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RECOAL

Reintegration of coal ash disposal sites and mitigation of pollution in the West Balkan Area

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Handbook on treatment of coal ash disposal sites

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Handbook on treatment of coal ash disposal sites

Preface

The “Handbook on treatment of coal ash disposal sites” offers guidelines for the management of established wet-disposed coal ash landfills.

Decisions for the management and remediation of coal ash disposal sites require social considerations, such as what is acceptable to those directly affected and who is and should be involved in the decision-making process.

The handbook provides a framework for coal ash pollution researchers and engineers, and supports policy-makers in the interpretation and synthesis of coal ash-related research for its incorporation into decision-making.

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Contents

1. Introduction – objectives, restrictions, context

1.1. Objectives

This handbook serves to promote and support the reintegration of coal ash disposal sites in the Western Balkan area and to mitigate environmental risks that might result from industrial coal ash disposal. The handbook provides structured tools to guide the user through key issues relevant to rehabilitating coal ash disposal sites. The individual tools detail step by step which information might be relevant, and provide guidelines why, when and how to collect and evaluate data/information in order to:

- Define the basic characteristics of a disposal site of interest.
- Define and assess relevant and likely environmental impacts from the site.
- Prepare a risk assessment study. Depending on the level of complexity of the problem, various environmental media and/or pollution pathways need considering: e.g. soil, water, air, food chain and fodder production. This handbook uses current legal/recommended threshold levels and thus enables the handbook user to evaluate specific risks from both a technical and legislative perspective.
- Decide on priorities and choose suitable techniques that will assist in effectively rehabilitating and reintegrating the site.

These tools and guidelines were developed on the basis of experiences gained from the RECOAL-project and supplemented by data from the literature. It must be stressed, however, that the recommendations for tools and techniques provided here strongly refer to the context of the RECOAL case study.

This implies several restrictions that need to be considered when applying methodologies introduced in this handbook for the assessment, and particularly the reclamation, of other sites. For example, this handbook does not cover geo-technical problems and sophisticated reclamation and water treatment options that could also be applied at other sites. Instead, this handbook focuses on low-cost remediation options as explained below. Tools dealing with site characterisation, risk assessment and evaluation of different alternatives for remediation are considered to be of a more generic character and can be applied beneficially to sites different to the Tuzla case study. Indeed, the tools can also be applied to characterise and assess degraded areas (e.g. through mining operations), contaminated sites and waste landfills other than coal ash disposal sites.

1.2. Restrictions - site characteristics

This section discusses the environmental and technical frame of this handbook, in order to expose the context of application of the methodologies developed in the following chapters.

Wet disposal[1]

Today, two major disposal methods are used for the treatment of coal ash: "dry" and "wet disposal". A third method, dumping of fly ash into the sea, was practised at a large scale in the North Sea but was stopped in 1992. "Dry disposal", where coal combustion residues (CCR) are disposed of in dry or slightly moist conditions in landfills, is carried out like conventional back-filling or earthmoving operations. "Wet disposal" or "lagooning" implies the mixing of CCR with water at the power station site and the subsequent hydraulic conveying of the slurry through pipelines either to a single or to a series of artificial lagoons where the slurry is discharged. The content of this handbook is restricted to wet disposal of CCR. This implies that the coal ash disposal sites have a relatively level surface and without major slopes that would necessitate a geo-technical assessment, contouring or reshaping and adapted re-cultivation technologies.

Stability and accessibility

The proposed remediation options are developed for stable and accessible disposal site surfaces. Stability of the surface largely depends on the amount of residual water and the ash's drainage capacity. It is furthermore affected by characteristics/conditions such as particle size and distribution, content of pozzolanic layers (hardened layers due to the "cement reaction") and exposure to wetting and drying cycles.

"Fresh" and in-use wet disposal sites need to be observed using geo-technical methods prior to accessing them since there is a risk of base failure. Methods to be applied are shear strength measurements, dynamic probing and cone penetration tests. Unstable sites probably need to be reinforced by either geo-textiles or adequate layers of gravel, construction debris or soil prior to accessing and recultivating the sites. Alternatively, pozzolanic amendments such as cement, lime (CaO) or gypsum could be used to reinforce the disposal surface.

Alkaline reaction

Ashes and disposal site effluents in the Tuzla case were of alkaline reaction (high pH value). Thus water treatment options discussed within this handbook imply alkaline effluents and focus on methods to lower pH.

Moreover, an acidic soil or substrate would likely lead to significantly higher heavy metal concentrations in effluents and then require more complex treatment techniques or plants. Additionally, this would possibly lead to higher metal concentrations in plants and therefore higher uptake into the food chain.

No other waste was disposed

The disposal of additional waste material (e.g. chemical wastes, gas cleaning substances, tars and oils (HC) particularly from coal gasification/ liquefaction plants contain a vast number of organic contaminants (PAH, BTEX, cyanides, and phenols) besides ash may constitute a major environmental problem, particularly with respect to soil, groundwater and effluent contamination and required treatment. Such contamination patterns are beyond the scope of this handbook.[2]

Abandoned sites

Remediation techniques proposed refer to abandoned sites, which are generally accessible and de-watered (see section on 'Stability and accessibility' above).

1.3. Land use management characteristics

Reintegration/remediation

The term reintegration is used in this handbook to mean: *treating the sites in a way that they become part of, or even merge with, the surrounding environment/landscape and, ideally, are no longer recognisable as industrial landfill sites*. Reintegration also means that main threats – such as dust dispersal from wind erosion which can seriously downgrade living conditions – are stopped. Also, this term reflects that treatment options could aim at re-establishing agricultural potential.

The term reintegration explicitly does not include land use options such as commercial use (and the associated preparation of land for building/infrastructure) and the development of industrial areas/parks.

Low-cost

Treatment options proposed for reintegration of disposal sites and mitigation of environmental impacts are robust, low-tech and low-cost. This handbook does not deal with sophisticated rehabilitation strategies that would necessitate extensive geo-technical, geo-chemical and groundwater surveys or specifically adapted remediation methods, such as sophisticated multi-layer coverings, sealing (sheet piles, concrete trenches), de-watering techniques, active water-treatment methods for effluents, surface run-off and groundwater (stripping, microbial decomposition, precipitation, use of chemicals).

In-situ

In-situ simply means that the disposed ash stays in place while treated. We are explicitly not talking about excavating ash and either treat it on-site (e.g. soil cleaning) or depositing it in abandoned mine sites.

1.4. Context - characterising coal ash management

In the city of Tuzla, located in Bosnia / Herzegovina, a thermo electric power plant is operated by the company JP ELEKTROPRIVREDA BIH. TERMOELEKTRANA "TUZLA" which provides heat and electricity to private households and industry. The power plant is fed with coal excavated from mines near Tuzla.

One of the by-products of energy generation from coal is huge amounts of combustion residues which need to be disposed of. In Tuzla, residues are pumped into settlement ponds in natural valleys bordered by dams. Five coal ash disposal (CAD) sites, covering an area of approximately 170 ha, have been established around Tuzla: Drežnik, Plane, Divkovici I and II and Jezero.

Due to the fact that residual ash from coal combustion is generally known to contain a wide variety of potentially toxic trace elements – in the Tuzla case particularly Ni, Cr, As and B –, it must be assumed that ash disposal of that magnitude constitutes a serious environmental problem.

The main hazards relate to:

- soil contamination;
- water/groundwater contamination due to leaching toxins (effluents and process waters);
- dust dispersion; and
- toxins entering the food chain.

Soil-covered CAD sites have been used for agricultural purposes (food and fodder production), which poses further risk for local residents

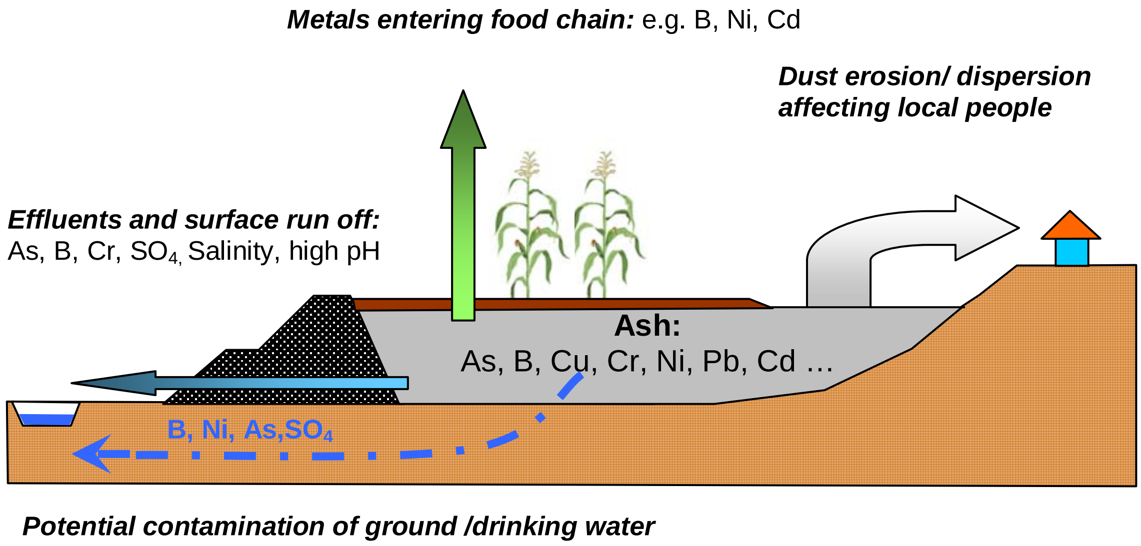


Figure 1: Potential Hazards and contamination path ways.

2. Minimum checklist

In order to define and assess relevant and likely environmental hazards and impacts resulting from any CAD site a minimum number of key actions and items – as detailed in the following paragraphs – need to be considered.

2.1. Historic research

Historic research is the basis for understanding the initial state and context of any disposal site. It is a prerequisite in order to define the frame of geographic, environmental and social investigations. Former studies that might be available as well as local residents and technical staff from the power plant need to be consulted to extract and evaluate the key issues. This may include information on the geological situation, hydro-geological situation, disposal technology applied (including disposal of additional wastes), changes of land use and settlement structure, reports/statistics on human health and social impacts. Any knowledge of changes in disposal technologies may be important to correctly interpret risk assessment data.

2.2. Current use of land and water

The current land use should be characterised and mapped in detail including the area on top of the CAD sites and also land in the surroundings that may be affected by the CAD site (e.g. agricultural land, forests, settlements, recreation area, waste dumps). The assessment of water use should also include quantities available and consumed. Based on the current land use possible exposure pathways can be defined; for example ash/soil – crop – human; or ash/soil – crop – livestock – human.

2.3. Coal and ash characteristics

Thermo-electric power plants keep statistics on their annual coal consumption and related ash production. Moreover power plant operators perform routine basic physico-chemical characterisations of the feed coal and ash which provide essential information for assessing potential risks.

2.4. Crop, plant, animal observations

Before planning an in-depth study, sites should be visited to obtain a general impression of the sites' structure and to note specific observations such as growth performance of crops and other plants (including native species), visual toxicity symptoms etc. Also, local residents may be interviewed to gain additional knowledge about local conditions.

2.5. Understanding local concerns and demands

Understanding the social context of remediation is a necessary (but not sufficient) condition to guarantee the long-term sustainability of the project. Ultimately, remediation proposals need to prioritise the concerns of those who are more affected by the contamination. Such research should ideally be done at the outset of the project, to inform its objectives and development. Understanding the local demands should not be understood as an add-on to the checklist, but rather an issue that should permeate the whole project.

