal axis. A scoring was assigned as follows (also indicated in Figure 7):

Considering the European Union in 2025, the impact of the development of the factor in the row on the development of the factor in each column was gauged using the scale:

(0) = No impact;
(1) = Weak / delayed impact;
(2) = Medium impact;
(3) = Strong / direct impact.

At the end of this phase, each group had completed their part of the influence matrix. [6]



	1 buying habits	2	3	4	5	6	7	8	9		35	36	active sum
1 buying habits		2	2	3	-	1	2	2	1		-	-	13
2 cashless money transfer	1		-	-	-	-	3	2	3		-	-	17
3 size of purchasing points	-	1		2	-	1	-	3	3		-	-	13
4 home-shopping	-	2	1		-	-	3	-	-		-	-	10
5 buying power	3	2	-	1		-	1	-	-		-	2	15
6 hours of opening	2	2	2	3	-		-	-	-		-	-	13
7 use of credit cards	-	1	-	-	-	-		1	1		-	-	10
8 use of consumer cards	-	1	-	-	-	-	2		3		-	-	6
⋮													
35 system of values	3	-	-	1	-	-	-	-	-			2	26
36 growth rate	2	-	-	-	3	1	-	-	-		-		19
passive sum	30	41	13	31	14	7	25	17	24		10	14	

Figure 7: Interaction matrix illustration (Gausemeier *et al.*, 1998)

[6] After the workshop it was possible to add up the rows and to obtain a full matrix containing all factors in the rows and columns – however, this was not done at the Oslo event, as the key objective here was to best sub-stantiate the assessments within the matrix.

The next part of the session used the World Café™ format, wherein participants were invited to discuss one by one the results of the other groups. The two group facilitators remained at the table while the groups circulated, and reviewed the assessments made by each group. At the end of this stage, the groups returned to their "home table" and revisited their assessments based on the feedback collected from the other groups. At the end of the session, the annotated posters and notes of facilitators were collected and interpreted.

3.3.3 Session general feedback

Overall, there was an intense and fruitful discussion in all groups. From the post session feedback, both organisers and participants expressed a wish that more time had been available as there was considerable devotion to the discussions. Most groups spent time debating the definitions of their factors, which were often perceived as being not specific enough. On the other hand, there was no request to add additional factors to the set of pre-selected determinants. Despite the short time available, all groups managed to discuss for all factors the respective impacts on the full set of determinants. In general, the groups were able to finalise the assessment for all factors.

The debates on definition during the first phase of the session were part of finding a common ground of understanding in the group on what the factors actually meant. These were rather general and broad definitions, with the intention of not prescribing a certain meaning or definition of any single factor. This approach was a trade-off of providing clarity regarding the factors to be assessed and leaving room to explore what the factors actually meant from the point of view of relevant experts.

Another general conclusion was that most expert teams found it easier to assess the impact of the set of general factors from the columns on their specific variables in the rows. They felt that they had been given the more difficult task to inversely do the assessment, i.e. being asked to evaluate the impact of their expertise factors in the rows on the full range of factors in the columns. This was expected by the organiser and it was the very reason that this more difficult task was given to the specialists' groups in the first phase of the session.

3.3.4 Specific feedbacks/insights from the expert groups

The "**Technology group**" was composed of seven experts with diverse backgrounds in academia, consultancy, contracting and NP development; three were from the NanoRem project. The covered factors were "Innovation on treatment of known contaminants with NP", "Innovations along NPs production chain", "Synergies with other technologies" and "NP treatment of emerging contaminants". Participants came up with an assessment for all technology factors on the full set of determinants.

The main points of the first phase were that the improvement of nanoremediation has unclear consequences on regulations, funding agencies and environmental policies, and the question: "Does the improvement of nanoremediation and its market introduction lead to more validated information on the application potential?" In the following phase of the session, when other groups reviewed the assessments, only few items were questioned – some however revealed considerable opposing perceptions. For those that were reassessed, there were cases with minor disagreement between the groups on the strength of impacts, yet in a few specific issues, an entirely different thinking was apparent. Conflict was found vis-à-vis the opinion from the group of Policy Makers and Regulators, which perhaps indicates a weak understanding of the policies on the side of technology developers, as stated by one participant. As an example: if there was a new technology for emerging contaminants that works, then

Technology experts expect (and decided to keep their assessment) that there will be no influence on the environmental policies nor a need for changing regulations, yet Regulation experts stated that they consider revisiting the existing governance and if needed adjust policies and regulations.

Another example of disagreement, where Technology experts rejected a revision, was with experts from the Economics table regarding the impact of the factors “Innovation on treatment of known contaminants with NP”, “Innovations along NPs production chain” and “Synergies with other technologies” on the “Costs of competitive technologies” – a link seen less direct and less strong by the Economists. On the other hand, Technology experts followed the advice of Economists that the “growth of the number of NP suppliers/ providers” (defined as more producers are entering the market and more suppliers gather the expertise, capacities and credibility to produce and distribute NPs) is more directly linked to these three mentioned technology factors, whereas experts from the Society table thought that this connection would be less significant. A final field of disagreement remained with regard to the perceived influence of technology factors on the “Science-Policy-Interface”; experts from the Society and Communication tables perceive a weak to medium impact of technology factors, which the Technology experts however did not agree with.

