Sustainable management of trace element contaminated soils – Development of a decision tool system and its evaluation for practical application - SUMATECS

University of Natural Resources
and Applied Life Sciences
Department of Forest and Soil Sciences

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www.rhizo.at/Sumatecs

What is a contaminated soil?

What is a contaminated soil?

based on Eikmann Kloke, 1993

anorganic parameters [mg kg^{-1}] - **based on total concentrations**

Nr.	kind-of-use	soil value	As	B	Ba	Be	Br	Cd	Co	Cr	Cu	F	Ga	Hg	Mo	Ni	Pb	Sb	Se	Sn	Tl	U	V	Zr	Zn
0	**all-purpose use**	**SV I**	20	25	100	1	10	1	30	50	50	200	10	0.5	5	40	100	1	1	50	0.5	2	50	300	150
1	**children's playgrounds**	**SV II**	20	25	100	1	10	2	30	50	50	200	10	0.5	5	40	200	2	5	50	0.5	2	50	300	300
		SV III	50	125	500	5	50	10	150	250	250	1000	50	10	25	200	1000	10	20	250	10	10	200	1500	2000
2	**gardens**	**SV II**	40	50	200	2	20	2	100	100	50	500	20	2	10	80	300	4	5	100	2	5	100	500	300
		SV III	80	250	100	5	100	5	400	350	200	2500	100	20	50	200	1000	10	10	500	20	20	400	2000	600
3	**sports grounds**	**SV II**	35	25	100	1	10	2	30	150	100	200	10	0.5	5	100	200	2	5	50	2	2	50	300	300
		SV III	90	125	500	2.5	50	5	150	350	300	1000	50	10	25	250	1000	5	20	250	20	10	200	1500	2000
4	**parks and leisure facilities**	**SV II**	40	100	400	5	40	4	200	150	200	1000	40	5	20	100	500	4	10	200	5	10	200	1000	1000
		SV III	80	500	2000	15	200	15	500	600	600	5000	200	15	100	250	2000	20	50	1000	30	50	800	3000	3000
5	**industrial areas**	**SV II**	50	100	500	10	50	10	300	200	500	1500	100	10	40	200	1000	10	15	200	10	20	200	1000	1000
		SV III	200	500	2500	20	250	20	600	800	2000	7500	500	50	200	500	2000	50	70	1000	30	100	800	3000	3000
6	**agricultural areas for fruit and**	**SV II**	40	50	300	2	30	2	200	200	50	1000	40	10	20	100	500	5	5	100	2	10	100	500	300
		SV III	50	250	1500	5	150	5	1000	500	200	5000	200	50	100	200	1000	25	10	500	10	50	400	2000	600
7	**non-agricultural lands**	**SV II**	40	50	300	10	30	5	200	200	50	1000	50	10	20	100	1000	5	5	100	2	10	100	500	300
		SV III	60	250	1500	20	150	10	1000	500	200	5000	200	50	100	200	2000	25	10	500	20	50	400	2000	600

SV I precautionary value
SV II trigger value
SV III action value

Eikmann T und Kloke A (1993) Nutzungs- und schutzgutbezogene Orientierungswerte für (Schad-) Stoffe in Böden – Eikmann-Kloke-Werte. In: *Bodenschutz – Ergänzbares Handbuch der Maßnahen und Empfehlungen für Schutz, Pflege und Sanierung von Böden, Landschaft und Grundwasser,* (Hrsg.: Rosenkranz, Bachmann, König, Einsele). Erich Schmidt Verlag, 3590.

Basis also for german federal soil protecion and contamination and ordinance

What is a contaminated soil?

What is a contaminated soil?

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anorganic parameters [mg kg^{-1}]		-	based on total concentrations																						
0	all-purpose use	**SV I**	20	25	100	1	10	1	30	50	50	200	10	0.5	5	40	100	1	1	50	0.5	2	50	300	150
1	children's playgrounds	**SV II**	20	25	100	1	10	2	30	50	50	200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.5	2	50	300	300
		SV III	50	125	500	5	50	10	150	250	250	1000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	10	200	1500	2000
2	gardens	**SV II**	40	50	200	2	20	2	100	100	50	500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	5	100	500	300
		SV III	80	250	100	5	100	5	400	350	200	2500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20	20	400	2000	600
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		SV III	90	125	500	2.5	50	5	150	350	300	1000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20	10	200	1500	2000
4	parks and leisure facilities	**SV II**	40	100	400	5	40	4	200	150	200	1000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	10	200	1000	1000
		SV III	80	500	2000	15	200	15	500	600	600	5000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30	50	800	3000	3000
5	industrial areas	**SV II**	50	100	500	10	50	10	300	200	500	1500	100	10	40	200	1000	10	15	200	10	20	200	1000	1000
		SV III	200	500	2500	20	250	20	600	800	2000	7500	500	50	200	500	2000	50	70	1000	30	100	800	3000	3000
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		SV III	50	250	1500	5	150	5	1000	500	200	5000	200	50	100	200	1000	25	10	500	10	50	400	2000	600
7	non-agricultural lands	**SV II**	40	50	300	10	30	5	200	200	50	1000	50	10	20	100	1000	5	5	100	2	10	100	500	300
		SV III	60	250	1500	20	150	10	1000	500	200	5000	200	50	100	200	2000	25	10	500	20	50	400	2000	600

The associated risk may be very different!

SV I	precautionary value
SV II	trigger value
SV III	action value

Eikmann T und Kloke A (1993) Nutzungs- und schutzgutbezogene Orientierungswerte für (Schad-) Stoffe in Böden – Eikmann-Kloke-Werte. In: *Bodenschutz – Ergänzbares Handbuch der Maßnahen und Empfehlungen für Schutz, Pflege und Sanierung von Böden, Landschaft und Grundwasser*, (Hrsg.: Rosenkranz, Bachmann, König, Einsele). Erich Schmidt Verlag, 3590.

Basis also for german federal soil protecion and contamination and ordinance

What is soil remediation?

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What is "gentle remediation"?

- Contaminated land remediation or stabilisation using in-situ techniques that **do not significantly impact soil function or structure**, such as phytoremediation, in-situ immobilisation, etc.

Gentle Remediation Technologies

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Two possible options:

- **Reduce the risk** posed by the contaminants by reducing exposure (prevent the contaminants from being spread to the surroundings and the groundwater): 'site stabilization techniques' (isolation and/or immobilization/inactivation)

- **Remove the contaminants** from the substratum: 'site decontamination techniques' (clean-up)

Gentle Remediation Technologies

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‘Clean up’

- **Phytoextraction**
  - Aided phytoextraction with chemicals
  - Aided phytoextraction with bioaugmentation
- Phytomining
- Rhizodegradation
- Phytovolatilisation

‘Inactivation’

- **Phytostabilisation**
  - Aided phytostabilisation
- **Immobilisation**
  - bioimmobilization
  - In situ stabilisation with amendments
- ***Natural attenuation***

Source: K. Adriaensen

Application of gentle remediation options?

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- Great deal of progress achieved at laboratory or bench scale (plus field pilot scale), but application as practical site solutions still in relative infancy.

- What are the preliminary identified barriers to application?

  - Timescales required for remediation

  - Need for long-term site monitoring

  - Uncertainties in what is bioavailable, and how to measure this

  - Other reasons???