There are different means to investigate the local context. A stakeholder analysis will help to investigate the different parties affected by and influencing the project. More detailed interviews can be carried out among institutional representatives, to explore different constraints influencing the remediation. Interviews among local residents will enhance researchers' knowledge about the research sites, and may help to highlight the more urgent problems that local residents have to confront in their daily lives. Finally, participatory methods, such as group interviews or workshops, may help to facilitate the communication between different stakeholders and help establish channels to pass different types of information to all the interested and affected parties.

2.6. Minimum set of investigations for individual pathways[3]

The minimum set of investigations listed below represents the lowest level for a reasonable environmental risk assessment of coal ash disposal sites. Suggestions for analysis of typical problem parameters and (radioactive) elements were taken from literature. Concentrations of organic pollutants associated with the burning processes such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzofurans (PCDFs) and polychlorinated dibenzo-p-dioxins (PCDDs) may be elevated in coal combustion residues but play a limited role compared to trace elements. Nevertheless, coal combustion residues are very heterogeneous substrates. Multi-element analysis has to be performed at least on a representative number of samples.

Characteristics of ash and cover soil

- pH
- Electric conductivity
- Total element concentrations: As, B, Cd, Cu, Cr, Hg, Mo, Se, Ni, Pb, Zn
- Concentrations of radioactive elements ^{40}K, ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, ^{210}Pb
- Water extractable elements and anions As, B, Cd, Cu, Cr, Mo, Se, Hg, Ni, Pb, Zn, SO_4^{2-}, Cl^-

Trace element concentrations in plants

As, B, Cd, Mo, Se, Cr, Hg, Ni, Pb, Zn

Waste water characteristics and toxicity

- pH
- Electric conductivity
- Total suspended solids
- Total concentrations (digests): As, B, Cd, Cr, Mo, Se, Hg, Ni, Pb, Zn, (Fe)
- Anions (in filtrates): Cl^-, SO_4^{2-}, (F^- NO_3^-, NO_2^-, PO_4^{2-})
- Standard toxicity tests using water organisms (e.g. Daphnia-tests)

2.7. Reference levels for pollutants

The risk assessment requires the establishment of levels of reference thresholds that define the presence of a certain risk. Such levels of reference may be established as part of a regulatory framework. At the moment of writing it appears that the legislation on contaminated land in Bosnia and Herzegovina is still to be developed.

From a regulatory point of view, the European Union strongly influences the development of new environmental policies in Bosnia and Herzegovina, which is considered a potential future Member State. Hence, it makes sense to refer also to the standards widely accepted within Europe.

The need for remedial actions depends primarily on the nature of contaminants (toxicology, mobility) and land use. References for normal concentrations in the environmental media soil, ash, plants and water can also be helpful for making comparisons. Examples can be found in the attached footnotes.[4]

Local pollutant background concentrations in soils and waters depend on the geological situation. For instance, the cover soils used to remediate some of the CAD sites in the Tuzla case study contained large concentrations of chromium and nickel. Such findings have to be considered to avoid ill-interpretation of the chemical analysis of plants and water from these sites.

In order to evaluate CAD sites the following threshold framework can be used:

- **Soil:** Maximum allowed concentrations for different land uses. For instance, if the surface is agriculturally used, the related soil protection guide for such land use has to be consulted. In the Tuzla case study, the cover soil was partly mixed with the underlying ash due to tilling practices.

- **Food:** Concentrations of contaminants in edible plants produced on abandoned coal ash deposits. Most legislation thresholds are based on concentrations in different fresh products (e.g. leavy vegetables, different cereals, potatoes).

- **Fodder:** Maximum concentrations of contaminants in fodder for animal nutrition are grouped for different products.

- **Waste:** The deposition of coal ash can be regarded as a special type of landfilling of waste. Waste management is beyond the scope of the RECOAL project. However, it may be useful to classify the disposed CCRs based on regulations for the landfill of waste.

- **Waste water:** Ash transport water and the leachate of ash deposits are considered as wastewater.

- **Drinking water:** Wastewater from ash deposition processes (ash transport water, ash landfill leachate) will generally exceed drinking water standards. Depending on the local situation local water resources used for drinking may be affected.

Depending on the geological situation and wastewater quality ground and surface water resources may be affected. Groundwater, collected from local tube wells, may be used for irrigation and drinking purposes. Therefore drinking water standards need to be consulted for the assessment of groundwater quality. The World Health Organisation (WHO) has developed one of the most comprehensive guidelines on drinking water standards, including substances that are generally not considered in national standards[5]. For instance, in the EU there are no legal standards available for Uranium whereas WHO offers a guideline value.

Bosnia and Herzegovina

At the moment of writing it appears that the legislations on contaminated land and water in Bosnia and Herzegovina is still to be developed. Therefore often foreign regulations from Croatia Serbia or EU are applied.

Food and fodder

Regulations on maximum concentrations in foodstuffs and undesirable substances in products for animal nutrition comprise only limited number of trace elements[6]. For all other elements well accepted reference values from literature have to be taken.[7]

Wastewater

Wastewater management is regulated within the Directive 2000/60/EC of the European parliament and of the council establishing a framework for Community action in the field of water policy. However, only a limited number of parameters have been regulated with certain directives For instance the urban waste water directive,[8] regulates classic water quality parameter such as phosphorus, nitrate but dues not refer to the large number of trace elements which may be enriched in ash transport waters and coal ash disposal leachate. These loads are still individually regulated by EU member countries. A comparative overview was published by Eurelectric[9].

Soil

EU has not yet released regulations on soil protection (maximum concentrations of heavy metals). Therefore we refer in the following to well-accepted guidance values which have been partly incorporated in the German Federal Soil Protection and Site Ordinance.

Eikmann and Kloke-values[10]

The scheme of Eikmann and Kloke (1993) defines reference, tolerable and action values based on total (aqua regia) concentrations. These values can be defined as:

- *Reference value* represents the maximum concentration of specific contaminant to allow unlimited multifunctional use of land.

- *Tolerated value* represents the maximum concentration of specific contaminant in relation to specific site- and endpoint-related land use. Concentrations of this value require monitoring or changing the land use.

- *Remediation value* is the threshold above which risk assessment and subsequent remediation is required.

Ammoniumnitrate (NH_4NO_3)-extractable fractions[11]

Similar to Eikmann and Kloke, Pruess (1993) also proposed a three-step scheme. Pruess's scheme is based on a 1 M NH_4NO_3-extract. This recommendation has been accepted as a Deutsche Industrie Norm[12].

German Federal Soil Protection and Contaminated SiteOordinance (BBodSchV)[13]

The German Federal Soil Protection and Contaminated Site Ordinance distinguishes between three pollution pathways:

- Pathway soil – human being (direct contact)
- Pathway soil – edible plant part
- Pathway soil – groundwater

Precautionary, action and trigger values are either based on aqua regia or (NH_4NO_3)-extractable fractions.

2.8. Informal current land use

The surface of coal ash landfills may be subject to uncontrolled use by local people as it is the case in Tuzla. People living nearby have been using the sites for food and fodder production, grazing, recreation and as waste dumps. A compilation of all land uses including the informal ones is essential to detect environmental and social interactions.

2.9. Current treatment of wastewater

Quality of wastewater (ash transport water and landfill leachate) need to be evaluated knowing current treatment practices such as sedimentation and pH control. For planning any water treatment a water balance of the individual sites is required. This includes inflow rates of natural streams (if present), precipitation, evapotranspiration, surface run-off, outflow rates from landfill leachates, and ash transport water flow rates. Missing quantities in the balance give an estimate of the amount of wastewater that infiltrates the groundwater. This will largely depend on the geological situation and the presence or absence of liners established before wet deposition of ash.

3. Decision support sools (DST) - flow-charts

3.1. Introduction to the framework

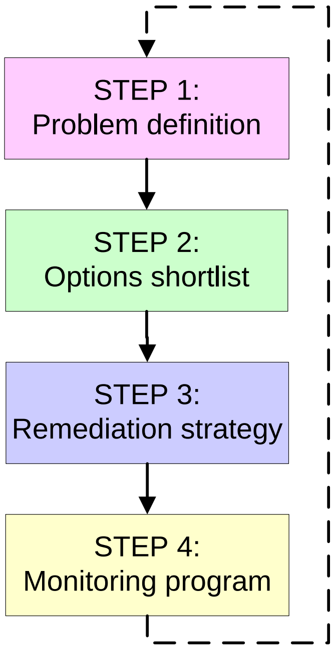
The decision support tools presented here are designed to orientate decisions about coal ash disposal (CAD) site remediation, balancing social and technical concerns. Traditional environmental decision-making assumes that finding the 'best' solution is predominantly a matter of compiling enough evidence. However, ideal solutions are rare when dealing with environmental contamination issues. Rather, decisions about remediation options depend on contextual factors, such as available materials and technical know-how, financial resources and legal requirements. Moreover, decisions require social considerations, such as 'what is acceptable to those directly affected?' and 'who is (or should be) involved in the decision-making process?'

Consequently, RECOAL has developed a basic conceptual structure – a framework – offering a route to structure coal ash management decisions that recognises the importance of contextual factors. Its objective is twofold:

- provide a framework for researchers and engineers involved in coal ash management to communicate their results to a wider audience of decision-makers and stakeholders; and

- guide policy-makers in the interpretation and synthesis of coal ash-related research for its incorporation into decision-making.

This conceptual framework thus addresses how environmental and social research can inform policy decisions and offers guidance on remediation science and management that incorporate public concerns.
RECOAL's research demonstrates that coal ash remediation solutions are context-dependent, i.e. local factors are a crucial influence on decisions. Hence, it is necessary to examine every case independently attending to its local environmental characteristics and social conditions. The decision-support tools are presented within a simple four-step framework (Figure 2) that can be used flexibly, according to the needs of the problem and the knowledge available.



Step 1 – Problem Definition. Define the objectives and motivations behind the remediation strategy. Such objectives may address local concerns and incorporate specific demands. Overall, the problem definition needs to satisfy legislative, social and environmental requirements.

Step 2 – Options Shortlist. Develop a list of potential options – a 'remediation palette' – for the remediation strategy. The application of a precautionary approach requires demonstrating an option's effectiveness in reducing pollution and its relative safety so that remediation options do not add unnecessary risks to those already posed by coal ash disposal.

Step 3 – Remediation Strategy. Develop an overall strategy for the setting combining several options from the 'remediation palette' to address the multiple dimension of the pollution problem. Alternative strategies can be compared as a whole, considering the interactions between different solutions.

Step 4 – Monitoring and Evaluation Program. Establish measures to assess and ensure the long-term sustainability of the strategy. In particular, periodic reviews of the strategy are necessary to check its performance against the original objectives as well as any emerging local concerns and changing environmental conditions.

Figure 2. Four-step framework approach

The development and connections between the different steps are outlined in Figure 3.