The “**Policy Makers and Regulators group**” was composed of seven experts working currently or having been involved in regulation and policy making on regional, national and European levels; two out of the seven were from the NanoRem consortium. The factors to be assed were “Regulation of nanoparticles”, “Standardisation for nanoparticles”, “Environment (especially soil) protection policies” and “Technology and research policies”. The group spent most of the allocated time of the first phase of the Session for the review and discussion of definitions of the factors. Regarding “Regulation of nanoparticles”, the group was looking at the production of nanoparticles and gave the reminder that nanoparticles production is regulated under REACH and CLP (Classification, Labelling & Packaging Regulations). There is no size-of-particles-discrimination, e.g. for iron in REACH meaning that nZVI is covered by that regulation.

The Policy group discussed “Standardisation” and reading the proposed definition, they felt two things: the standardisation of the production of NP and the standardisation of other aspects, such as deployment and monitoring. The classification of NP is already covered under the CLP and REACH – the standardisation of “the rest” would, however, be too broad to discuss, and it was questionable if standardisation was “what we want or what we need” as the rapporteur from the group reported. The factor “Standardisation” was dropped from the assessment. Following a discussion with the Technology group in the second phase of the session, the regulators proposed the standardisation to be changed to “Common protocols for assessment and monitoring”.

Regarding “Environment protection policy” soil protection was considered to be less important than groundwater protection. The Groundwater Daughter Directive (GWDD) is considered most relevant, in particular with respect to the “prevent and limit” requirements. However, other directive drivers may need to be considered, including the Industrial Emissions Directive (IED). Nanoparticles are already classified as hazardous under REACH. The Regulation and Policy experts raised their concerns over uncertainties on how nanoparticles will be assessed and if they become hazardous substances (GWD directive). In the UK, still no information on this as substances are being assessed on a priority basis – starting with existing List I and List II substances. Finally, on “Technologies and research policies” the group agreed that this factor was making references to Europe and national policies (e.g. ERANET). Based on this understanding, the experts managed to fill in the matrix in the remaining time of the first phase of the Session. The most direct and strongest impacts originating from the policy factors were perceived on the factors “innovation for treatment of known contaminants” and the “innovation on treatment of emerging contaminants”.

Only few changes were advised by the other expert groups. For the role of emerging technologies on regulation, see above in the Technology group. Revisiting the reviews from other expert groups, the biggest dispute was on the “Production of NP” and the “Synergies with other technologies” which was initially rated as zero influence by Regulators, whereas the Technology experts perceived a medium to direct impact of “Environmental protection policies” and “Regulation of NPs” – after discussion, the regulation experts retained their initial rating of zero impact, because nanoparticle production was already regulated in the same way as other products and particles (under REACH and CLP). Information is required to be held on safety datasheets (as for other non-nano scale products). No big evolution in the regulations is anticipated by the regulators that will be specific to nanoremediation. There is clearly a perception issue on whether changing or emerging regulations have the possibility of impacting the production of NPs specifically. Regulation experts found no further cases of severe dispute or opposition.

The “**Economy group**” was composed of seven participants with diverse backgrounds – being either concerned with making their business in consultancy and project development in the remediation market, producing NPs or working in academia on economic issues; two participants in the groups were from the NanoRem consortium. This group started by reviewing the factors to be assessed from an economic perspective. “Costs of competitive technologies” were understood to refer to already established technologies in the market; “Growing number of nanoparticles suppliers” was refined to recognize that suppliers have access to more producers; the third factor was “Real estate market development”.

The group discussed extensively the probable links of these factors to the full set of determinants – however, they felt that it would be more obvious and easier to assess the potential impacts the other way round. In general, it was found that the “real estate market development” has a rather low influence on the remaining determinants and should therefore be regarded as a minor importance factor. The other two economic factors were found to behave in quite a similar way, suggesting a kind of redundancy or common underlying driver. In the second phase of the session only minor revisions were suggested by the other groups, which was interpreted by the Economists as having been well in line with perceptions of other key informants – or respectively of other stakeholders having a considerable market knowledge.

There were few changes by one scoring level; the few discrepancies with more intense discussions were on the links of regulation and economic factors with the Regulators group. Regarding “Regulation of NPs”, the Regulators pointed out that NPs production is regulated under REACH. However, stakeholders from the Economy group asked if there could be the perception that that was not enough – whereas Regulators said they would be most happy if at least existing REACH regulation would be applied to their full extent, still the Economist group members suggested that the given governance structure could be perceived by some market actors as being not sufficient to recognize the specific properties of nanoparticles.