What is SUMATECS?

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- Sustainable management of trace element contaminated soils – Development of a decision tool system and its evaluation for practical application
- (October 2007 – October 2008)
- 13 partners from 8 countries (AT, IT, CZ, BE, FR, UK, SE, DE)
- Evaluation of existing information on gentle soil remediation technologies
  → describing state of the art (including a country-specific state of the art and current procedures review)
  → identification of knowledge gaps and reasons of hindrance for application as practical site solution
  → development of a decision tool system

Project structure

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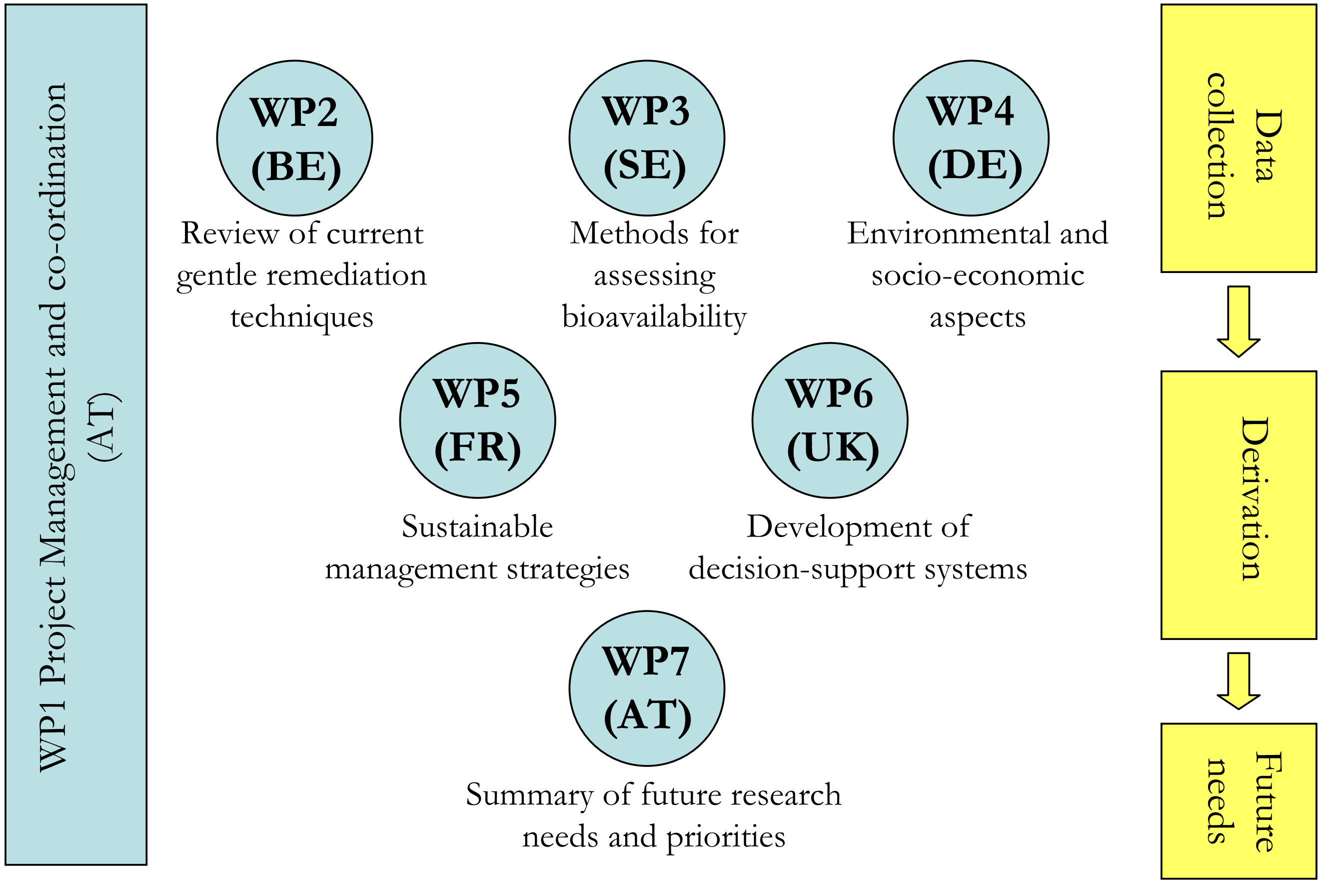
Figure 2: Project structure



Review of the state of the art (WP2)

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- Overview on options: phytoextraction, (assisted) Phytostabilisation, in situ Immobilisation, …
- Summary of technical data (efficiency, durability, biomass valorisation,…)
- SWOT analysis
  → description of site conditions in which the various options are applicable
  → identification of lacking knowledge or data to make a certain option applicable
- Summary of field experiments conducted so far
- Review and evaluation of the existing methods for determination of the bioavailable trace element fraction in soils, including novel up to date techniques (e.g., DGT, whole cell biosensors) (WP3)

Environmental and socio-economic aspects of remediation and related technologies (e.g. biomass valorisation)

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- Identification, description and evaluation of
  → 1) Environmental impact (positive or negative)
  → 2) Socio-economic impact (positive or negative)

  - in comparison to other remediation techniques
  - true impact (existing sites) and potential risk of impact
  - „site and treatment related effects“

- Identification, description and evaluation of
  → 3) Reasons for hindrance (based on information derived from 1. and 2.)
  → 4) Pathways or tools to overcome negative impacts or reasons for hindrance

Environmental and socio-economic aspects of remediation and related technologies e.g. biomass valorisation)

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- Literature review on **environmental impacts** (60 references)

Literature review of about 60 references dealing with gentle remediation techniques and addressing one or more of the following soil biological or functional aspects:

- soil respiration
- enzyme activity
- mineralization activity
- microbial diversity
- other microbial parameters

- toxic for fauna
- uptake by fauna
- other faunal parameters

- Leaching of metals or nutrients
- C-balance
- Nutrient availability
- other effects

Environmental and socio-economic aspects of remediation and related technologies e.g. biomass valorisation)

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- Literature review on environmental impacts (60 references)

	Cmic	enzymes	soil respiration	mineral. activity	microbial diversity	other microb.	toxic for fauna	uptake fauna	other faunal	leaching	other effects
phytoextraction w/o additives										X	
phytoextraction w/ chelators					XX		X	X		XXXXXXX	
biosolids (alone and combined)	XXX	XXX	XXX	X	XX	XX	XXXX	X	XX	X	
other organic	XXX	XX	X		X	XX	X			XXXXX	
lime	XXX	XXX	X		XXXX	X				X	
Fe-Oxides, Fe	XXXX	XXXX	X		XX	XX	XX			XX	
clay	X										
phosphates	XX	X				X	XXX	XXX			X
zeolite	XX	XX	X		X						
other inorganics	X						XX			XX	

Environmental and socio-economic aspects of remediation and related technologies e.g. biomass valorisation)

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- Literature review on environmental impacts (60 references)