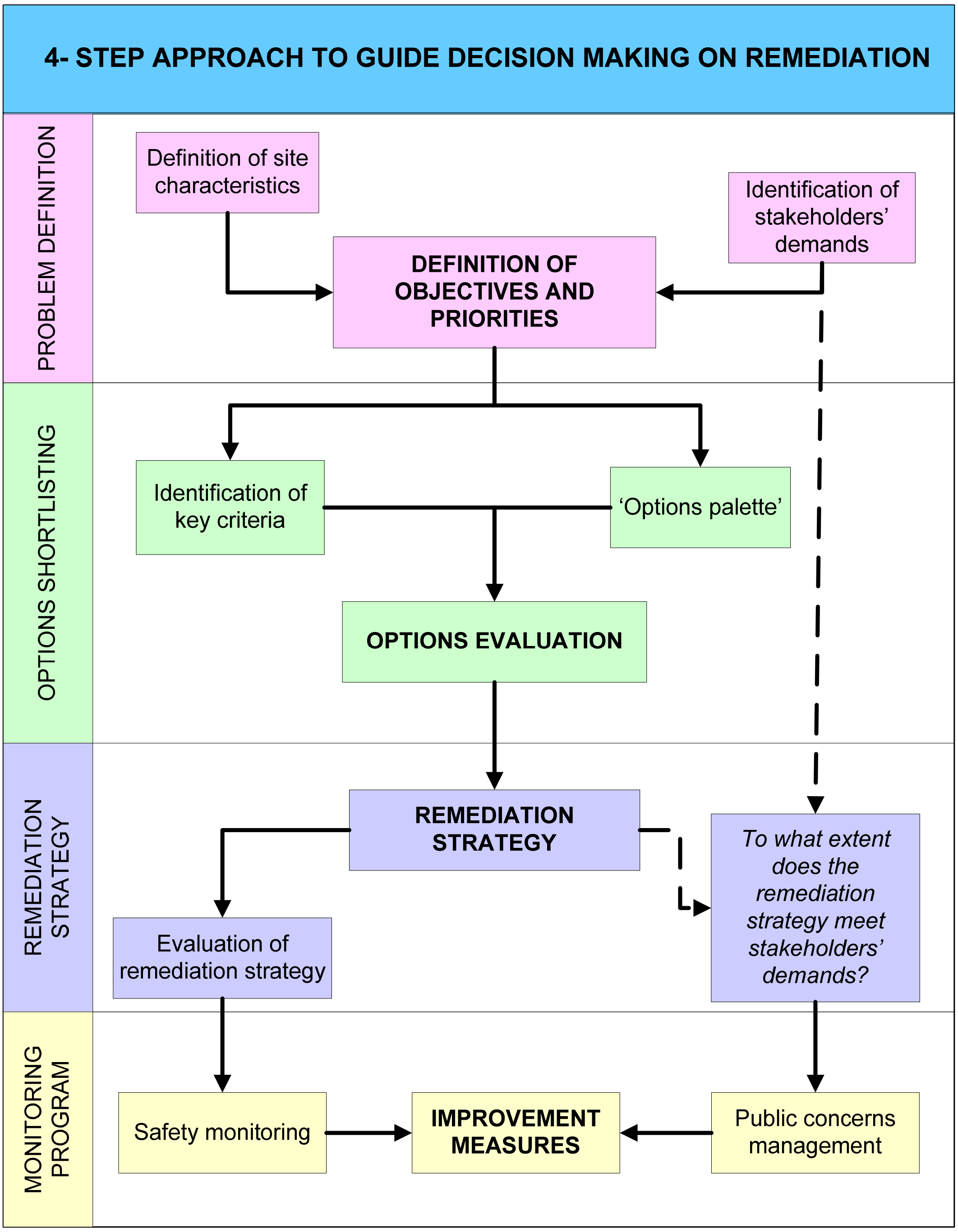


Figure 3. Flow chart summarising the 4-step remediation approach

3.2. Step 1: Problem definition

The problem definition step focuses on the identification of local requirements and demands to ensure that the remediation plan will deliver the desired range of benefits, establishes the scope of the strategy and limits the costs. Figure 4 summarises Step 1 components.

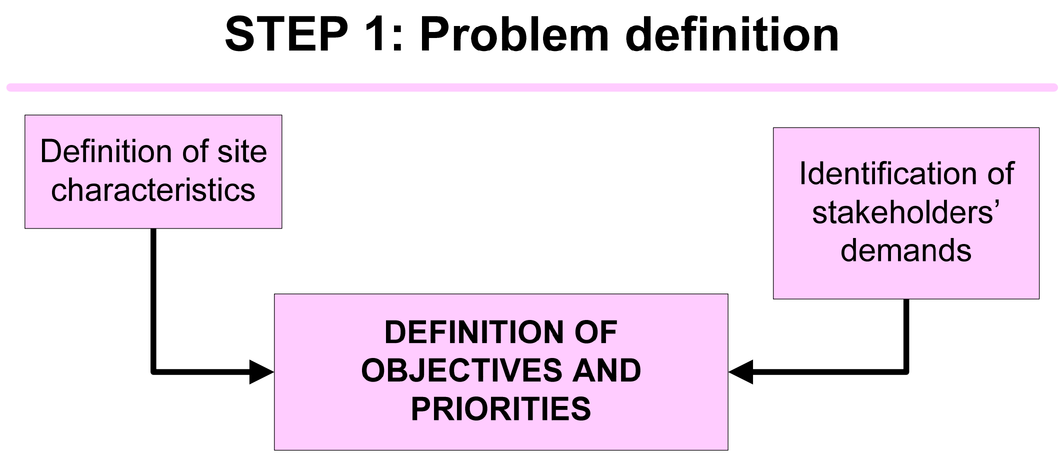


Figure 4. Components of Step 1: Problem Definition

1.a. Definition of site characteristics

Knowledge about the key features of the site and its context are required to establish why and what kind of remediation is needed. Information from previous studies and site management should be consulted, complemented by a general site reconnaissance survey and new desk-based research on the pollution/remediation issues. If resources are available, more detailed studies on specific environmental site conditions may help refine the remediation objectives. These may include a soil survey; water flow map; geo-technical stability assessment; physicochemical analysis of water, soil and vegetation; ecological survey.
Table 1 takes the case study in Tuzla as an example to illustrate the types of information that should be adressed in Step 1. This should include administrative, environmental, social and technical information and explain the policy/political and legal context of the remediation.

Table 1. Examples of initial information requirements		
Site description	Name	Deznik Coal Ash Disposal Site
	Location and extent	*e.g. map of site/area; extent in hectares or m^2; volume in m^3; administrative designations*
	Climatic conditions	*e.g. prevailing winds; microclimate; extreme events (temperature, precipitation, wind)*
	Administrative, policy and legal issues	*e.g. health and safety requirements; property rights; land use planning legislation*
Motivation for the remediation strategy	Accessibility	Several roads accessible by vehicles
	Demographics	*e.g. size and characteristics of population living close to the disposal site; existing dependence on / use of the site*
	Land use interests	Agricultural use; industrial use; cemetary; recreational use
	Civil society concerns	Local opposition to high-polluting industry; unemployment; perceived high numbers of respiratory diseases and cancer sufferers; communication between actors and stakeholders
	Laws and regulations	*e.g. international, national and regional laws and regulations*
	Actual and potential hazards	*e.g. related to industrial effluents* (e.g. wastewater; leachate; contamination of drinking water) *and wastes* (e.g. land contamination; dust dispersal)*; arising from past or existing management* (lack of wind barriers and immobilisation of waste)*; related to past or existing land use* (e.g. contaminants reaching the food chain through agricultural and pastoral use)
	Initiators	Bosnian researchers, with support from EU country researchers
Coal ash characteristics	Origin	Thermo-electric power plant (TEP) Tuzla
	Parent coal	Brown coal; lignite
	Other fuel	*e.g. burning of other materials/wastes with coal*
	Disposal technologies	Wet disposal: ashes are mixed with water from a reservoir in Lukavac and transported by pipes to the disposal site(s)
	General physical properties	Good stability; podzzolanic properties
	General chemical properties	Highly alkaline ashes; *toxins/pollutants present in ash*
	Disposal of other wastes	Illegal dumping of domestic waste on top of the ashes
Land use	Disposal site in use	Yes / No; *when did site stop to be used for disposal*
	Vegetation cover	Mixture of natural re-vegetation; sown pasture; sown crops
	Uses of the site	Agriculture, grazing livestock
Requirements of or demands for remediation solution	Local dependence on the site	*e.g. how many people use the site to gain an income (mention products / services) or subsistence - are there safer/acceptable alternatives?; recreational uses*
	Financial feasibility	*e.g. need for low cost solutions; in situ remediation*
Information sources	(Locally) available resources	*e.g. technical and environmental data from industry; government statistics; NGO publications; academic research reports*
	Specialist information	*e.g. academic journals; books; national and international guidelines*
	New research	*e.g. laboratory experiments; field experiments; stakeholder analysis and interviews*

1.b. Identification of local demands

Understanding what local people want and think requires conducting social research. Such research needs to be tailored to the requirements of the project. This involves determining who the 'local people' are (i.e. who should actively be involved or consulted in the decision-making process) and what type of approach will be appropriate and effective in engaging them in the remediation strategy.

Residents living close to a disposal site may (be perceived to) feel threatened by the disposal activities. In Tuzla, an estimated 4000 people live around the disposal sites. Hence, residents' perceptions of the environmental, social and health impacts of coal ash pollution need to be considered before proceeding with any remediation plan. This type of research is also essential in cases where widespread public opposition exists to existing management practices. In contrast, if the sites are relatively isolated and local residents content with the management practices and levels of impacts, social research targeting local community representatives, policy-makers, plant managers and environmental and social lobby groups may be sufficient to gain an appropriate level of understanding of the social context for the planned remediation strategy.

Exploratory research is recommended to identify local demands; including a characterisation of the case study population and choosing appropriate sampling and data collection methods. Table 2 lists some of the methods used for the Tuzla case-study, and the targeted sampling population.

Table 2. Social research methods used by RECOAL for the Tuzla case-study

Population sample	Data collection	Sampling method
Policy-makers; representatives of local institutions, industry and NGOs	Loosely structured interviews about the future uses of the disposal sites	Snowball sampling, drawing on existing contacts
Residents living close to the disposal sites	Semi-structured interviews about the local perceptions of environmental pollution	Approaching households around the different disposal sites
Those with an interest in or affected by the management of the Tuzla coal ash disposal sites (incl. representatives of the local communities; municipality officials, canton officials, local academics, local NGOs and interest groups, RECOAL project partners)	Workshop with working groups on assessing the sustainability of proposed remediation options	Identification of potential participants by RECOAL members and local contractors

1.c. Definition of objectives and priorities

The information compiled in 1.a and 1.b will help in drafting the core objectives. Meaningful and clear objectives are necessary for putting together a focused and effective research strategy using Steps 2 and 3 (see Figure 3).

Social research can elicit different types of information to be incorporated into the objectives. For example, social research in the case study Tuzla helped make explicit:

- the main local concerns regarding coal ash disposal;
- the interviewees' level of acceptability of the risk posed by the emissions and wastes of the thermo-electric plant;
- the history and relationships between different social actors that may complicate or facilitate the adoption of particular solutions;
- the preferred uses of coal ash and the disposal sites; and
- the divergent interests between and within different interest groups.

This information was fed into the objectives using a brainstorming exercise that compiled both local demands and issues identified by the research team (Figure 5).