The “**Communication group**” consisted of seven experts, all with an interest in how NP enhanced options of remediation are communicated between relevant stakeholders; four out of the seven were from the NanoRem project. Definitions of factors were discussed by the experts and adjusted. “Validated information on NP application potential” was refined to include validated, independent information on the performance and fate of NPs from field studies. “Public stakeholder dialogue” was clarified to mean communication with the public and “Science-Policy-Interface” to include communication with others, including site owners.

A conclusion from the second phase of the Session was that most other experts would have marked the influence of the communication factors on average one mark lower than the team did initially – something that was explained rather with the general attitude of the group “being a more positive table”. Revisions to the initial ratings from other groups were not found significant with the only exception of the group of Regulators. They meant regulation of NPs was about products and production and not about the overall application, therefore a change in score was suggested. Good validation and good communication will influence creation of good regulation.

The Social table considered risk (toxicity, eco-toxicity) to be more important than application. In discussion with the Technology experts, discrepancy remained on the influence of “public perception” related to emerging contaminants. Using the PFOS example, it was argued by Communication experts that the general public would not be aware of emerging contaminants and therefore that the treatment of those would be not influenced. (In later discussions, it was pointed out that the PFOS example is internationally diverse – being a non-hot topic in the UK, but in different cases in Germany). The Technology people had a different definition of validation, considering it more as fundamental science, not field studies.

The **“Society group”** consisted of seven experts with diverse backgrounds in academia, business, a site and “problem” owner and project developers; two were from the NanoRem project. This group also started off with reviewing the definitions of the factors to be assessed. Regarding “Public perception of NPs in general”, it was asked “What is the public? Just general public/laypersons, or any affected/concerned body? Does it include local community representatives, GMOs, regulators, the media?” – the debate within the group about whether to work with a broad conception of public(s) or narrow down to just the “general public” was not clearly decided, but many in the group thought that just the general public was too narrow. Further discussion reflected the issue of whether it was right to talk of consumers when the focus is on nanoremediation. The groups answer was “possibly yes”, since people’s attitude towards nano in general can be influenced by their reaction to other nano-products. But they also recognised that people can distinguish between different uses: just because they do not like nano in sun cream does not mean that by default they will reject nanoremediation.

The original wording of the “public perception of NP” could lead to the impression that “the public” was irrational, the group suggested the definition should be revised to reflect that public perception of NPs is ambivalent with mixed consumer knowledge and ambiguity in risk perception. Some recognize the potential benefits, whereas others get sceptical by (unsubstantiated) reports on uncertainties. Concluding, the factor was understood to represent “What people think about nano”. For the factor “Innovation attitude”, given the definition and investment criteria, the group felt that this refers to commercial actors, but could include a wide range, consultants as well as producers etc., shorthand: “If you like innovation”. Finally, “Environmental Awareness” was understood as “Care about the environment”. Public perception and environmental awareness were discussed to be rather influenced by several factors– in particular regarding the technology and innovation related items.

Regarding the real estate market development, it was supposed that environmental awareness impact could arise from pressures not to build on green belt. In the subsequent phase of reviewing by other expert groups, Regulators did not think that "Technology and research policies" would influence whether projects are financed – they would be funded whatever public perception is. Hence, impact would be weak/indirect; however, this might be country specific. The Economists group commented that "Public perception" etc. would maybe not have an influence on costs, but would be an influence on whether nanoremediation is selected as a remediation option. The Technical experts generally marked a lower influence of public perception on the drivers, but for many of the technical drivers thought that there would be a high influence from innovation and environmental awareness – in contrast to the Society group's conclusions. This disagreement may well reflect that the Society group was evaluating on the state of affairs – which is how the drivers are phrased, and the Technical group on drivers for getting to that state of affairs. For example, being environmentally aware will not necessarily make a remediation environmentally friendly, although it might be a driver and incentive to try to get there. Concluding note from the group was: definitions are crucial. Differences in ranking can be due to differences in definitions, including who/which group is being included in the driver. This is the biggest take-home message.

3.3.5 Session conclusions

The session closed with an outlook on the next activities, which are to collate the workshop outputs and merge them into a complete influence matrix in order to identify factors that are most active in impacting the market development. This information will be used to develop scenarios on the nanoremediation market in Europe in 2025 in order to derive from these projections recommendations for entrepreneurs and policymakers. Towards this objective, the next steps are in particular to further disclose the potential future development directions of the key factors identified above. These will be discussed in future stakeholder and expert engagement activities. Based on these discussions, scenario storylines will be established that reflect in a consistent way the interdependencies identified in the Oslo workshop and the directions of factors' developments to be discussed in the upcoming expert engagement events.

4 Conclusions

Addressing sustainability as part of the evaluation of remediation technologies demands a broad perspective, including intergenerational aspects and a better understanding of the relationships between environmental, social and economic factors. Discussions about the sustainability of nanoremediation need to be site specific and have to include comparisons to other *in situ* technologies. For these technologies a clear technical understanding of what the advantages and limitations are (operating windows) should be available and evaluated. While many of the generic issues regarding the sustainability of nanoremediation are similar to those for other remediation technologies, uncertainties in risks and benefits related to use of nanoremediation technology were deemed to be one of the most important factors impacting on its future development.