Phytoextraction
plant cover provides organic matter as substrate, and soil physical stability against erosion, temperature and moisture buffering,

positive effects	negative effects	neutral effects
increased faunal, microbial & enzyme activity in barren soils followed by revegetation *(Williams et al. 1979, Clark and Clark 1991, Sorenau 1983, Jasper et al. 1998, Scullion et al. 1988, Stroo and Jenks 1982, Naprasnikova and Markova 1992, Balicka and Wgrzyn 1984, Klubek et al. 1992)*	if assisted by addition of acid or chelators (see below)	no reports found on specific effects of certain hyperaccumulator plant species

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Assisted Phytoextraction

Use chelating substances to increase metal solubility, provide substrate (some), are toxic (some), may affect plant nutrients

positive effects	negative effects	neutral effects
Lettuce yield doubled after EDDHA + Thlaspi (4 mo) *(Keller & Hammer 2004)*	DTPA, EDTA reduced plant growth *(Sohli et al. 2005, Shen et al. 2002, Grcman et al. 2001)*	EDDS not toxic to fungi *(Grcman et al. 2001)*
EDGA increased microbial biomass *(Bouwman et al. 2005)*	EDTA toxic to soil fungi *(Grcman et al. 2001, 2003)*	EDDHA not toxic (BioMet sensor) *(Keller & Hammer 2004)*
EDDS, MGDA increased CFU greatly *(Cao et al. 2007)*	EDTA increased leaching risk *(Shen et al. 2002)*	
	EDTA reduced survival and cocon production of earthworms *(Jones et al. 2007)*	
	EDGA altered nematode population *(Bouwman et al. 2005)*	
	EDGA increased DOC from 85 to 1900 mg/l *(Bouwman et al. 2005)*	

In situ immobilisation by Fe-oxides, red mud and Fe_o

provide sorption sites for TEs

positive effects	negative effects	neutral effects
increased enzyme activities *(Kumpiene et al. 2006; 2008 Stempelmann, unpubl.)*	increased leaching of Cd & Pb *(Hartley et al. 2004)*	no effect on enzymes or microbial biomass *(Stolz 2008)*
decreased microbial toxicity (BioTox, Luminesc.) *(Lombi et al 2002, Kumpiene et al. 2006)*		no effect on bacterial and fungal species richness *(Mench et al., 2006; Renella et al 2008)*
plant biomass doubled *(Kumpiene et al. 2006, Ruttens et al. 2006)*		
increased earthworm survival *(Mench et al. 2006)*		
increased microbial biomass and diversity (red mud) *(Lombi et al 2002)*		
increased nodulation (w/ beringite) *(Mench et al. 2006)*		
increased soil respiration (WWS) *(Stolz 2008)*		
increased nitrification (WWS) *(Stempelmann, unpubl.)*		

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Environmental and socio-economic aspects of remediation and related technologies (e.g. biomass valorisation)

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- Aspects of **biomass valorisation** during remediation

→Economic aspects (economic feasibility):
- Economic potential for changes in land use towards biomass production
- Bottleneck problem of valorisation: general aspects of biomass production and special issues for biomass produced on contaminated land under different treatment options
- Is biomass production a possible, stable and sustainable site end use?

→ Technical aspects (technical feasibility):
-How to produce and handle „contaminated"biomass
–evaluating technical treatment options
-Evaluating maximum contaminant concentrations in biomass with respect to valorisation

Environmental and socio-economic aspects of remediation and related technologies (e.g. biomass valorisation)

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- Aspects of **biomass valorisation** during remediation

→ Social aspects (social feasibility):
- Using a „green“ treatment option that delivers a „green cover“ to bare land
- Delivering income to land owners
- Acceptance *versus* time needed for remediation: Where could biomass production really take place?

→ Environmental aspects (environmental feasibility):
- Evaluating the environmental impact of biomass production, treatment and valorisation

Environmental and socio-economic aspects of remediation and related technologies (e.g. biomass valorisation)

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- **Public / social aspects** of gentle remediation

  - General issues on contaminants, risk and remediation: **information and acceptance, public fears, driving forces**

  - **Time** aspects of remediation

  - Political, comercial, social and personal **interests in remediation**

  - The **different points of view**: the scientist/engineer, the decision maker, the persons (feel) concerned and all the stakeholders

  → how to **bundle and integrate** all these different intentions into one remediation option

Current perception of gentle remediation – a questionnaire:

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- In early 2008, questionnaires were developed, translated and sent out to about 200 regulators, regional and local administrations, consultants, land owners and other stakeholders in 8 European countries that were believed to deal with the remediation of trace element contaminated sites.
- The objective was to learn more about:

… **their knowledge about g.r.o.**

… **their experience with g.r.o.**

… **their evaluation of g.r.o**

… **their recommendations**

… **their criticism**

Environmental and socio-economic aspects of remediation and related technologies

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- Current perception of gentle remediation –a **questionnaire:**

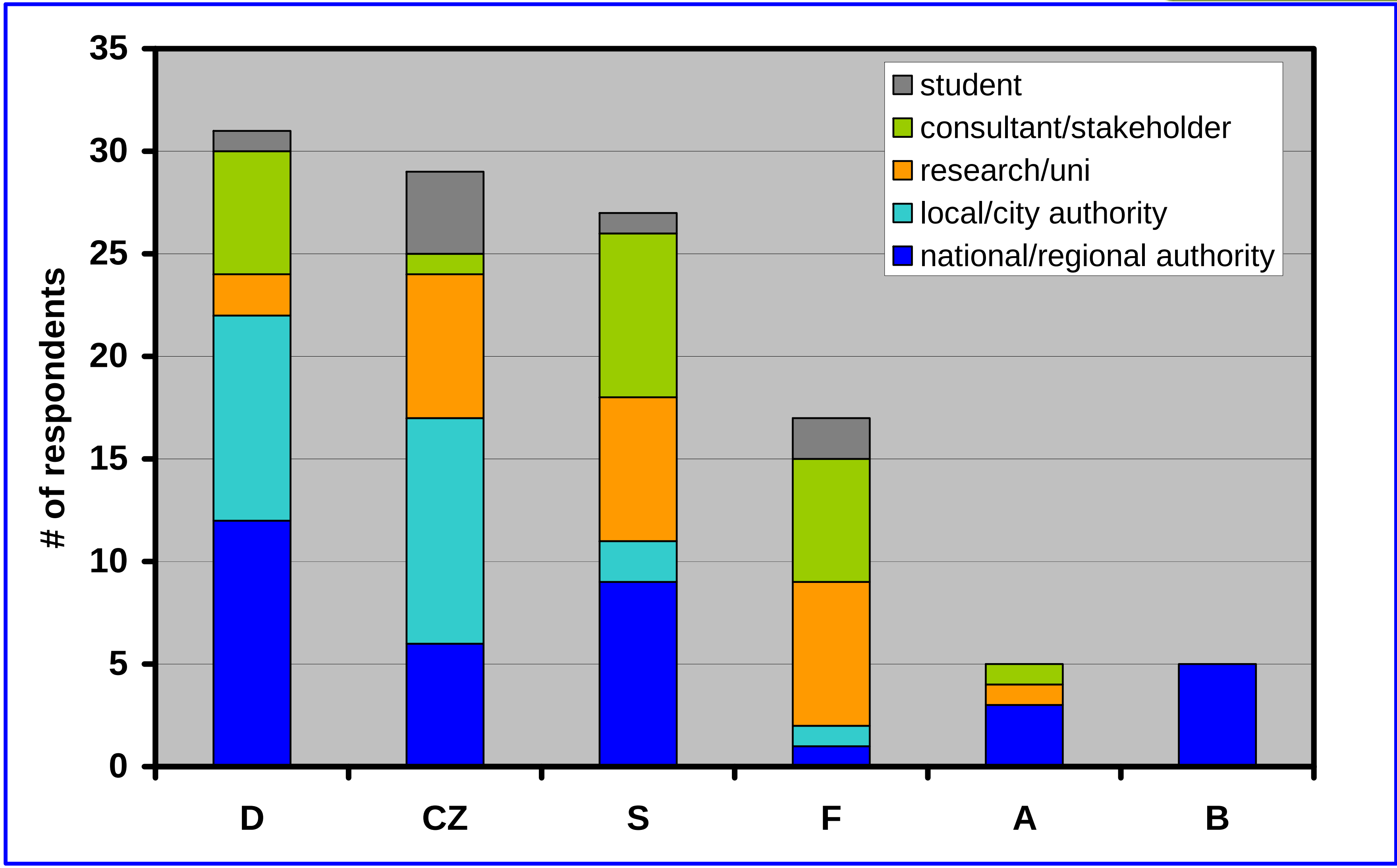
  - 20 questions (+ additional for experts), + glossary