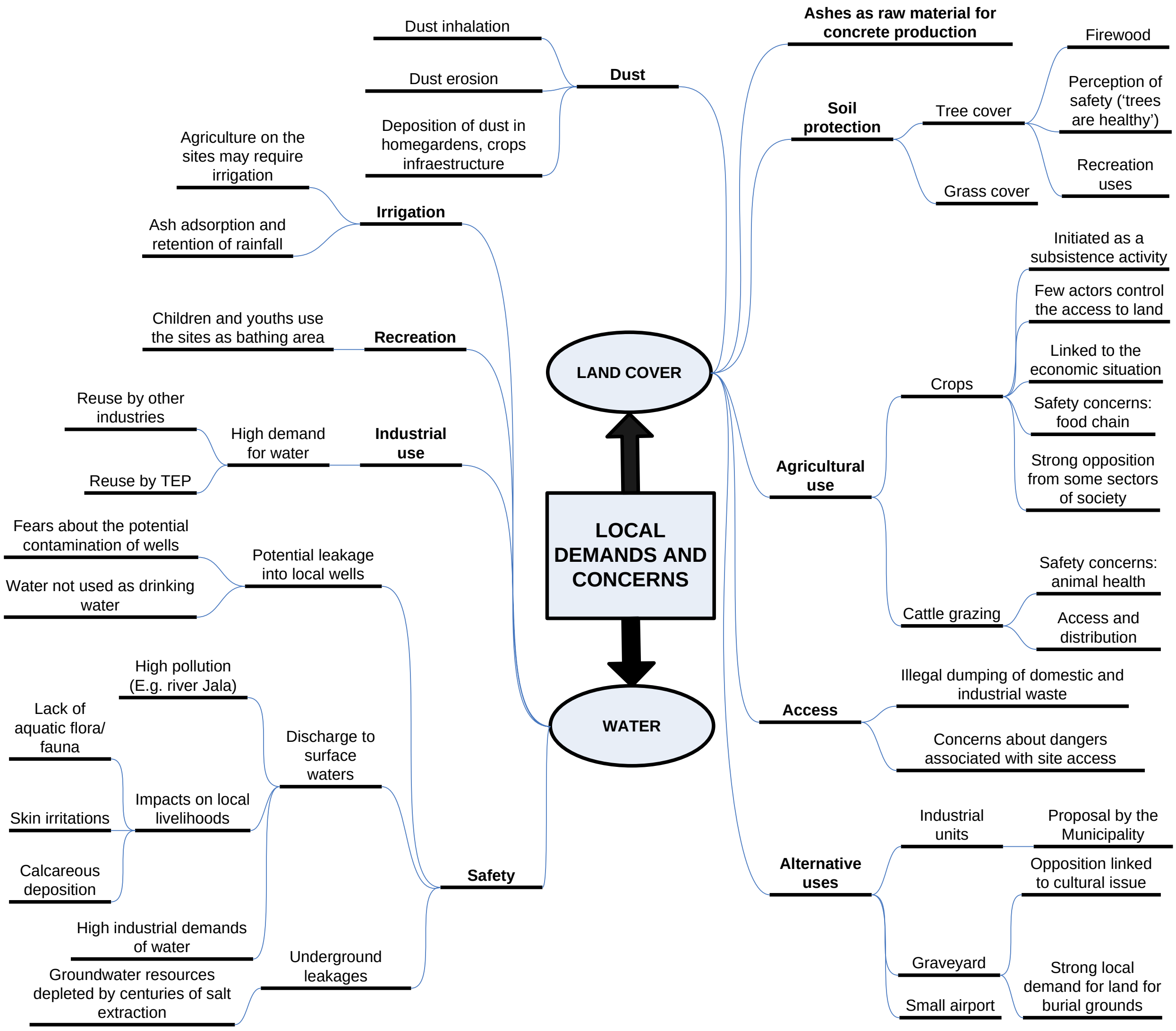


Figure 5. Overview of range of coal ash disposal issues identified by researchers and local stakeholders

In principle, the objectives for the remediation strategy should reflect local concerns and demands related to coal ash management. When this is not possible, the motivations for alternative objectives need to be made explicit referring to the original motivation for the remediation strategy. For instance, RECOAL focused on researching the safety of cultivating certain crops on the coal ash disposal sites (being the dominant existing land use there) but paid less attention to assessing the suitability of the sites for establishing a graveyard. However, it appears that, given current demand for land in the vicinity of the city, the Municipality is considering the graveyard as an option. Thus the opportunity was missed to examine the potential requirements for and impacts of this option during the RECOAL project.

3.3. Step 2: Shortlisting of options

Step 2 defines potential options that could be integrated into the CAD site management strategy, to form a 'remediation palette' from which to draw up the remediation strategy. The identification of options needs to be in accordance with the objectives established in Step 1. Based on the defined objectives and priorities evaluation criteria should be formulated against which each option can be assessed. Using these criteria it should be possible to eliminate options that fall outside the defined remit and thus avoid wasting resources on them.

The evaluation of the options is guided by a precautionary approach: it puts emphasis on establishing evidence that the implementation of the options will not increase or pose additional risks to the environment and society. Each option needs to be evaluated for its own merits and checked for its suitability to local conditions. Next, a smaller set of options can be selected according to the priorities defined in Step 1, whether it be maximum reduction of polluting impacts and risks, or reduction of costs, or a combination of priorities – based on what emerged from the contextualising process in Step 1.

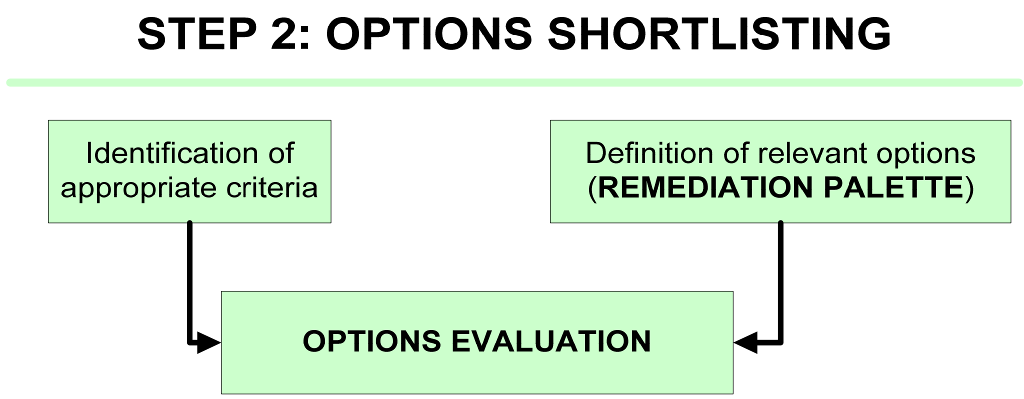


Figure 6. Components of Step 2: Options shortlisting

2.a. Definition of relevant options

This stage requires the elaboration of a preliminary list of available remediation options. It is important that the initial list is comprehensive and up to date. The list should be inclusive, rather than exclusive, to avoid overlooking relevant solutions. Table 4 (appended at the end of this chapter) proposes a comprehensive (but not exhaustive) list of remediation methods that may serve as the basis to compile a list adapted to each particular context.

Even though the list of options should aim to be inclusive, it is important to focus on evaluating options that respond to the initial objectives; options that are currently unfeasible or encounter significant opposition from the stakeholders should be excluded.

2.b. Identification of appropriate evaluation criteria

In order to develop an appropriate remediation strategy proposed options need to be evaluated according to a set of criteria. During the RECOAL project researchers and stakeholders identified and focused on the following five broad criteria or categories: safety, remedial power, feasibility, acceptability and long-term sustainability. The precise meaning of each of these may vary for different contexts, so it is important to define the bounds and meaning of each criterion prior to the evaluation.

While accommodating flexibility, it is important to maintain transparency in defining options, criteria and the overall evaluation process, and to remain vigilant to stakeholders' concerns and priorities. Table 3 provides an example of criteria included in the evaluation of applying ash amendments as a remediation option.

Table 3. Examples of criteria used in the evaluation of ash amendments as a remediation option

Criteria	Examples
Safety	Kinds and levels of uncertainties associated with the option; e.g. regarding the robustness of the experimental data (Was the length of the study appropriate? What gaps in the assessment remain? Can the quality of the added material be assured?) and the interaction of components between the ash and the added materials (Is the amendment likely to fix or mobilise pollutants?) Track-record; i.e. past experience with this option in other case studies Known side-effects of the remediation option Disposal of remediation by-products
Remedial power of the solution	Reduction of pollutant concentrations / nuisance Improvement in soil fertility Reduction of dust dispersion
Feasibility	Availability of materials Transport costs Labour costs
Acceptability	Conflict with local values Value added to the local economy Value added to the well-being of the local communities
Long-term sustainability	Obsolescence period Maintenance required

In developing the criteria, a balance needs to be struck between accuracy/available data and descriptive power. Both quantitative and qualitative criteria are important in evaluation. The identification of new pathways through which pollutants can reach humans is, for example, a descriptive criterion. This may appear to be vague but is essential in pre-empting potentially dangerous side-effects and considering alternative potential outcomes in the absence of available data.

For instance, one of the solutions tested by RECOAL has been the establishment of a phyto-filtration system for effluent water. Research has shown that residents' recreational activities include bathing in the basins formed by the discharged water from the disposal sites. Hence, the phyto-filtration bed may cause a new pollution pathway by attracting bathers to a wetland-like environment. However, this can be addressed by establishing an appropriate location for the basin and ensuring that the site is fenced and signage erected.

2.c. Options evaluation

The evaluation of options concludes step 2, by comparing each option against the evaluation criteria. Figure 7 provides a flowchart that can be used to conduct a systematic evaluation. The flowchart may have to be interpreted flexibly or amended according to the objectives of the specific remediation objectives and demands at hand.

In some cases one single criterion will be enough to eliminate an option. For instance, a high-cost remediation option may be discarded immediately if there are no available resources for its implementation. For instance, *ex-situ* remediation methods were discarded early in the RECOAL project, because the project's focus was explicitly on locally available low-cost methods. Alternatively, an option may be included even if it does not meet all the criteria. For instance, RECOAL tested various crops for land cover on the coal ash disposal sites, even though there are serious doubts about the safety of using the sites for food and fodder production. This was done because of a local interest in finding new areas for agricultural production.

The options evaluation flowchart can be used to indicate the kind of information needed as a minimum to assess a particular option's suitability for a specific remediation problem/context. It is proposed for use as an open-ended iterative process (to ensure long-term effectiveness and suitability of a remediation strategy) rather than a one-off linear process.

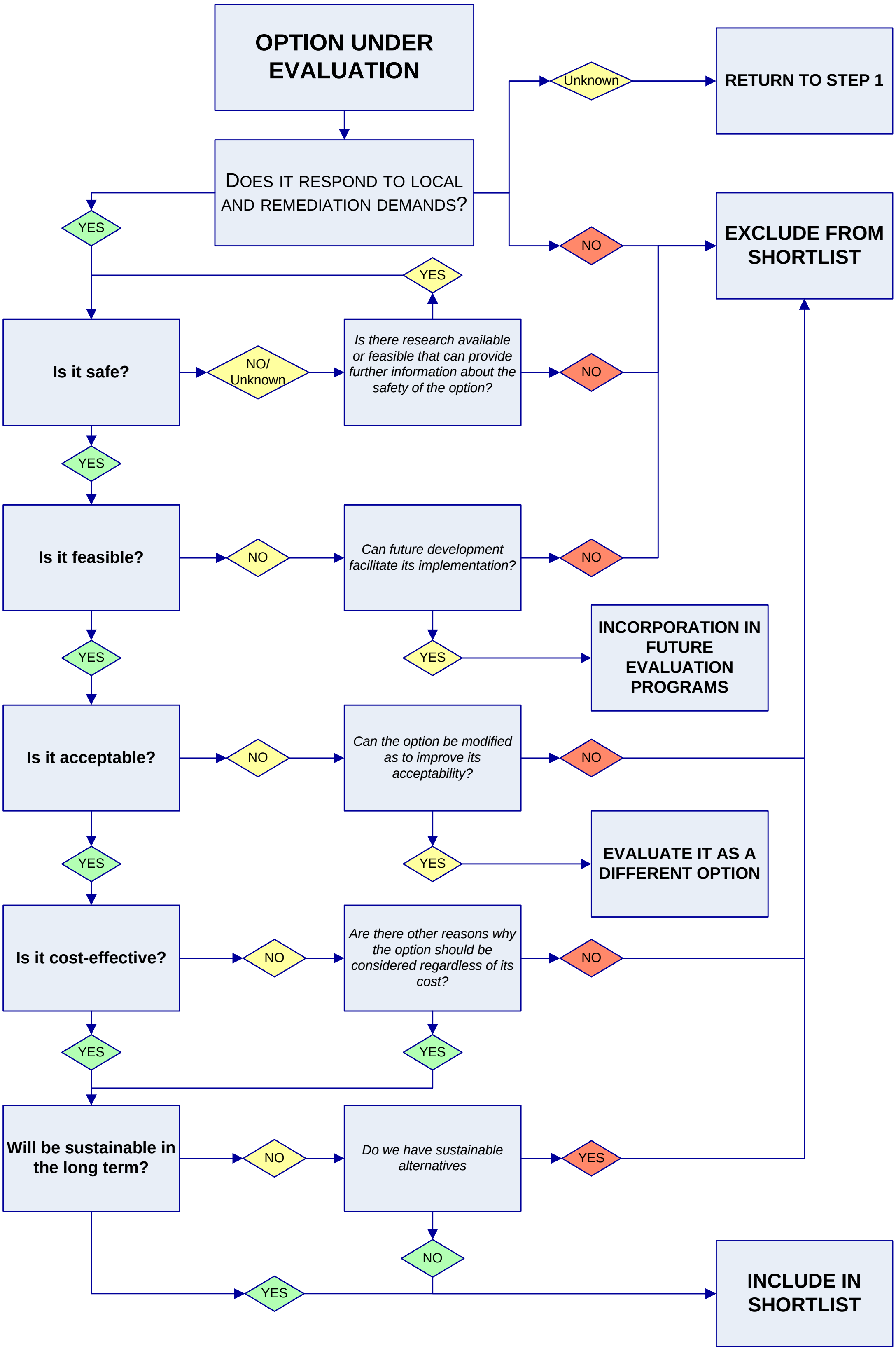


Figure 7. Options evaluation flowchart

3.4. Step 3: Development of remediation strategy

The main aim of Step 3 is to develop a remediation strategy based on a holistic understanding of the remediation problem. Sometimes, one remediation option may be sufficient; more often, however, a combination of measures will be necessary to treat different pollutants, media and pathways through which pollutants affect the environment and reach humans.