In addition to the issue of uncertainties, the workshop identified the following challenges for improving the sustainability of nanoremediation:

(1) reduction of production costs for the different nanoparticles,

(2) enhancing the transport mobility of the particles in the subsurface (or strictly speaking in the aquifer),

(3) increasing the lifetime of the product in order to justify the production cost,

(4) identification of possible synergies with other *in situ* remediation techniques, and

(5) establishment of a control analysis to determine environmental fate of particles.

These challenges as well as many other issues raised during discussions, serve to further validate[7] the NanoRem research agenda.

Session-specific conclusions are as follows:

Session 1 - Generic nanoremediation sustainability issues

- Important environmental benefits include that nanoremediation may be less invasive and can have a lower impact compared to some alternatives. Environmental concerns were largely related to the perceived potential intrinsic hazards of nanoparticles themselves, including the potential for air release of the particles and particle migration resulting in negative environmental effects outside the treatment zone.

[7] Similar results were obtained during the special session that NanoRem has organized as a part of the 3rd International Conference on Sustainable Remedation TOMKIV, Y. & BARDOS, P. 2014. SustRem 2014 – NanoRem special session report. Nanoremediation: hopes or fears from the sustainability perspective. Proceedings of 3rd International Conference on Sustainable Remediation, 17 - 19 September 2014, Ferrara (Italy) http://sustrem2014.com/APPENDIX%201%20SustRem%202014%20-%20NanoRem%20Special%20Session%20Report.pdf.

- Economically, nanoremediation could be faster and cheaper compared to some alternatives. However, some concerns were raised about the currently high production costs for NPs.
- Social benefits included the potential for job creation and a greater number of contaminated sites to be remediated. Concerns related to social aspects included the public perception of nanoparticles and existing knowledge gaps and uncertainties related to nanoremediation.
- Overall, more research, demonstration projects, and reduction in the knowledge gaps would be integral to an improved sustainability assessment.

Session 2 - (hypothetical case study)

- For the site in question, the most important indicator categories (to help differentiate between nanoremediation and alternatives) were determined to be:
  - Groundwater and surface water;
  - Natural resources and waste;
  - Direct economic costs and benefits;
  - Project lifespan and flexibility;
  - Human health and safety;
  - Community and community involvement;
  - Uncertainty and evidence.
- The relative importance of each indicator category varied depending on the compared treatment, e.g. “Natural resources and waste” may strongly differentiate nanoremediation from pump and treat, but other categories may be more important for differentiating between nanoremediation and bioremediation.
- It was generally agreed that there was little to differentiate between in situ bioremediation and nanoremediation apart from uncertainty and evidence. Numerous categories differentiated nanoremediation and pump and treat.

Session 3 – Market development

- A scenario approach can improve understanding of the factors determining the evolution of the market for nanoparticle use in remediation in Europe until 2025. Workshop participants scored a series of factors obtained through preliminary research, and these were ranked according to importance. In the workshop, experts discussed and assessed how the development of each factor is having/ will have an impact on the development of the other factors up to 2025.
- All groups had intensive discussions about the definitions of the factors allocated to their field of expertise. Potential pitfalls in the interpretation of results due to unclear definitions were identified. Each group’s scores on the impact of one factor’s development on those of the other groups were reviewed by the other groups and revised in a final round by the experts for their own subset.
- The next step will be to use the results to elaborate scenarios on the potential market development. These will be used to derive recommendations for use in an exploitation strategy.

The workshop results will be used to improve the retrospective sustainability assessment that will be carried out for NanoRem field trial sites and to prepare exploitation strategy for nanoremediation.

Finally, although a number of participants thought that the key benefits and concerns of nanoremediation were already well defined, there were comments that the workshop was scheduled too early in the NanoRem project, as many uncertainties still exist. It was suggested a similar workshop event be held at a later stage of the project when more information is available and number of uncertainties will hopefully be reduced. Notwithstanding, the early involvement of stakeholders in discussions generated a great deal of information that will be useful for the further work in the NanoRem project.

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Appendix A: List of participants