  - example:

6) Are you familiar with "gentle" remediation options* such as phytoremediation* or immobilization*?

☐ Yes, I know about them and have planned / decided / operated on them
☐ Yes, I know about them but have only limited practical experience
☐ Yes, I know them but only theoretically, I have never chosen or used them
☐ I know too little to decide on them / use them
☐ I am not aware of them

Questionnaire respondents: origin and position



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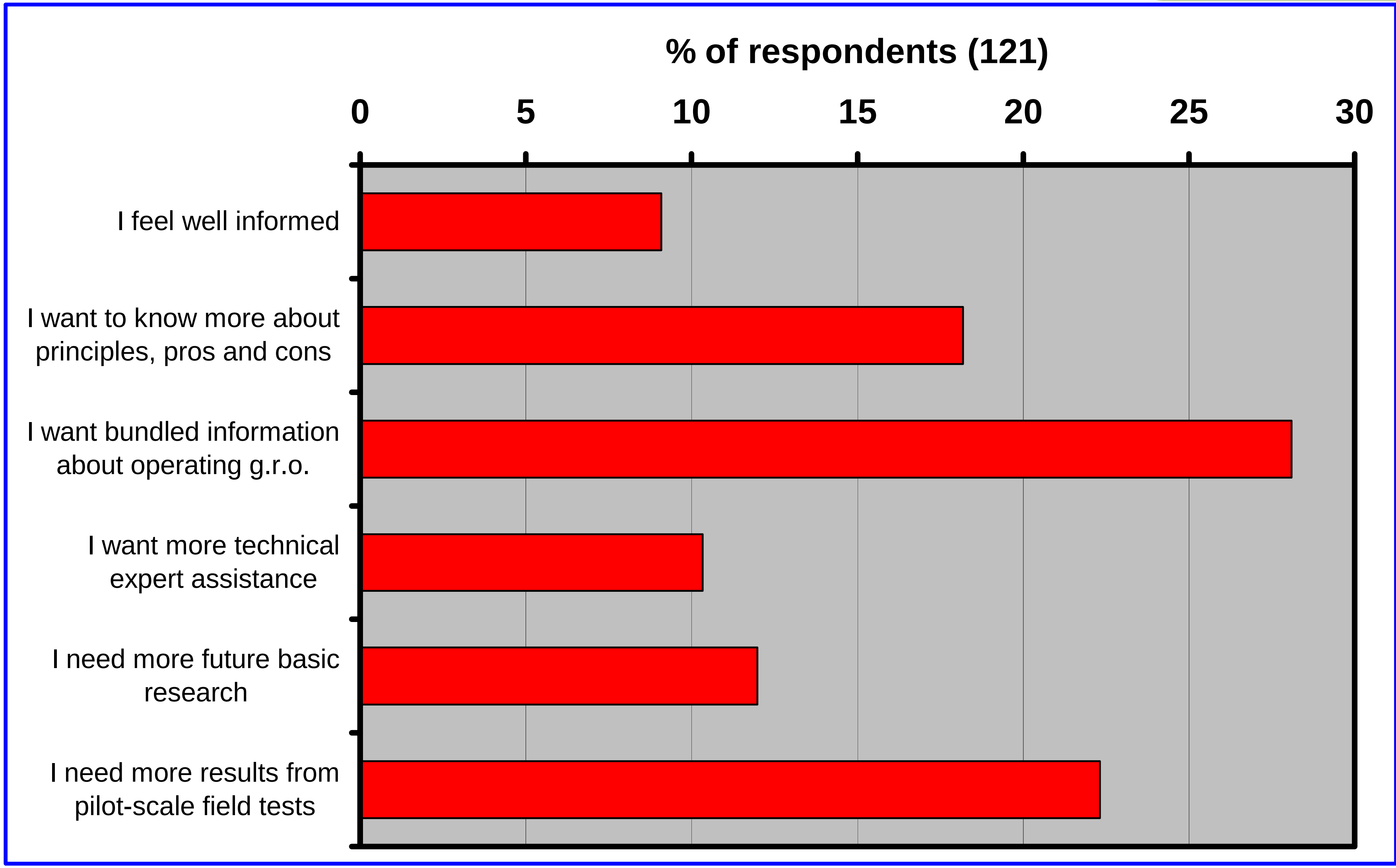
What is your knowledge about gentle remediation options?