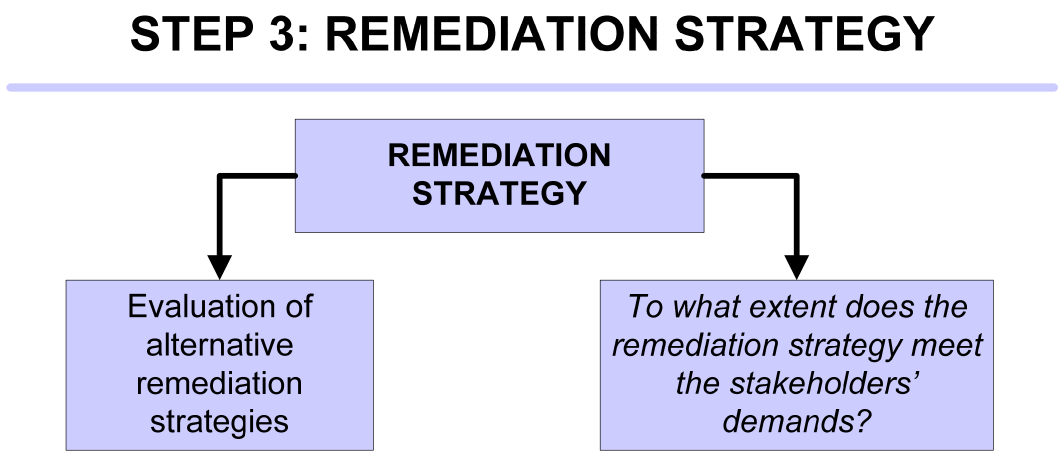


Figure 8. Components of Step 3: Remediation Strategy

3.a. Remediation strategy development

Sometimes, (part of) a remediation strategy may evolve without explicitly going through stages 1 and 2. A case in point is the cultivation of the coal ash disposal sites in Tuzla, which occurred spontaneously. TEP responded to residents' concerns about dust pollution by establishing a thin soil cover on top of the ashes. No formal process or procedures were put in place to control the sites' use and local residents soon started cultivating the sites. When the RECOAL team started to investigate the feasibility and safety of the cultivation practices, crops had been produced uninterruptedly for at least ten years (despite concerns by some over the safety of this land use). Assessing the safety of the cultivation practices and the products became one of RECOAL's main objectives; alternative land covers (such as concrete or asphalt; or establishing trees) were relegated to a secondary place.

This demonstrates the influence of specific local circumstances in determining 'remediation'. It also illustrates the importance of the initial phases – defining the problem and identifying the range of potential solutions – so that the breadth of issues is addressed in the remediation strategy. Using a systematic approach (e.g. this four-step framework) can help communicate associated uncertainties and limitations in the remediation approach and options alongside their specific opportunities and benefits.

Following the initial site investigation, additional queries and issues may arise in the construction of the remediation strategy and thus require additional research and information gathering. Some of the considered options may need modifying and re-examining as the strategy advances.

Usually, several remediation proposals will be available to address a particular site problem and these should be systematically compared and evaluated (as outlined in 3.b). Different approaches can be used, such as a multi-criteria assessment, scenario analysis, cost-benefit analysis and a variety of recently developed participatory mixed method approaches[14].

Here, we outline the use of scenario analysis to help decide on an appropriate remediation strategy. It is a well-established technique to help construct and evaluate different possibilities by either focusing on desired end states (and assessing whether the proposed steps are likely to get us there) or by testing what a particular approach is likely to achieve in a given time period. The process is thus illustrative and capable of accommodating quantitative and qualitative information as well as highlighting ambiguities and uncertainties.

An initial step is to develop different scenarios. This usually involves proposing different plausible hypothesis to explain how things will plan out; here, the real options available for remediation. Scenario development allows for a holistic treatment of the remediation problem, constructing different combinations of options and their likely interactions. Building and comparing possible scenarios acknowledges and works with uncertainty, being open to the various paths and endpoints a strategy may involve. Remediation scenarios are often developed intuitively by researchers, and here we encourage the user to make the scenario-development step more explicit. It is also important to be realistic in the selection of options and their combinations with regard to available resources (especially cost of proposed strategy and finances for the evaluation stage as outlined in the following section).

The approach consists of the development of complete scenarios for a site in which remediation activities for the simultaneous remediation of water, soil and vegetation cover problems are considered. In each scenario, different remediation options from the 'palette' can be combined to fit the needs of the site (i.e. size, distribution, topography, slope, water flows, etc.). Once several possible scenarios have been developed, they can be evaluated, as explained in the following step.

3.b Evaluation of alternative remediation strategies

An effective tool to evaluate different scenarios is to assess the associated risks for each of them. In Step 2 we have addressed the safety of the remediation options, taking a precautionary approach. Here, we propose using traditional risk management approaches to compare the different remediation scenarios, and to evaluate which one is likely to be the most effective strategy whilst posing the least risks.

The rationale behind this procedure is that risk is something unavoidable. Nothing is risk-free. However, we can compare different strategies explaining why one remediation strategy is likely to pose fewer risks than another strategy. The framework works towards minimising risks; i.e. it aims to find a feasible remediation strategy that is effective in reducing pollution and nuisance while at the same time posing the least risks. Each remediation strategy should be compared against the baseline scenario (i.e. the state of the disposal site prior to remediation). The results of this risk analysis can be used to assess the hypothetical scenarios. Experimental methods can give additional information to develop the hypothetical scenarios. For instance, RECOAL's approach included field experiments with crops and ash amendments and laboratory experiments (see Section Tuzla case study).

The strategy that emerges as least risky should be reviewed against the five key principles: safety, remedial power, feasibility, acceptability and long-term sustainability. This way, not just the individual steps but also the whole strategy is evaluated. This step can help justifying the choice of the final strategy and may flag up potential difficulties for its implementation.

3.c. To what extent does the remediation strategy meet stakeholders' demands?

The final test of the strategy requires going back to the stakeholders' demands on coal ash waste management and checking which concerns are addressed in the strategy and to what degree. For those concerns that could not, or only partially, be addressed, clear explanations should be given eliciting the underlying reasons. The rationale behind this component is that the final strategy will necessarily be a compromise between options available and competing demands. These choices should be made transparent and, if not negotiated with the stakeholders, at least be communicated to them.

Local residents are an important group of stakeholders who need to be considered since the strategy is likely to have repercussions in their lives. Hence, policy-makers and researchers should consider carefully how the strategy will affect different stakeholders, and which additional measures could mitigate any anticipated negative effects. Sometimes it may be useful to present the stakeholders with the different scenarios or remediation strategies and gauge their reactions.

For example, in Tuzla some local residents defended the cultivation of the disposal sites, while others regarded such practices as creating significant risks for the community. In this context, if cultivation was to be recommended as a way to reintegrate the coal ash disposal sites, clear evidence would have to be available to demonstrate that such activities and uses are safe according to existing knowledge. If the research raises some concerns, as for example was the case for the RECOAL case study sites, agricultural and pastoral activities should be avoided.

Offering stakeholders the opportunity to consider and comment on the proposed strategy can be beneficial in several ways and need not be costly. If the strategy gets the approval of stakeholders (in a workshop or similar event), decision-makers can then proceed to implement the strategy more confidently. If stakeholders disapprove of the strategy, the given reasons may help to redefine the initial objective(s) or identify a wider range of contextual factors to aid the revision of the strategy, improving its applicability and long-term sustainability

3.5. Step 4: Monitoring program

Step 4 addresses requirements for a remediation strategy to remain sustainable and effective in the long-term. Any remediation strategy should aim at establishing a long-term solution and not pass the burden of remediation on to future generations.

In practice, we often encounter limitations about the sustainability of remediation. Firstly, 'remediation' may differ significantly from 'restoration'. For instance, in Tuzla, the coal ash disposal sites can not be returned to their original state, because the disruption of and alterations to the landscape have been too profound. Thus, remediation here focuses on minimising pollution risks and finding suitable new uses for the sites. Secondly, an inherent degree of uncertainty exists in decision-making, especially where complex interactions exist between many different factors. What is considered a good remediation strategy today may prove to become a liability in future years in the light of new discoveries about coal ash pollution, or perhaps due to shifting concerns in public opinion. Moreover, short-term solutions may be the only remediation option in economically stressed or politically unstable regions.

Hence, a remediation strategy needs to be treated with flexibility, as flexibility may be the key to successful long-term remediation. In other words, a remediation strategy needs to adapt to the changing conditions in which it is implemented.

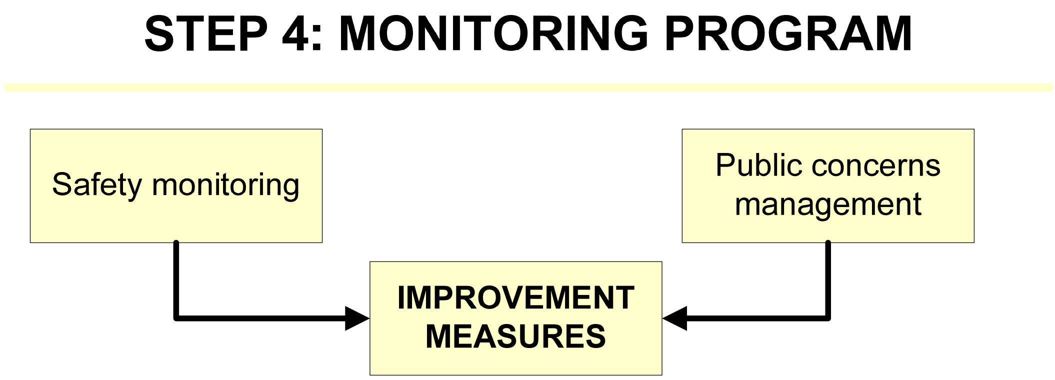


Figure 9. Components of Step 4: Monitoring Program

4.a. Safety monitoring

The aim of monitoring is to ensure that a remediation strategy does not loose effectiveness. In this sense, safety monitoring should avoid being excessively ambitious, to guarantee cost-effective and regular implementation, but at the same time needs to encourage reflexivity and be able to identify problems. In its simpler form, the safety monitoring may consist of a checklist to evaluate the safety of the site and the potential emergence of new risks. An example of such 'minimum monitoring checklist' for coal ash disposal sites is provided in Section 2 of the Handbook (Minimum Checklist).