Surname, Name	Country	Company/working group (for NanoRem-associated participants)
Bardos, Paul	United Kingdom	r3 Environmental Technology Ltd *Dissemination, Dialogue with Stakeholders and Exploitation*
Bartke, Stephan	Germany	Helmholtz Centre for Environmental Research *Dissemination, Dialogue with Stakeholders and Exploitation*
Bleyl, Steffen	Germany	Helmholtz Centre for Environmental Research *Design, Improvement and Optimized Production of Nanoparticles - Non-ZVI and Composite Nanoparticles*
Bone, Brian	United Kingdom	r3 Environmental Technology Ltd *Dissemination, Dialogue with Stakeholders and Exploitation* *Up-Scaling, Risk and Sustainability*
Bosch, Julian	Germany	German Research Center for Environmental Health *Design, Improvement and Optimized Production of Nanoparticles - Non-ZVI and Composite Nanoparticles*
Braun, Juergen	Germany	University of Stuttgart, IWS/VEGAS *Pilot Site Applications and Field Demonstrations*
Coutris, Claire	Norway	Bioforsk - Norwegian Institute for Agricultural and Environmental Research *Environmental Impact of Reactive Nanoparticles*
Hampson, Craig	Czech Republic	AQUATEST *Pilot Site Applications and Field Demonstrations*
Harries, Nicola	United Kingdom	Contaminated Land: Applications in Real Environments (CL:AIRE) *Dissemination, Dialogue with Stakeholders and Exploitation*
Joner, Erik	Norway	Bioforsk - Norwegian Institute for Agricultural and Environmental Research. *Environmental Impact of Reactive Nanoparticles*
Kleiven, Merethe	Norway	Norwegian University of Life Sciences *Analytical Methods for In-Situ Determination of Nanoparticles Fate*
Koschitzky, Hans-Peter	Germany	University of Stuttgart, IWS/VEGAS *NanoRem project coordinator*
Limasset, Elsa	France	BRGM, French geological survey *Dissemination, Dialogue with Stakeholders and Exploitation*
Nathanail, Judith	United Kingdom	Land Quality Management Ltd *Dissemination, Dialogue with Stakeholders and Exploitation*
Oughton, Deborah	Norway	Norwegian University of Life Sciences *Dissemination, Dialogue with Stakeholders and Exploitation*
Tomkiv, Yevgeniya	Norway	Norwegian University of Life Sciences *Dissemination, Dialogue with Stakeholders and Exploitation*
Aspray, Thomas	United Kingdom	Heriot-Watt University
Aarset, Bernt	Norway	Norwegian University of Life Sciences
Bakker, Laurent	Nether-lands	Tauw
Birnstingl, Jeremy	United Kingdom	Regenesis
Brucek, Petr	Czech Republic	DIAMO
Bruns, Johannes	Germany	Independent expert
Darmendrail, Dominique	France	Common Forum

Surname, Name	Country	Company/working group (for NanoRem-associated participants)
Edgar, Steve	United Kingdom	VertaseFLI Limited
Gerhardt, Rolf	Germany	Deutsche Bahn AG
Hartley, Sarah	United Kingdom	The University of Nottingham
Irminski, Wojciech	Poland	Geo-Logik
Martac, Eugeniu	Germany	Fugro consult
Mueller-Grabherr, Dietmar	Austria	Environment Agency
Mueller-Wagner, Christian	Germany	AXA MATRIX Risk Consultants
Parkman, Rick	United Kingdom	URS Infrastructure & Environment UK Limited
Thomas, Alan	United Kingdom	ERM UK
Vanneck, Peter	Belgium	BroCap
Verheyen, Astrid	Belgium	OVAM
Waduge, Anil	United Kingdom	ARCADIS (UK) LTD
Wynne, Brian	United Kingdom	University of Lancaster

Appendix B: Workshop agenda

2. December 2014

19:00 – Informal reception

20:00 – Dinner

Day 1: 3. December 2014

Session 1: Sustainability

0900-0910 Welcome and Introduction to the meeting (Aims, objectives, what will be discussed and when, ground rules for discussion)

0910-1030 Brief introduction:

- *Contaminated land management, risk assessment*
- *Nanoremediation and other technologies*
- *The concept of sustainable remediation*
- *Life cycle inventories of nanoparticle production*

1030-1200 The World Café - How sustainable do you think nanoremediation really is?

1200-1300 Plenary conclusions

1300-1400 Lunch

Session 2: Cases: Socio-ethical, economic, and environmental issues

1400-1440 Presentation of a case study

1440-1500 Q&A on case study

1500-1630 Group discussion - a sustainability assessment based on the case study

1630-1645 Coffee

1645-1715 Plenary feedback from groups and discussion of the results.

What has changed?
Which issues remain most important,
Which issues would block or facilitate Nanoremediation?

1715-1730 Summarizing the day

2000 Workshop dinner

Day 2: 4. December 2014

Session 3: Market opportunities

0900-0920 Introduction on drivers/uncertainties of market development and the dependencies which exist between those drivers (the results of marked assessment)

0920- 1010 Group discussion on market drivers and their matrix of interaction.

1010-1115 World Café style feedback from groups

1115-1140 Plenary feedback/report from facilitators

1140 -1200 Plenum on next steps: disclosure of potential future development directions (based on the discussion of market drivers).