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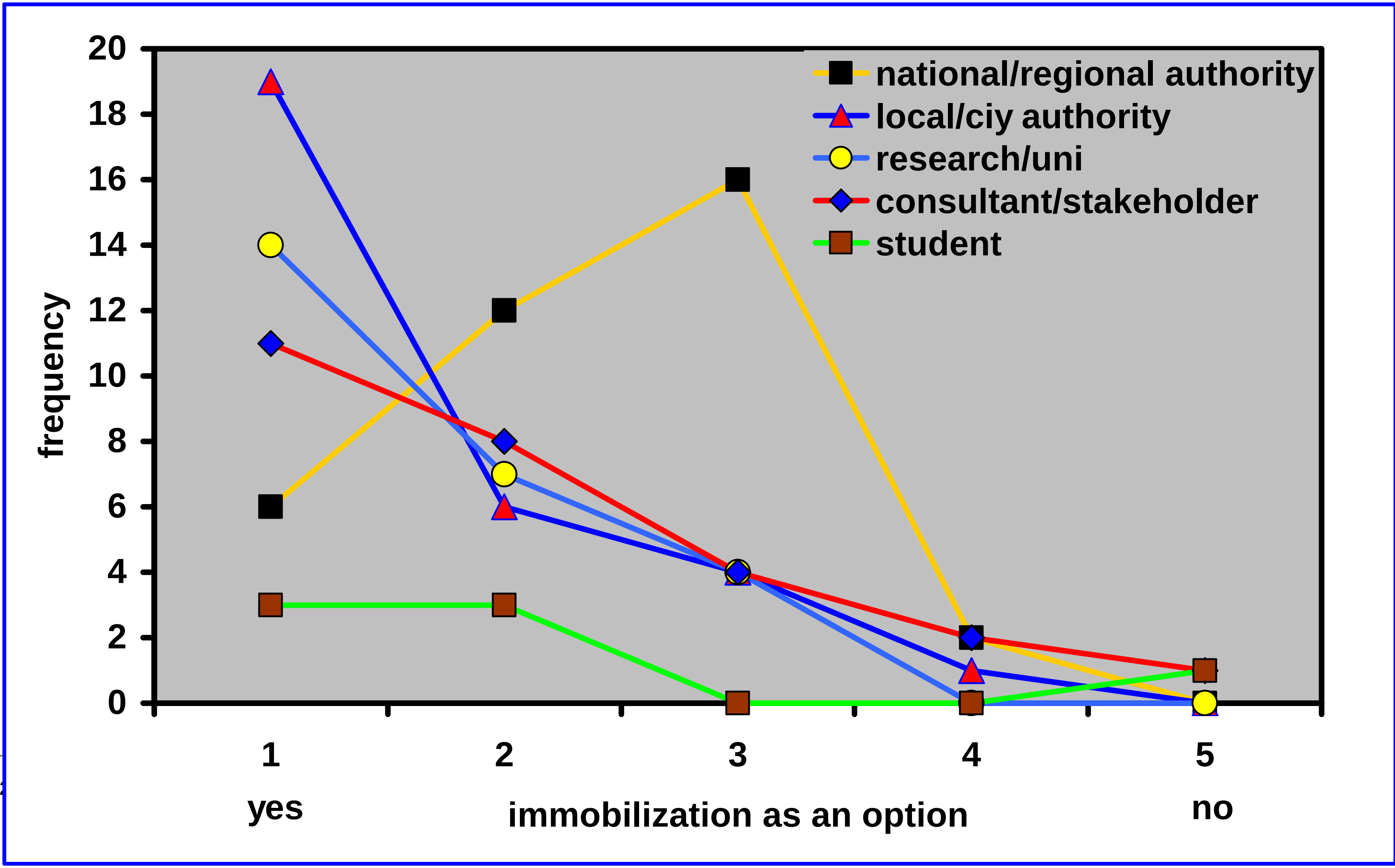
Is immobilization a useful remediation option?



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Con's of gentle remediation options

LONG-TERM MONITORING NECESSARY (10x):

DURATION OF MEASURE (8x):

not compatible with the current administrative procedures

NOT APPLICABLE TO ALL METALS/SITES (10x):

What happens with the rest fraction?

The use of mild remediation techniques is limited by lower urgency and therefore very low need of action can be seen.

KNOWLEDGE AND PRACTICAL EXPERIENCE (5x):

I don't know any successful project working with phytoextraction.

There are few well documented references.

COSTS (2x):

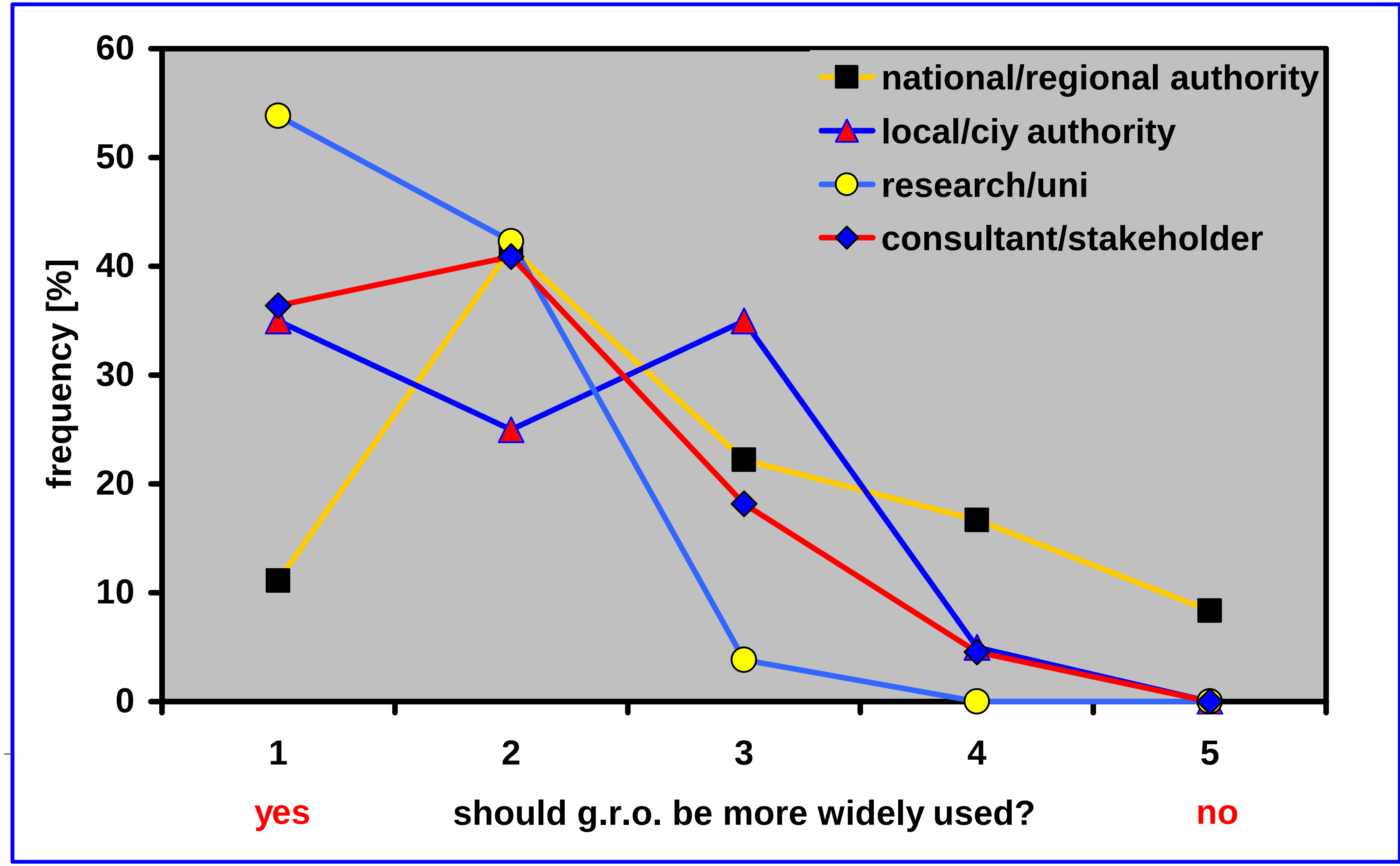
Higher costs of preliminary stages (lab/field).

Is it economical feasible?

USABILITY DURING REMEDIATION (1x):

During process, people should be kept aware that the site is still polluted

Should gentle remediation options be more widely used?