A remediation strategy needs to consider minimum maintenance guidelines and establish at which frequency the safety monitoring needs to take place. The checklist needs to contain measures to identify significant problems which may require a complete re-evaluation of the strategy, or the implementation of alternative options.

4.b. Responses to changes in public opinion

The monitoring strategy may incorporate guidelines to be able to respond to changes in public opinions and attitudes. Those responsible for the safety of the disposal site may wish to scan the local media and/or hold regular meetings with stakeholder groups (maybe once or twice a year). These and other available low-cost strategies may help to draw attention to emerging changes in requirements or signs of unforeseen side-effects, which then would need further attention.

Involving stakeholders in the implementation of the remediation strategy is probable the best way to monitor the site, identify emerging needs and help adapt the strategy as necessary and feasible.

4.c: Developing improvement measures - adaptation

A remediation strategy should be able to accommodate changes, such as considering the feasibility of (new) options, particularly to take advantage of new technological developments or changes in cost. In order to do this the strategy needs to acknowledge and be explicit about its own shortcomings. With this knowledge in mind it is possible to respond quickly to new options, and keep shortcomings to a minimum.

Another issue that facilitates adaptation is the identification of sources of uncertainty and the limitations of the research informing the original strategy. For instance, lack of data about the safety of a particular option or the notion of significant risks associated to it would in most cases exclude that option from being considered for the remediation palette. However, further research may help dissipate some of the uncertainties associated with an option. For instance, in Tuzla, some of the crops cultivated on site (e.g. potatoes, maize) are suspected to cause potential health risk when introduced into the food chain. Although at this stage RECOAL would not recommend cultivation of these crops on the CAD sites, further experiments can be carried out to investigate the conditions in which such cultivation could be safe.

Regular monitoring and consultation with stakeholder groups should naturally lead to cross-checking different elements of the remediation strategy and its adaptation to new and evolving circumstances.

Table 4. Overview of range of methods available for removal of target pollutants					
Remediation	Description	Advantage	Disadvantage	Medium	Target
GENERAL TREATMENTS					
Physical Barriers	Trench filled with materials such as bentonite to contain and retard water flow	Versatility	Long term degradation	Soil and Water	Any
Passive/ Reactive Treatment Walls	Underground structures with fillings that react with pollutants, to trap them or precipitate them	Allows continuous use of the land	Walls require maintenance	Soil and Water	Most organic and inorganic substances
IN SITU BIOLOGICAL TREATMENT					
Bioremediation / Biodegradation	Using fungi, bacteria and other microbes to break down and degrade contaminants	Low maintenance, use of natural processes	Organisms specialise on particular pollutants and conditions	Soil and water	Fuels; VOCs
Phytoremediation	Phytoextraction uses plants to take up pollutants from the soil. The same process to remediate water is called Rhizofiltration (using a water bed to facilitate the absorption of pollutants). Phytodegradation processes, using plant's enzymes, are also available	Relatively cheap, social acceptance tends to be high	Works on surface pollutants only; problem of accumulation of pollutants in plant material.	Soil and water	Fuels; VOCs; specified metals (depending on plants used)
Natural Attenuation	Use natural processes to stabilise the contaminants or transform them into less toxic compounds/elements.	Low maintenance, low cost	Slow process; requires monitoring of effectiveness	Water	Fuels; VOCs
Land Treatment / Bioventing	Using aeration or tilling to encourage biological activity and degradation and improve the physical soil properties	Simple measure	Results limited	Soil	PAHs, coal waste; specified metals
IN SITU PHYSICAL/CHEMICAL TREATMENT					
Chemical Oxidation / Reduction	Addition of chemical oxidants such as hydrogen peroxide, potassium permanganate, ozone and dissolved oxygen	Stabilisation / degradation of pollutants	Not always complete stabilisation or degradation	Soil and water	Metals
Electrokinetic Separation	Application of a low-intensity direct current, that mobilises charged species towards ceramic electrodes	Used in saturated low-permeability soils	By-products and undesired effects	Soil	Heavy metals; polar organics
Soil Flushing	Solution is injected into the soil to facilitate the extraction of contaminants	Low cost	Limited success / it can affect the groundwater flow	Soil	VOCs and inorganics
Solidification / Stabilisation	A binder (cement, chemical fixation) to physically immobilises contaminants; can also be used *ex-situ*	Low cost; widely available	Future liabilities	Soil	Inorganic compounds; radionuclides
Thermal Treatment	Heat is used to volatilise contaminants and facilitate their extraction	Efficient, destruction of contaminant	High costs	Soil and water	Organic contaminants
Air Sparging / In well air stripping	Pollutants volatilised by injecting air into the water	Long-term solution	Difficult application	Water	Fuels; inorganic compounds
EX SITU BIOLOGICAL TREATMENT (ASSUMING EXCAVATION)					
Bio-piles	Contaminated soil is mixed with soil amendments in aerated piles	Short-term process, natural degradation	Costs	Soil	VOCs; some specified metals
Composting	Addition of organic materials to improve the carbon/ nitrogen balance and promote microbial activity	Simple process	Costs of space, release of VOCs	Soil	PAHs
Slurry Phase Biological Treatment	Creation of a slurry phase to suspend contaminants and facilitate the microbial degradation	Short to medium term treatment	Difficulties and costs of handling it	Soil	Organic and inorganic compounds
Bio-reactors	A water circuit facilitates the reaction of pollutants and microorganisms	Relatively economical	Slow process	Water	VOCs; PCBs
Constructed Wetlands	A wetland facilitates the sedimentation of pollutants and their stabilisation; can also be *in situ*.	Natural process, relatively stable	Long- term liability	Water	Inorganic compounds, particularly metals

Remediation	Description	Advantage	Disadvantage	Medium	Target
EX SITU PHYSICAL/ CHEMICAL TREATMENT (ASSUMING EXCAVATION)					
Chemical Extraction	Extraction of contaminants using acids or solvents	Concentration of contaminants	High costs; toxic solvents may substitute the original pollutants	Soil	Heavy metals; non-metals; organic compounds
Chemical Oxidation / Reduction	Chemical oxidants (e.g. hydrogen peroxide, potassium permanganate, ozone and dissolved oxygen) are used to transform pollutants into less aggressive states	Fast and long term species conversion	Process may be incomplete	Soil	Heavy metals; semi-metals
De-halogenation	Removal of halogen groups from the chemicals, transforming the pollutant into a non-toxic salt and volatilises the contaminant	Contaminant destruction	Treating low volumes, high costs	Soil	Halogenated VOCs; PCBs; Dioxins
Separation	Using physical or chemical methods to concentrate and remove pollutants	May allow reuse	Availability of methods, disposal of extracted pollutants	Soil and water	Organic and inorganic compounds
Soil Washing	Extracted soil is washed using water and additives	Reduces the volume of contaminated soil	Post-treatment of the washing solutions	Soil	Fuels; heavy metals
Solvent extraction	A solvent is added to the soil which removes the contaminants and facilitates its extraction	Reduces the volume of contaminated soil	Recuperation of solvents, pre- and post-treatments	Soil	Organic and oily wastes
Ex situ thermal treatments	Incineration, pyrolisis (incineration in the absence of oxygen) and thermal desorption (heat volatilisation) are methods used to extract and destruct contaminants	Effective removal and destruction	Controlled systems, expensive, operational difficulties	Soil	Organic compounds; coal ashes; coal waste
Adsorption/ Absorption	Sorbents are used to concentrate chemicals	Easy to use	Disposal of the sorbent	Water	Selected inorganic contaminants
Air stripping	The water is sprayed to an air flow which facilitates the removal of contaminants	Relatively low cost	Additional treatment required	Water	VOCs
Filtration	The water is passed through a porous medium that removes solid particles; can also be used *in situ*	Pre-treatment alternative	Additional treatment required	Water	Suspended solids and particles
Ground Water Pumping	Removing the contaminated water from the site to prevent contamination plumes	Common and well-known method	Disposal of water	Water	Dissolved pollutants
Ion exchange	An ion exchange material (e.g. resin) exchanges contaminating ions for less aggressive ones	Mature technology	Disposal of resin and metals	Water	Metals
Precipitation / Flocculation	Additives are used to cause the precipitation of pollutants and facilitate their removal	Mature technology of removal	Disposal of the precipitate	Water	Metals; radionuclides
Reverse Osmosis	Contaminants are removed by passing water through a membrane under pressure	Reduction of pollutant volume	Expensive	Water	Metals; radionuclides
CONTAINMENT					
Landfill Cap	Establishment of a layer over the landfill to minimise interactions of the contaminated materials with the ecosystem	Effectiveness related to the material used; low costs	Long-term liability, leakage	Soil	Any
Landfill Cap Alternatives / Amendments	Amendments designed to interact with the contaminant(s) (e.g. correct the pH, conductivity, porosity) for stabilisation and control	Easy design, low costs	Long-term liability	Soil	Any, in stable landfill sites
Off-site Disposal	Soil excavated and disposed at a site where it posses fewer risks	'Quick and dirty'	Misplacing pollutants	Soil	Any
Geotechnical Systems	Use of engineering structures to contain and reduce the exposure of contaminants	'Quick and dirty'	Long-term liability	Soil	Any
Directional Wells	Drilling techniques to access groundwater	Access to chemicals	Costly, incomplete	Water	Any

4. Risk assessment approach

The suggestions on assessment strategies are based on the experience of the RECOAL project gained in Tuzla. Three main pollution pathways of coal ash landfills were identified which can be classified as:

Risk assessment of the landfill surface
Food chain contamination
Ash dispersion by wind and water erosion

Contamination of ground and surface waters (landfill leachate and ash transport water).

The establishment of a robust- sampling design is essential to create significant and reliable data. Samples have to be taken with appropriate numbers of replicates to allow statistical comparisons. Sampling and laboratory procedures as well as chemical analysis need to follow well established norms including the analysis of certified reference materials.

4.1. Risk assessment of the site surface

Food chain contamination[15]

Potential threats to the food chain may be detected by assessing the concentration of pollutants in agricultural (human food chain) and native plants (wild life food chain) growing on ash disposals. Grazing livestock, as observed in the Tuzla case study, may also affect the human food chain via meat consumption. Both, pollutant concentrations in the growth substrate (ash, cover soil) as well as plant concentrations need to be analysed.

The pollutants may enter the food chain via the roots of food and fodder plants as well via plant-adhering ash and soil particles. Moreover grazing livestock inevitably ingest the growth substrate and thereby enhance the pollutant transfer into the food chain.

Ash dispersion by wind erosion[16]

Upon landfilling, ashes typically exhibit single grain structure. Moreover, large fractions of CCR are in the particularly erosion susceptible silt size. Thus, dried-out active or abandoned ash disposal sites are particularly prone to wind erosion and serve as a significant source for dust pollution . Wind erosion starts immediately after water has evaporated (after the lowering of the water table in the case of wet disposal and after evaporation of the remaining moisture in the case of dry disposal). Over time, however, self-hardening properties, which have been described for many fly ashes, might alleviate erodibility. Very few studies provide quantitative data on wind erosion of coal ash disposals.

Measurements of ash were not part of the RECOAL project. However, evidence of wind erosion is documented in Figure 16. Dust deposition can measured with bulk samplers placed in the surroundings of ash deposits.

Ash erosion can only be prevented by an appropriate deposit surface treatment (application of soil or a comparable substrate, establishment of a vegetation cover etc.)