Session 4: Summary

1200-1300 Nanoremediation in comparison to other available technologies (using the identified market drivers and sustainability issues, and assessing with the participants, how different technologies do/might develop against them)

1300-1400 Lunch

1400-1430 What can Nanoremediation do better (in a more sustainable way)? – a closing discussion

Workshop wrap-up

1500 Departure

Session 2: Case Study – Information for participants

Aim:

To examine the sustainability of nanoremediation against comparators and in a site context

Group Tasks:

1. Appoint a rapporteur to feed back the discussion highlights.
2. Assess the sustainability of nanoremediation for this site, based on one NanoRem pilot test site, against a baseline condition and another remediation technology. The assessment is **qualitative**.
3. You will be given an indicator set to work with. For this set, identify indicators for which broad agreement is reached within the group, and for which significant differences of opinion exist.
4. Identify specific criteria that you (as a group) feel may strongly differentiate between nanoremediation and other approaches.
5. As an individual, rank the criteria in order of potential importance.

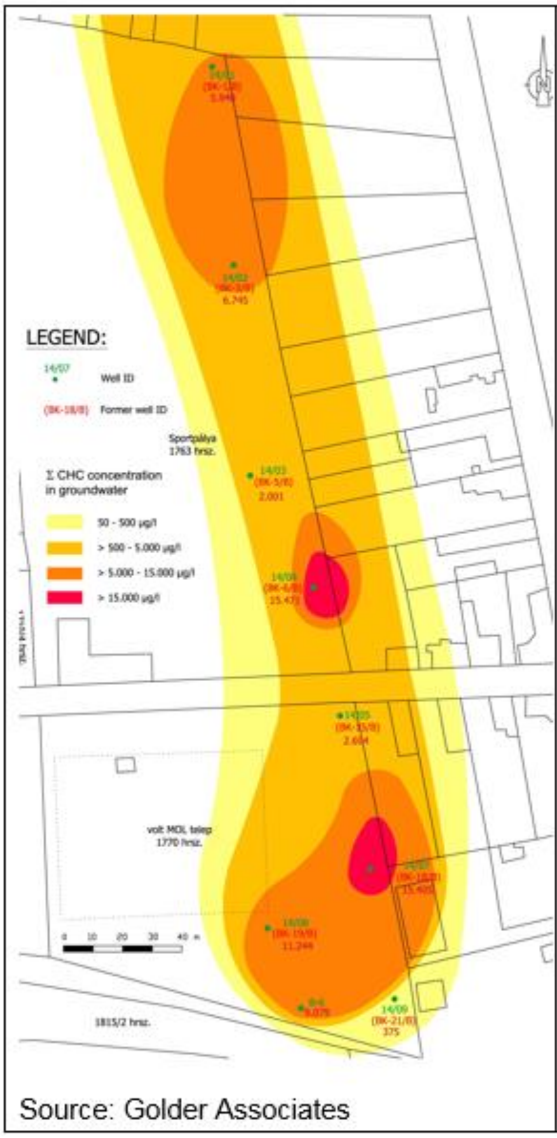
You are provided with:

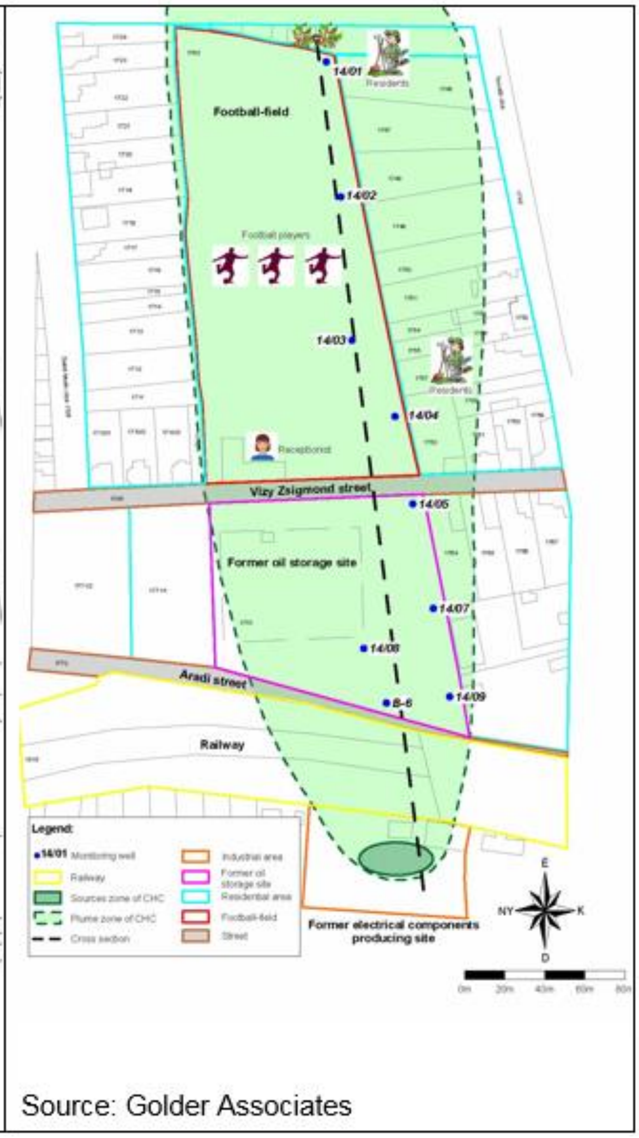
- A summary of the site
- A summary of the sustainability assessment framing
- A set of headline indicators for environmental, economic and social attributes
- The indicator set your group will work with and the comparators to use.