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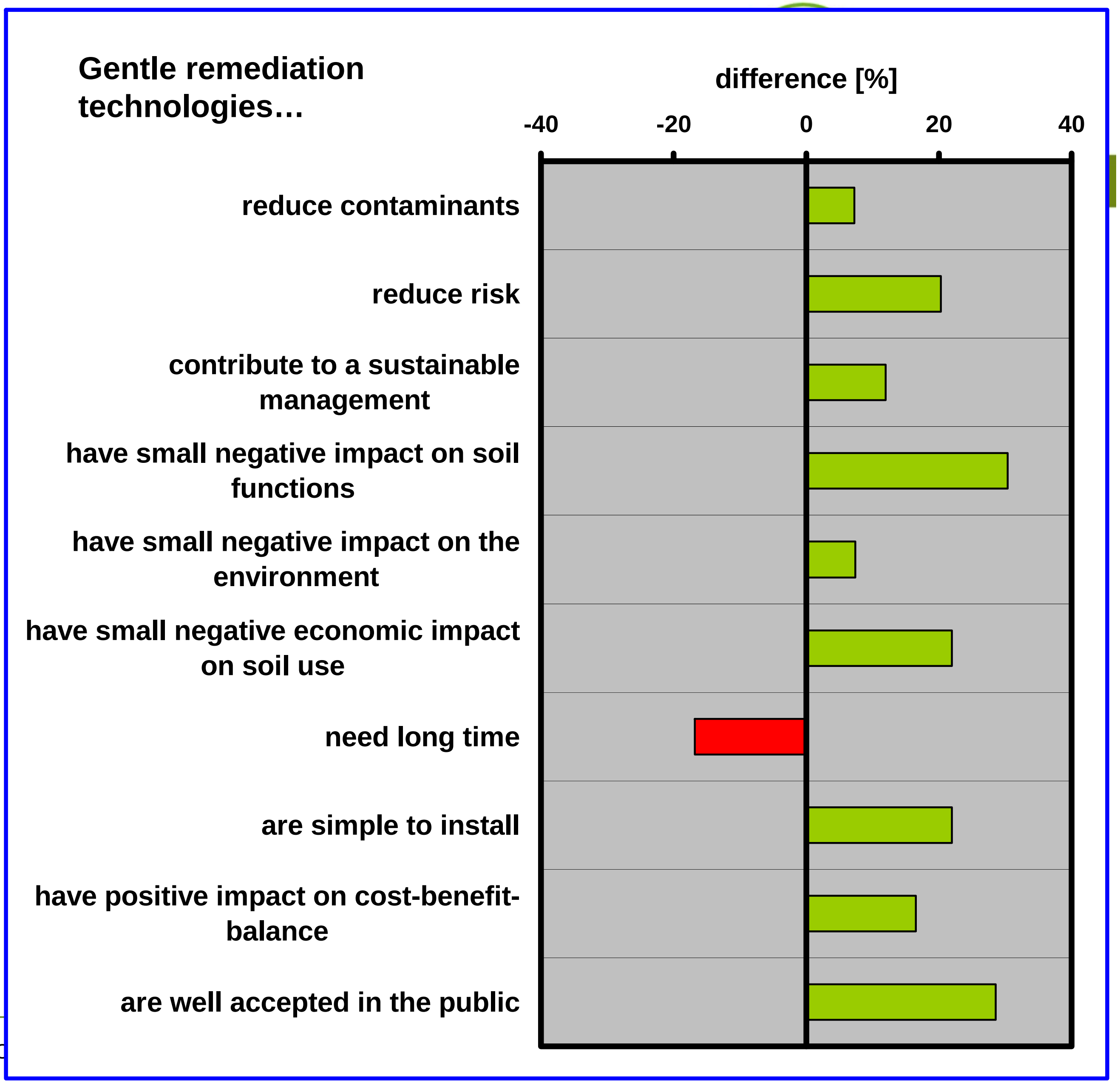
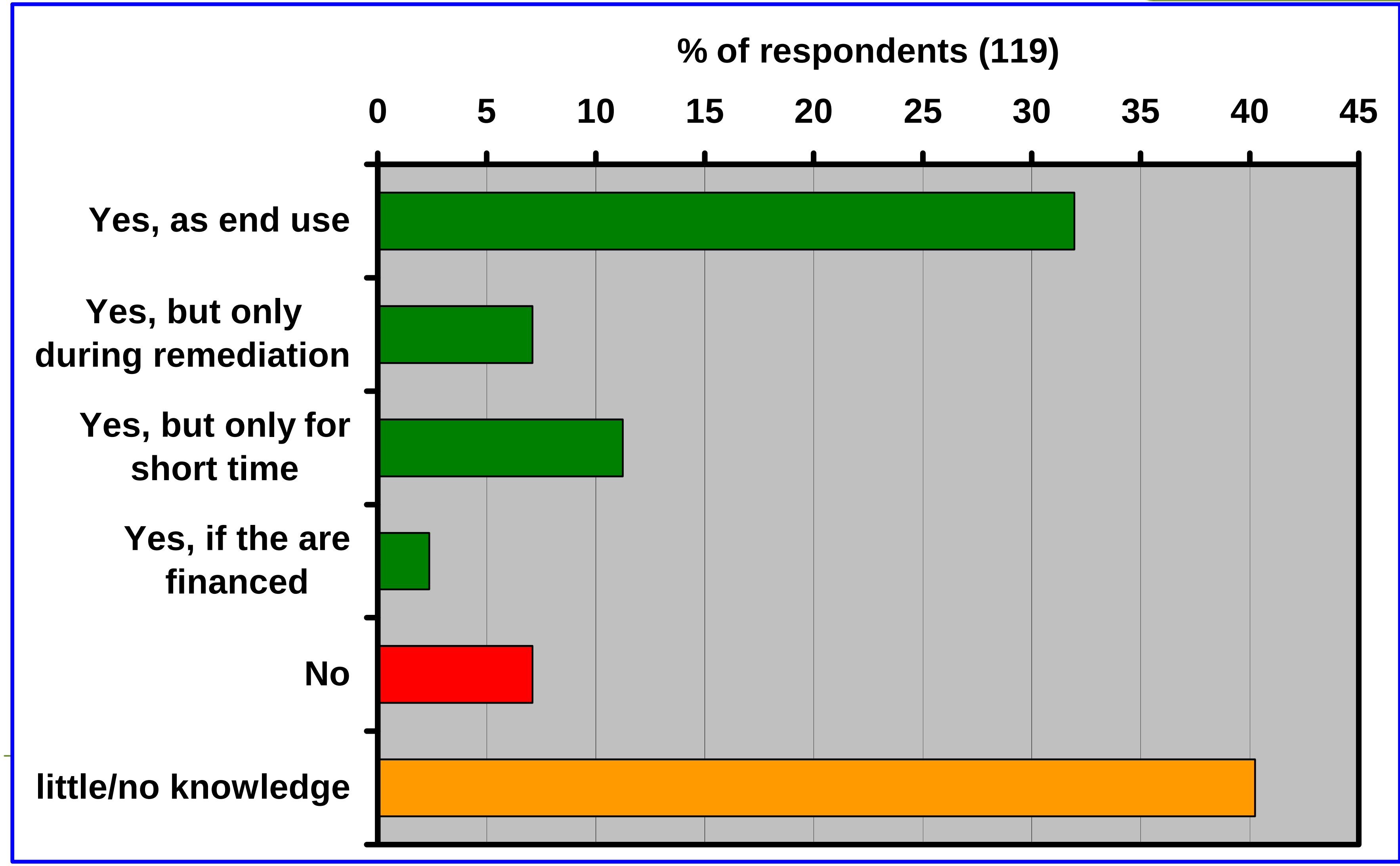
Respondents with g.r.o. experience evaluate g.r.o.'s more positively than the unexperienced

[exp(yes-no) - nonexp(yes-no)]



Can biomass valorisation be a relevant land use for TECS?