4.2. Risk assessment of waste waters

Wastewaters from wet-disposed coal ash land fills can be classified into:

- The water used in the ash transport
- Landfill leachate

Quantitatively water used to transport the ash is by far more important than landfill leachate since a constant waste water stream is generated to convey the ash to sedimentation ponds. After sedimentation the overflow is usually released to the next tributary. This water contains dissolved ions and large amounts of suspended and floating ash particles. The total load of waste waters needs to be analysed in acid digests following standard procedures as described in national water regulations[17].

Threats to groundwater are reduced if ash transport water is being fed directly in tight canals to tributaries. However, the threat of polluting surface water resources remains. Particularly small tributaries with low water flow rates may be significantly affected.

Figure 10. Release of ash transport water in Tuzla. The large particle and salt load results in the accumulation of large depositions and precipitations along the waste water canal (photos: W Fitz).

Contamination of groundwater can be tested in local wells and by comparing in-flowing and out-flowing groundwater layers. Effects of seepage from permeable landfill sites can also be detected in local wells and groundwater layers. One way to measure groundwater layers is to compare upstream and downstream groundwater concentrations.

Generally, landfill leachate contains fewer suspended solids and floating particles because the ash body acts as a filter. During this process, however, more/other ions may be dissolved. The quality of landfill leachate may change with time, particularly because coal combustion residues are subject to ageing. Both, natural attenuation processes and a reduction of the redox potential in the ash body (due to the absence of oxygen) can trigger dissolution processes and release redox-sensitive elements such as arsenic.

5. Environmental impact of coal ash deposition – Tuzla case study

5.1. The context of coal ash disposal in Bosnia and Herzegovina

The demand for electricity is rising due to increasing internal consumption in Bosnia and Herzegovina, and the revitalisation of the economy through energy exports. Elektroprivreda of Bosnia and Herzegovina (Elektroprivreda BiH) is a public company generating, distributing and selling electricity produced by hydro and thermal energy plants[18]. The thermo-electric plant at Tuzla (TEP) is currently the company's largest energy production unit with a net production of 2,806 GWh in 2006, which accounts for 58% of the thermal energy production and 44% of the total energy produced in BiH[19]. The raw coal (75 % lignite and 25% black coal) comes from different sources, including the open-cast mines of lignite in the nearby municipalities Banovici and Dubrave.

Energy production from coal continues to be highly significant due to the country's available coal reserves and existing infrastructure. As part of the country's transition to a market economy national and foreign private investors start to participate in the country's energy market. This is manifest in the establishment of new privately managed power plants such as the thermal power plant planned at Doboj[20].

Combustion by-products include emissions to air, thermal pollution and coal combustion residues (CCR), consisting of: bottom ash (BA), fly ash (FA), flue gas desulphurisation waste (FGD) and boiler slag. These wastes may contain high concentration of potentially hazardous elements (such as arsenic, barium, boron, cadmium, chromium, copper, lead, molybdenum, nickel, radium, selenium, thorium, uranium and zinc) depending on the origin and properties of the coal used and the conditions in which combustion occurs. Other problematic properties of coal ash include extreme pH, increased concentrations of soluble salts, and physical particle characteristics that make them easily dispersed by wind.

Some CCR can be used as raw material in other industries (e.g. concrete production) but often most of the ash is land-filled using wet and dry disposal methods. Wet disposal is the method used in Tuzla, where ashes are mixed with water and pumped into valleys enclosed by a dike. We refer to these sites as coal ash disposal (CAD) sites. The disposal uses up huge amounts of space and fundamentally alters existing landscapes characteristics. When the water is drained fine particulates deposit on the surface of the sites and easily become airborne, posing a serious environmental and health hazard for the surrounding areas. The pollutants can also migrate from the CAD sites to the surrounding areas suspended or dissolved in water, which can have negative impacts on surface and underground waters and associated habitats.

5.2. The industry's impact on the local environment

Energy production from coal affects the environment in several ways, particularly through the emission of harmful pollutants during combustion and disposal of CCR. In Tuzla, TEP's environmental impacts contribute to an already degraded state of the environment resulting from industrialisation. The number of emission sources in the area is large, including the thermo-electrical power plant, as well as chemical and other industries such as SIPOREX, HAC, KOKSARA Lukavac and Cementara Lukavac.

From an environmental viewpoint, Tuzla municipality is likely to be one of the most endangered areas in Bosnia and Herzegovina. Pollution affects the air, surface and underground water bodies, soil, plants, animals and humans. Complex interactions and dependencies between different pollutants could increase the magnitude and severity of these impacts. Furthermore, industrialisation has dramatically changed existing ecosystems by consuming and transforming large areas or valleys.
Air pollution is one of the main local concerns in Tuzla. Currently, there are 59 confirmed industrial air pollution sources in Tuzla emitting approximately:[21]

- 74206 t/year of sulphur dioxide (SO_2); TEP accounts for 73590 t/year or 99 %
- 13120 t/year of nitrogen oxides (NO_x); TEP accounts for 13000 t/year or 99 %
- 19150 t/year of small particles; TEP accounts for 18390 t/year or 96 %.

Even though there is a lack of in-depth research, recent local measures indicate that Tuzla's air also has elevated levels of carbon monoxide (CO), hydrocarbons (C_xH_y), hydrogen sulphide (H_2S), lead (Pb) and chlorine (Cl), amongst others. Their levels exceed maximum allowed concentration (MAC) according to Federal law.[22] The information presented in the following sub-sections focuses on the environmental impacts associated with the disposal of bottom ash from TEP, being one of the main polluters of the land, air and water.

5.3. Coal ash disposal

TEP produces between 0.4 and 0.9 m³ of ash per MWh; at maximum production this would amount to approximately 1.7 million m³/year. In 2006-2007, about 0.9 million m³/year of ash were produced. There are five CAD sites in the vicinity of TEP and the city of Tuzla. So far, nearly 40 million m³ of waste material have been deposited in the CDA sites. A summary of the characteristics of the CAD sites is presented in Table 5 and an aerial view of the sites is provided in Figure 11. Coal use and ash production decreased dramatically during the first half of the 1990s (reduced energy production during the war) but has increased steadily ever since.

Table 5. Main characteristics of the coal ash disposal sites in Tuzla

Name of disposal site	**Plane**	**Drežnik**	**Divkovici I**	**Divkovici II**	**Jezero**
Type of landscape	backfilled coal mine	natural valley	backfilled coal mine	backfilled coal mine	natural valley
Start of disposal	1964	1981	1985	1985	1991
Abandoned	1990	1991	1995	still in use	2003
Area (ha)	18	45	45	44 (final: 68)	24
Cover established	1991/1992	1993	2004	-	-
Covered (ha)	18	nearly 45	10	0	0
Cover soil thickness (cm)	10-30	10-30	10-15	0	0
Land use	agriculture	agriculture	-	-	-

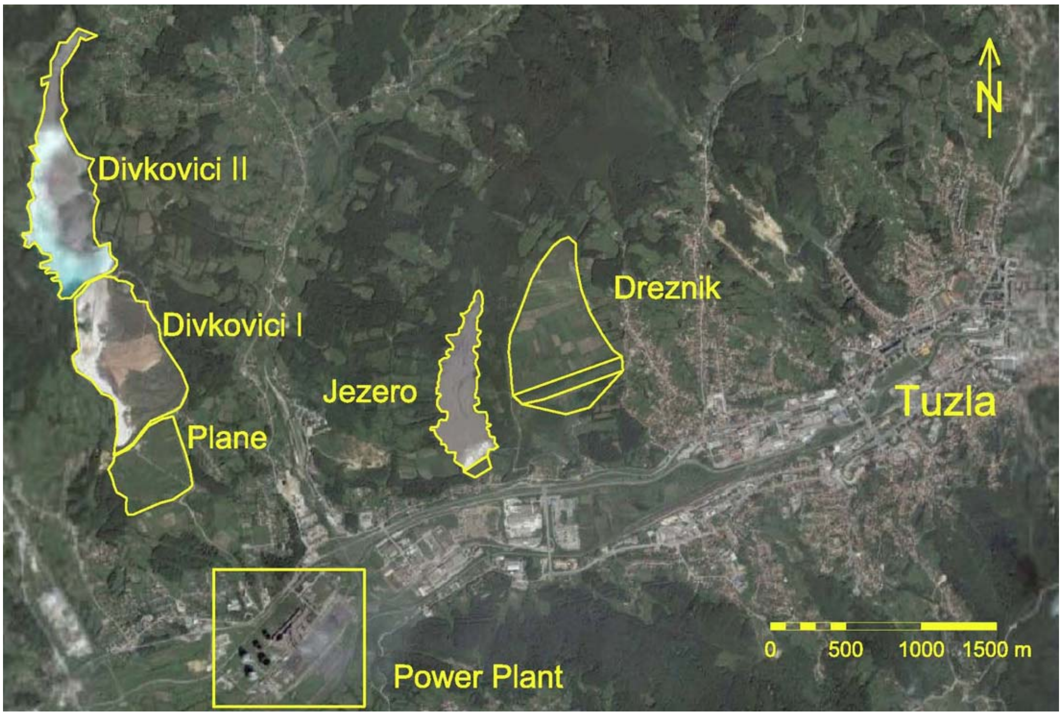


Figure 11. Aerial view of disposal sites and power plant in the vicinity of Tuzla (based on Google Earth 2007)

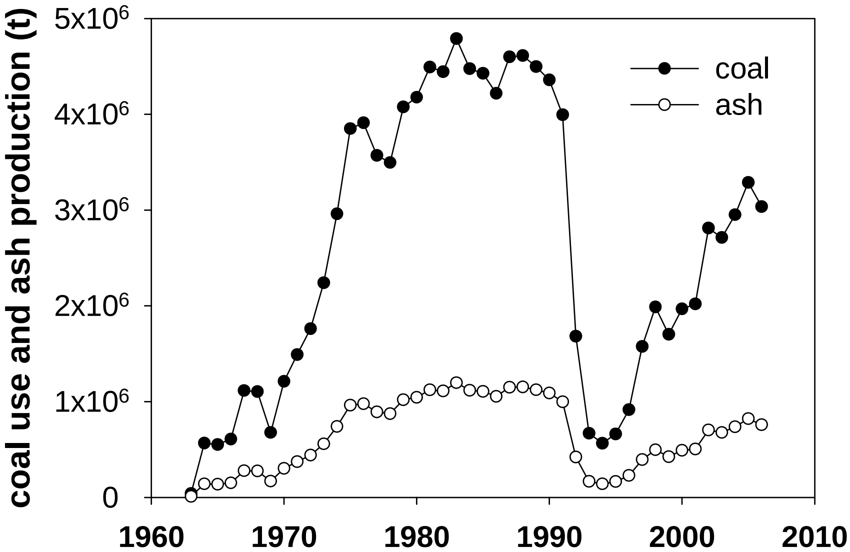


Figure 12. Annual consumption of coal and related ash production by TEP in Tuzla

The transportation of bottom ash from the furnaces to the disposal sites is by hydraulic suspension system mixing water to the solid material in an 11:1 ratio; that consumes 37 m³ per minute of water. The surplus water spills over from the disposal site into the surface waters, particularly the river Jala.