Site Summary:

Site owner:	Local government
Current use:	Recreation (football field and weekly market)
Site status:	Brownfield, national priority site
Site geology:	Sand and gravel with subordinate, impersistent clays
Groundwater flow:	South to north
Contaminant type:	Chlorinated ethenes
Contaminant source/s:	Former industry (car component manufacturing plant)
Proposed action:	Plume treatment/management
Volume of contaminated groundwater:	190,000 m^3
Contaminant depth:	11 – 18 m below ground level

Conceptual model summary:





Extent of plume **Receptors**

Source	Pathway	Receptor
Chlorinated ethenes	Migration in aquifer	Uncontaminated groundwater Water (irrigation) wells
Chlorinated ethenes	Ingestion of local vegetables and fruit	Residents
Chlorinated ethenes	Inhalation of indoor air	Residents Workers and users of football field
Chlorinated ethenes	Inhalation of outdoor air	Workers and users of football field Market workers and users

Summary of sustainability assessment framing:

Assumptions:

- The baseline condition is not an option for this site, but forms a useful comparator.
- Nanoremediation and the other comparators are capable of achieving remediation objectives. [Evidence for nanoremediation from the NanoRem pilot test.]

Framing:

Decision/Action:	Qualitative assessment of feasible remediation options to select sustainable option for plume management
Stakeholders:	Contaminated land consultant
	Remediation contractor
	Local government – land owner
	Local government – regulator (permitting)
	Regional water authority
	Local residents' representative
	Football club representative
Options considered::	Baseline (*status quo*)
	Nanoremediation
	Either: pump and treat or *in situ* enhanced bioremediation
Constraints:	Permit conditions
	Continuity of use of football field and market
	Security – safety of site visitors (football & market)
Boundary conditions:	Time – time to fully achieve remediation objectives
	Life cycle – site-related resources (e.g. manufacture of consumables/reagents, but do not take construction of plant into consideration)
	Cost – qualitative comparison based on estimated cost/kg of Contaminant
Scope:	Qualitative assessment against 15 headline indicators
Assessment criteria:	Subjective judgement (e.g better or worse, 1, 2, 3, smileys), ranking by comparing against a range of options

Headline indicators: Social (from CL:AIRE 2011)

Category		Issues that you may need to consider	Cross-reference to other Indicators

SOC 1	**Human Health & Safety**	• Risk management performance of the project (long term) in terms of delivery of mitigation of unacceptable human health risks.
		• Risk management performance of project (short term) in terms of duration of remediation works, incl. consideration of:
		  ○ Site workers, site neighbours and the public
		  ○ Remediation works and ancillary operations.
		• Consider both chronic and acute risks
			ENV 1 for issues related to e.g. dust which do not relate to effect on humans
			SOC 3 for issues affecting humans (not related to health concerns e.g. amenity)

SOC 2	**Ethics & Equality**	• How is social justice and/or equality addressed? • Is spirit of 'polluter pays principle' upheld with regard to distribution of impacts/benefits? • Are the impacts/benefits of works unreasonably disproportionate to particular groups? • What is the duration of remedial works and are there issues of intergenerational equity (e.g. avoidable transfer of contamination impacts to future generations)? • Are the businesses involved operating ethically? • Does the treatment approach raise any ethical concerns for stakeholders?	None
SOC 3	**Neighbourhood & Locality**	• Impacts/benefits to local areas (tangible amenity changes), including: ○ Effects from dust, light, noise, odour and vibrations during works and associated with traffic, including both working-day and night-time/weekend operations. • Wider effects of changes in site usage by local communities (e.g. reduction in antisocial activities on a derelict site). • Changes in the built environment, architectural conservation, conservation of archaeological resources.	**ENV 1** for issues related to e.g. dust which do not relate to humans **ENV 4** for impacts of light, noise & vibration on ecology **SOC 1** for anything related to human health considerations
SOC 4	**Communities & Community Involvement**	• Changes in the way the community functions and the services they can access. • Quality of communications plan. • Effect of the project on local culture and vitality. • Inclusivity and engagement in decision making-process. • Transparency & involvement of community, directly or through representative bodies. • Compliance with local policies/spatial planning objectives	**SOC 3** for tangible changes to neighbourhoods & regions **ECON 2** for compliance with national policies, legislation, regulatory standards, best practice
SOC 5	**Uncertainty & Evidence**	• Robustness of sustainability appraisal for each option considered • Quality of investigations, assessments (incl. sustainability) and plans, and their ability to cope with variation. Accuracy of record taking and storage. • Requirements for validation/verification. • Degree to which robust site-specific risk-based remedial criteria are established (*justified* & realistic CSM versus *unnecessarily* conservative and/or precautionary assumptions/data)	None