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Summary of questionnaire results

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- **Gentle remediation technologies are known to most respondents but rarely applied.**
- **Regulators are more sceptical than scientists and consultants.**
- **One disadvantages of gentle remediation technologies is seen in the need for long-term monitoring**
- **Dealing with gentle remediation technologies improves knowledge and acceptance.**
- **Lack of knowledge, experience and successful pilot projects are the main obstacles for more general application of gentle remediation technologies**

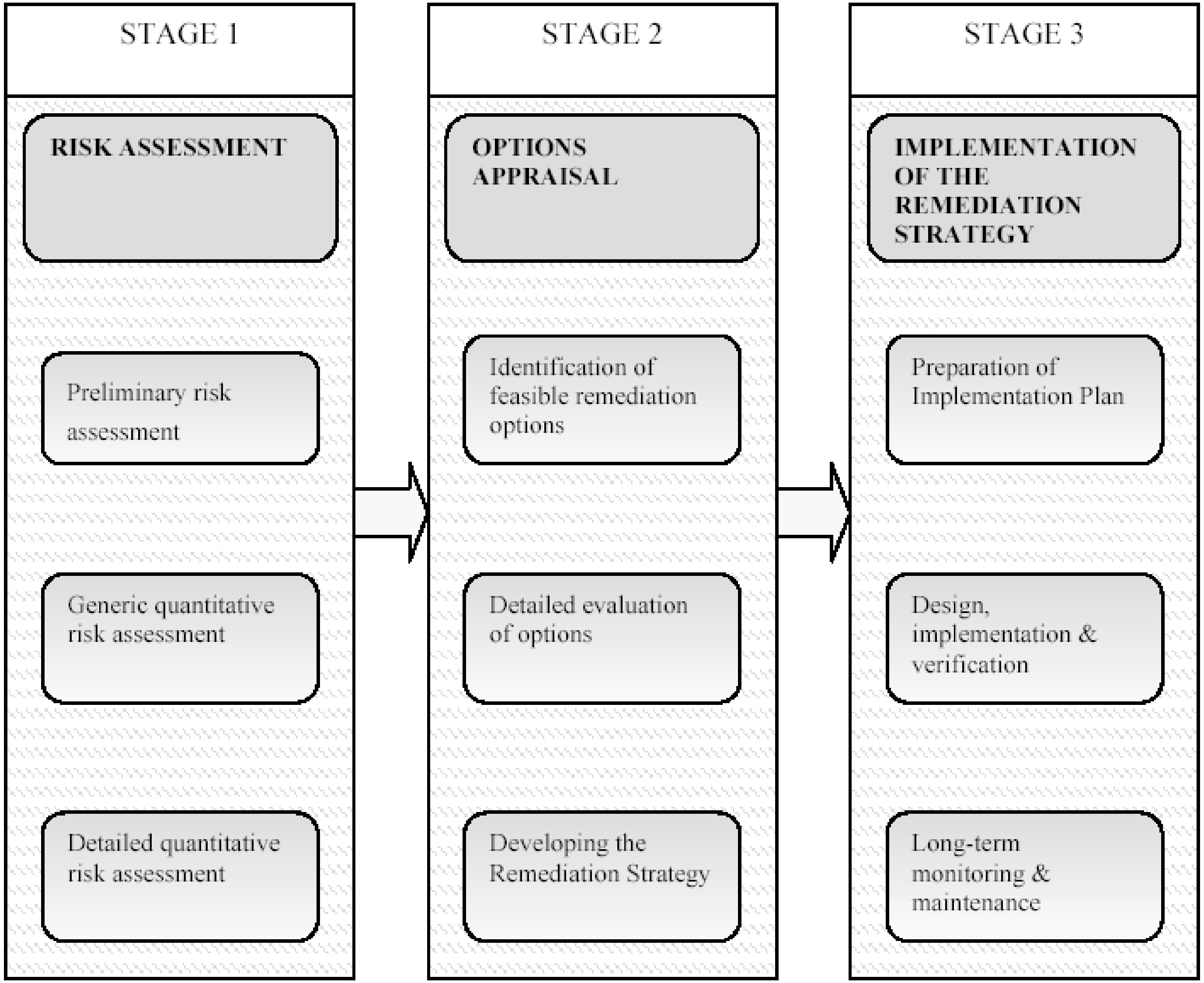
How to implement gentle remediation into sustainable management strategies? (WP5): Stages of the management of TECS

- **Risk assessment** establishing whether unacceptable risks exist and, if so, what further action needs to be taken in relation to the site;

- **Options appraisal** evaluating feasible remediation options and determining the most appropriate remediation strategy for the site;

- **Implementation** carrying out the remediation strategy and demonstrating that it is, and will continue to be, effective.

How to implement gentle remediation into sustainable management strategies? (WP5): Stages of the management of TECS



Phases

The process is phased, with scope for iteration within individual components

(*source: Environment Agency Guidance on Requirements for Land Contamination Reports Version 1 July 2005*)

Development of a decision tool system as a basis for selecting the most applicable remediation option

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- A number of (gentle) in-situ remediation options are available, and thus some form of decision support is required to allow the user to make an informed decision on which is the **most suitable technique(s)** for the site requiring remediation or management.

- Site management and/or remediation should also be **affordable**, **feasible**, **effective** & **sustainable**; factors which also need to be built in to the decision support process.

Key factors in decision making in remediation technology selection (CLARINET, 2002)

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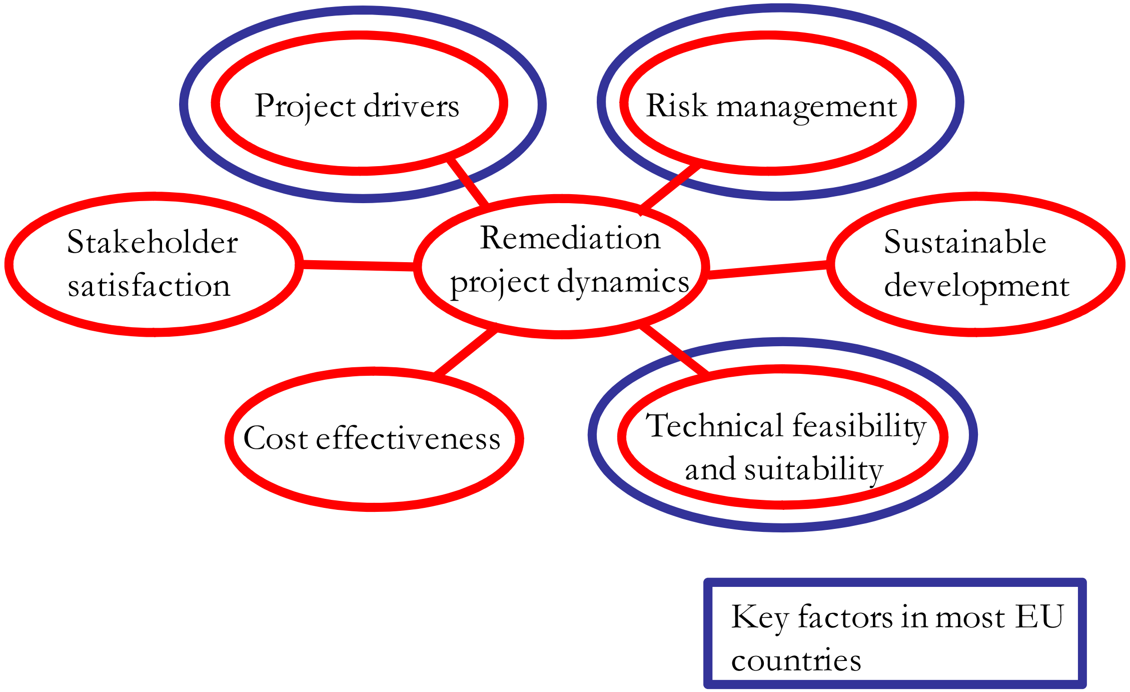
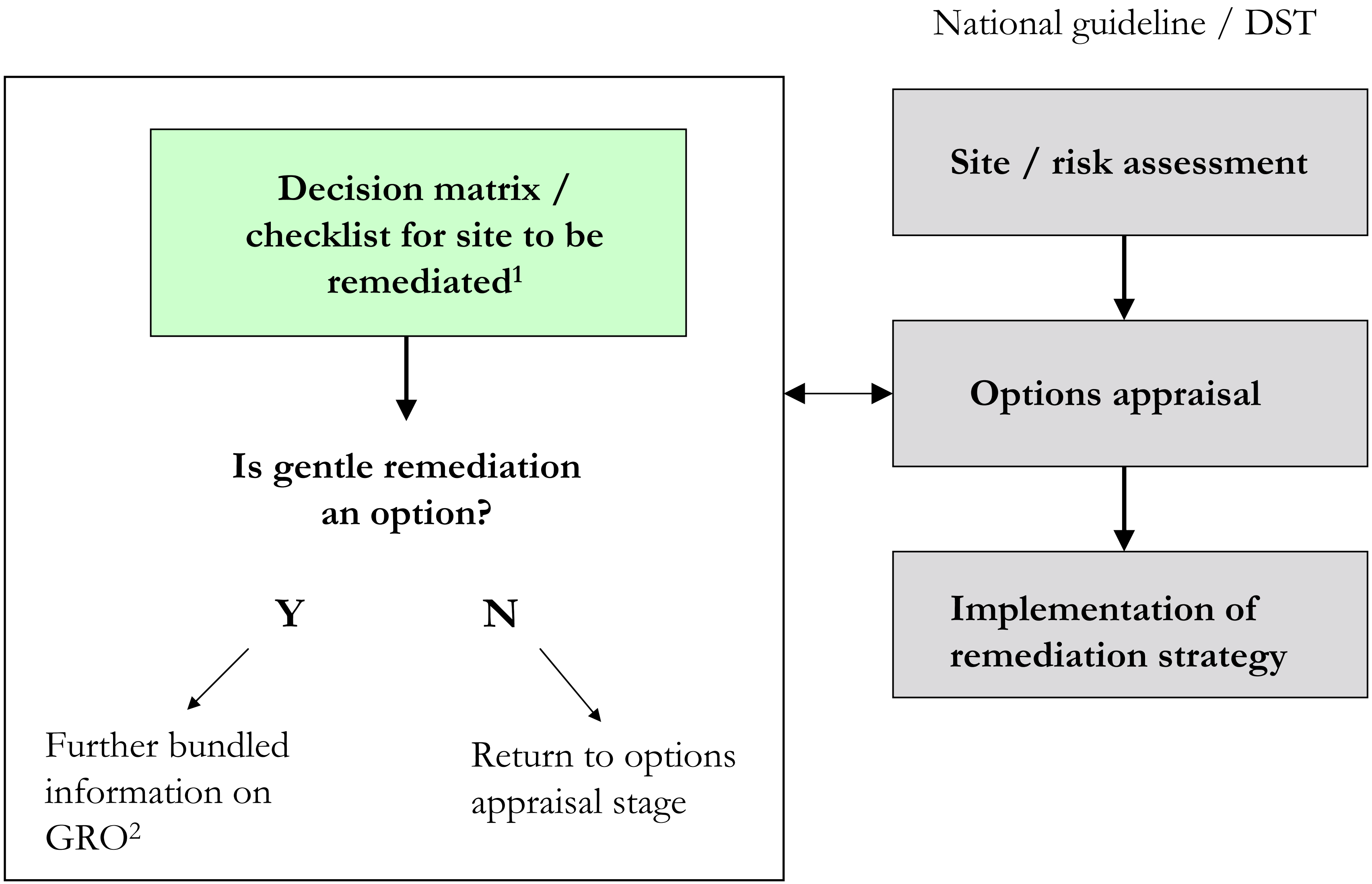


Recommended form of DST– diagrammatic outline



Key factors in decision making in remediation technology selection (CLARINET, 2002)

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			Criteria addressed			
Tools	**Principle**	**Target techniques**	**Risk Assessment**	**Cost**	**Sustainability (environmental impacts)**	**Socio-economic factors**
REC (Risk Reduction, Environmental Merit and Costs)	Multi Criteria analysis and Life Cycle Analysis	Gentle remediation (Phytoremediation)	Yes	Yes	Yes	No
ABC (Assessment, Benefits and Costs)	Life Cycle Analysis	Aggressive and gentle techniques	Yes	Yes	Yes	No
PRESTO (PREselection of Treatment Options)	Not applicable does not serve as an assessment tool	Aggressive and gentle techniques	No	No	No	No
CARO (Cost Analysis of remediation options)	Assesses the overall cost of remediation techniques	Aggressive and gentle techniques	No	Yes	No	No
ROCO (Rough Cost Estimation Tool)	Assesses the rough cost of specific remediation techniques such as dig and dump/pump and treat	Aggressive techniques	No	Yes	No	No
ROSA	Approach based on balance between cost, environmental compartments versus risk reduction and reduction in liabilities	Not indicated	Yes	Yes	No	No

Most important research needs identified by SUMATECS

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- There is a need for **large-scale field demonstration projects** for all gentle remediation techniques
- Improvements of the **risk assessment using appropriate techniques** such as microbial biosensors as well as whole cell biosensors are still needed; need for **harmonization**!
- A **financial valuation of soil functions** must be implemented in order to allow the financial comparison of various remediation options
- There is a need to **minimize potential negative impacts** of gentle remediation techniques (e.g., negative effects on soil microbes)
- **Development of simple checklists or decision matrices** providing a good basis for decision makers integrating gentle remediation-focused decision support tool in existing DST

SUMATECS – Project consortium

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- BOKU -University of Natural Resources and Applied Life Sciences (AT)
- Austrian Research CentersGmbH –ARC (AT)
- Hasselt University (HAU) (BE)
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- Saxon State Agency for Environment and Geology (DE)
- Ruhr-University Bochum (DE)
- INRA (Institut National de la Recherche Agronomique) (FR)
- INERIS (InstitutNational de l'Environnement industrielet des RISques) (FR)
- INERTEC (FR)
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- University of Brighton(UK)
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- UniFi(University of Florence) (IT)


Thank you very much!!
B 8