Headline indicators: Economic (from CL:AIRE 2011)

Category		Issues that you may need to consider	Cross-reference to other Indicators

ECON 1	**Direct Economic Costs & Benefits**	• Direct financial costs and benefits of remediation for organisation
		• Consequences of capital and operation costs, and sensitivity to alteration e.g.:
		  ○ Costs associated with the works (incl. operation and any ongoing monitoring, regulator costs, planning, permits licences)
		  ○ Uplift in site value to facilitate future development or divestment
		  ○ Liability discharge
			None

ECON 2	**Indirect Economic Costs & Benefits**	• Long term or indirect costs and benefits, e.g.:
		  ○ Financing debt
		  ○ Allocation of financial resources internally
		  ○ Changes in site/local land/property values
		  ○ Fines and punitive damages.
		  ○ Financial consequences of impact on corporate reputation.
		  ○ Consequences of an area's economic performance.
		  ○ Tax implications.
			SOC 4 for compliance with local policies/spatial planning objectives

ECON 3	**Employment & Employment Capital**	• Job creation • Employment levels (short and long term) • Skill levels before and after • Opportunities for education and training • Innovation and new skills.	None
ECON 4	**Induced Economic Costs & Benefits**	• Creating opportunities for inward investment, • Use of funding schemes, ability to affect other projects in the area/by client (e.g. Cluster) to enhance economic value	None
ECON 5	**Project Lifespan & Flexibility**	• Duration of the risk management (remediation) benefit, e.g. fixed in time for a containment system) • Factors affecting chances of success of the remediation works and issues that may affect works, incl. community, contractual, environmental, procurement and technological risks • Ability of project to respond to changing circumstances, including discovery of additional contamination, different soil materials, or timescales. • Ability to respond to changing regulation or its implementation. • Robustness of solution to climate change effects • Robustness of solution to altering economic circumstances • Requirements for ongoing institutional controls	None

Headline indicators: Environmental (from CL:AIRE 2011)

Category	Issues that you may need to consider	Cross-reference to other Indicators
Air	○ Emissions that may affect climate change or air quality, or considerations that may allow overall reduction in impact on climate change, e.g. greenhouse gases ; NO_X, SO_X; particulates (especially PM5 and PM10)	**SOC 1** for issues associated with human health **SOC 3** for other issues affecting humans
Soil & Ground Conditions	• Changes in physical, chemical, biological soil condition that affects the ecosystem function, goods or services provided by soils (these may be improvements OR deteriorations). May include: ○ Soil quality (chemistry), ○ Water filtration and purification processes (incl. sediment generation or reduction) ○ Soil structure and/or organic matter content or quality; ○ Erosion and soil stability (incl. drainage) ○ Geotechnical properties (incl. compaction) ○ Impact/benefits to sites of special geological interest e.g. SSSIs and geoparks.	**ENV 4** for Ecology within this ecosystem
Groundwater & Surface Water	• Changes in the release of contaminants (including nutrients), dissolved organic carbon and/or silt/particulates (these may be improvements OR deteriorations), affecting: ○ Suitability of water for potable or other uses ○ Biological function (aquatic ecosystems) and chemical function, ○ Mobilisation of dissolved substances ○ Marine, brackish/transitional, freshwater waters • Effects/benefits of water abstraction resulting from the remediation process or its outcome, • Issues associated with flooding (e.g. increase risk of, or protection from, flooding)	**ENV 4** for Ecology within this ecosystem **ENV 5** for any water abstraction use or disposal issues
Ecology	Effects on ecology (excluding ecological impacts considered in ENV 2 and 3), including effects on the following (these may be benefits OR impacts): • Flora, fauna and food chains (esp. protected species, biodiversity, SSSIs, alien species) • Significant changes in ecological community structure or function • Effects of disturbance (e.g., light, noise and vibration) on ecology • Use of equipment that affects/protects fauna (e.g. bird/bat flight, or animal migration)	**ENV 2** & **ENV 3** for soil and aquatic ecosystems **SOC 3** for impacts of light, noise & vibration on humans
Natural Resources & Waste	• Impacts/benefits for: ○ Land and waste resources, ○ Use of primary resources and substitution of primary resources within the project or external to it ○ Use of energy/fuels taking into account their type/origin and the possibility of generating renewable energy by the project ○ Handling of materials on-site, off-site and waste disposal resources ○ Water abstraction, use and disposal	**ENV 3** for issues associated with Groundwater and Surface water not linked to abstraction use or disposal

Group Indicator Sets and Comparators:

Group 1

ENVIRONMENT

Baseline and Pump & treat

Group 2

SOCIAL

Baseline and Pump & treat

Group 3

ECONOMIC

Baseline and Pump & treat

Group 4

ENVIRONMENT

Baseline and In situ enhanced bioremediation

Group 5

SOCIAL

Baseline and In situ enhanced bioremediation

Group 6

ECONOMIC

Baseline and In situ enhanced bioremediation