Compared to world-wide mean trace elemental concentrations in coals[23] the coals mined at Banovici and Dubrave are significantly enriched in chromium, nickel and arsenic. Boron occurs within the range of concentrations typically encountered in coals[24]

Table 6. Mean concentrations of trace elements (standard deviation in brackets) in coals mined at Banovici and Dubrave (n=3)

Coal origin	As		B		Cd		Co		Cr		Cs	
	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)
Banovici	29,9	5,5	310	18,3	0,10	22,2	12,7	4,9			3,44	21,6
Dubrave	141	2,1	347	6,6	0,58	2,4	80,4	0,8	1050	0,5	16,6	0,6

	Cu		Fe		Mn		Mo		Ni		P	
	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)
Banovici	25	1,0	15500	3,2	225	13,5	1,11	4,8	291	3,1	130	3,8
Dubrave	197	0,2	93100	0,4	1610	0,1	3,67	0,5	1130	1,0	582	0,2

	Pb		Rb		Tl		U		V		Zn	
	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)	mg/kg	s.d. (%)
Banovici	7,46	36,8	8,82	9,6	0,09	43,9					32,7	29,9
Dubrave	40,2	5,6	75,6	2,6	0,73	6,9	3,53	4,6	272,5	0,2	232	3,1

In general, observed negative environmental impacts of coal ash disposal include the destruction of landscapes and contamination of land and water:[25]

- Changes in the hydrological system, both in terms of redefinition of the underground flows and their chemical composition
  - Pollution of associated surface waters,
  - Potential contamination of underground waters, particularly fresh water springs;
- Air-pollution and deposition of ash particles;
- Introduction of pollutants such as heavy metals into the ecosystems and potential distribution of these pollutants into the food chain.

Figure 13. The recently abandoned CAD site of Jezero (photos: W Fitz)

The disposal of CCRs consumes large areas of land (Table 5), and thus TEP needs to consider whether to (1) extend the capacity of existing sites, (2) identify and secure new sites or (3) find alternative coal ash management solutions that reduce the amount of ash requiring deposition.

Also, large volumes of water are used for the wet disposal process (usually between 0.4 m^3/s and 0.85 m^3/s). The changes to the water routes and flows over time affect the whole local hydrological system. For example, the artificial outflow created together with the changed physical and chemical properties of the outflow water affect the flow and composition of surface waters (here, the river Jala) and groundwater. Also, the large settling ponds cause increased evaporation. RECOAL calculated that about 30% of the water inflow to the disposal site either infiltrates the ground or evaporates. Analyses of samples from the spillover water taken over several years has shown the waters to be highly alkaline (pH around 12) and rich in hydrocarbonates, sulphates, calcium and magnesium. Relatively high concentrations of certain trace elements were also noted, especially boron, chromium and nickel.

The quantity of water used for slag and ash transport, in conditions when the quantity of water inflow at TEP amounts to 0.5 m^3/s (27216 m^3/day) of which 1/3 is reused for slag and ash transport (9072 m^3/day). The remaining amount (18144 m^3/day) is discharged to the Jala River as wastewater. By mixing of slag and water in the ratio of 11:1 and a daily use of 27216 m^3/day about 2474 m^3 of slag and ash is transported per day resulting in average annual amounts to 903.076 m^3/year.

Table 7. Water consumption of TEP.

Water usage (m^3/s)					
TEP's water inflow	Quantity used for transport of slag and ash	Quantity for production of "DEMI" and "DECA" water (evaporation)	Consumption for other technological needs	Undefined losses	Sum of total used quantities
0.500	$0.315 - 0.105_{Rec.} = 0.210$	0.215	0.06	(0,0165) 0.015	0.500
Daily water usage (m^3/day)					
43200	$27216 - 9072_{Rec.} = 18144$	18576	5184	(14256) 1296	43200
Rec. = recirculated amount of water; DEMI = Demineralised water for steam production; DECA = Decarbonised water for cooling					

Source: HEIS (2005) "Water Balance and Pollution Load Balance at Tuzla Thermal Power Plant"

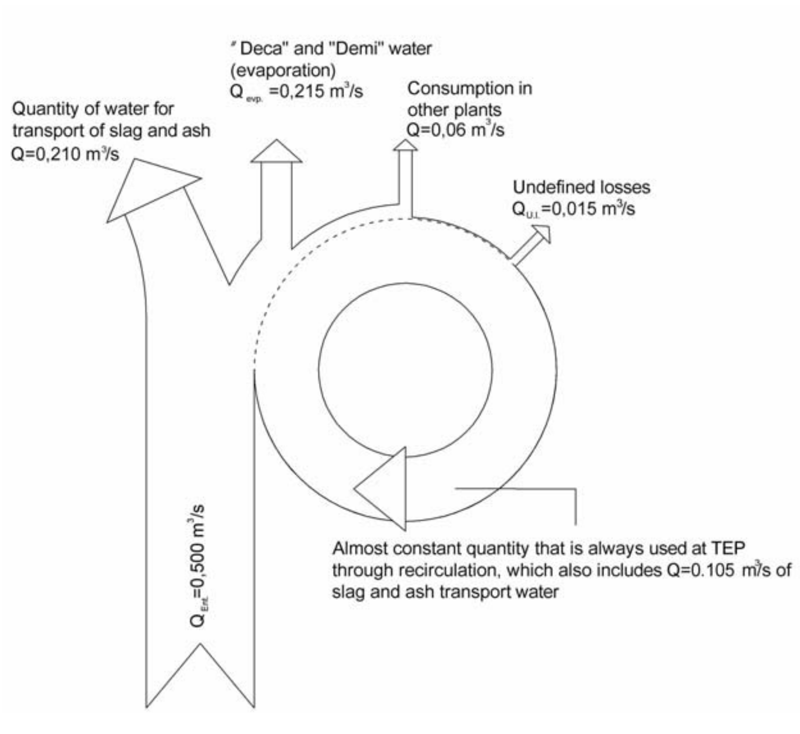


Figure 14. Sankey diagram of TEP's water use balance.

As the coarse ashes and fine particles settle and water drains away and evaporates, ash particulates become airborne. These particulates have a small specific mass and large specific surface (1500 to 3500 cm²/gram) and thus they can be dispersed over several kilometres by the wind. This is particularly severe during the hot summer months, when there is little rainfall and winds are of higher magnitude. Ash particles thus affect the surrounding biosphere and life of local people in the settlements around the disposal sites. To date, there has been little research to evaluate the specific impacts of coal ash disposal around Tuzla. However, its negative impacts are reflected in the discourses of local people about how ash particles damage their properties, crops and home-gardens, and about their reservations over TEP's plans to expand the power plant.

The coal ash disposal sites affect land, air, water, people and animals both directly and indirectly. The ash extents over large areas and has substantially altered what was once good agricultural land or nice countryside. Thus, the CAD sites constitute a significant area of land near settlements that has dramatically reduced land potential over a shorter or longer period of time. Furthermore, the land and transport water become contaminated by various heavy metals and pollutants from the CCRs.

Figure 15. Toxicity symptoms on leaves of Salix growing in pure ash on Divkovici I coal ash disposal site.

5.4. Addressing the concerns and demands of local residents

The RECOAL project followed up on some experiments carried out in the early 1990s, motivated by concerns over coal ash dispersal and the decreasing quality of water resources within the local communities. Our research thus tried to determine the main risks associated with the disposal sites based on concerns identified among the local population. The following section summarises the findings of sociological research (mainly using one-to-one and small group interviews) performed by the RECOAL team among local residents and representatives of local institutions and civil organisations.

5.4.1. Local health and well-being

Several concerns and issues regarding the coal ash disposal sites are expressed verbally by those living in their surroundings. A general preoccupation exists with the safety of the sites and the impacts of coal ash pollution on the population's health and the area's safety. Many interviewees observed respiratory illnesses and neighbours suffering from or dying of cancer. Health conditions are perceived as alarming. Local health practitioners confirm that there is evidence of an elevated percentage of registered cancer and respiratory incidences likely to be linked to the state of the environment. Both citizens and representatives from the health professions voiced concerns over the lack of explicit monitoring of health impacts.

Linked to the observation of many locals suffering from cancer is the fear about the ashes being radioactive. Thus, RECOAL took samples from old and new coal ash disposal sites and had them analysed by an independent company.[26] The analysis performed showed no above normal levels of radioactivity; thus unless the sources of coal change (some coal mines show elevated radioactive levels) or radioactive materials/wastes are added to the furnace, there should be no risk of increased exposure to radioactivity for the local population.

However, RECOAL identified other risks associated with the disposal sites, particularly the high concentrations of Arsenic, Chromium, Boron and Sulphates in the water and the uptake of pollutants by plants on the disposal sites as further discussed in the following section.

Several residents reported environmental incidences of the late 1990s, such as snow turning 'black' and rain leaving a yellowish residue. More generally, many local citizens perceive the coal ash disposal sites and bordering areas as creating a negative image of their communities. As people lose pride in their local environment, some do not hesitate now to discard litter and dump household waste there. A key demand by local residents is thus the enforcement of clear and effective regulation to improve the environment, alongside monitoring impacts on health, improving the local infrastructure (especially water supply), and restoring the coal ash disposal sites for locally beneficial and relevant land use.

Local communities demand an adequate legal framework that stimulates co-operation between industry and (local level) government actors to increase citizens' well-being. One proposition is to use the 'Polluter Pays Principle', as put forward in EU legislation, to make industry pay for the pollution associated with their production processes and waste generated. These payments should then be used for environmental improvements, such as establishing central district heating from TEP's waste heat, maintaining and updating infrastructure, or creating green space. Looking towards Western Europe, local communities would like to see the installation of state-of-the-art technologies that prevent or significantly reduce environmental and human harm. Past investment by TEP in better air filters was able to visibly reduce pollution and thus people are keen to see further investment and appropriate remediation approaches to significantly bring down pollution levels.

5.4.2. Dispersal of coal ash particles

Coal ash dust is associated with human health problems, particularly respiratory infections and negative impacts on plant and animal health. The interviews with local residents illustrated that the dust pervades most aspects of their lives and can make them feel like prisoners in their houses. The dust clouds (Figure 16) reach their peak during the summer. With lack of existing wind barriers and sparse vegetation dust can travel several kilometres before it deposits again.

Permanent vegetation is an effective measure to protect a surface from wind erosion. As ash is particularly prone to wind erosion, establishing a soil cover in the first instance already helps to reduce the problem. For example, Drežnik and Plane disposal sites have had 10-30cm of soil added which helped 'stabilise' the site. The added soil helps retain moisture as well as allows certain plants to root and grow, a process that will take much longer if the coal ash disposal sites are left uncovered.

However, the establishment of a soil cover can in some cases also add problems. In Tuzla, for example, the cover constituted another pathway for pollutants to reach local residents. Firstly, it appears that some of the materials of the soil cover may have been polluted before their application to the coal ash disposal sites; thus, pollution risks actually increased. Secondly, over several years, ploughing and tilling formed part of the agricultural cultivation of the disposal sites at Drežnik and Plane. This meant that ash sediments were mixed with the soil cover and brought back to the surface, thereby increasing the risks of pollutants entering the food chain and ash particles being once more exposed to erosion processes.

Establishing a permanent grass or tree cover is likely to protect the soil well. If agricultural use of a site is considered to be safe, care has to be taken to choose suitable crops that protect the soil from erosion especially outside the growing season. Some of the crops grown on the CAD sites in Tuzla such as spring-sown arable and fodder crops (e.g. corn, potato and fodder beet) have limited early plant mass and leave strips of soil exposed to strong winds during spring. In contrast, high-density winter or spring crops (e.g. wheat, barley, oat, rye or oil seed rape) reduce erosion risks.

The natural site characteristics are another factor controlling wind erosion. For example, the CAD site at Jezero is located in a former dale and has fewer problems compared with the CAD sites Divkovici I and Divkovici II, both located in an open area.

Figure 16. Ash cloud over disposal site Divkovici I. The photo was taken in May 2007 (B. Zarod).

5.4.3. Water supply and quality

Having a safe water supply and maintaining the local infrastructure are important local issues. Interviews showed that local communities perceive their closeness to the coal ash disposal sites as a factor that worsens the state of public infrastructures and water supply. This adds to the general feeling of living in a 'dirty' place, with foul odours and unpleasant sounds. The regeneration of old disposal sites and the establishment of different disposal techniques (switching from wet to dry deposition) may have positive impacts on communities by improving access roads and water availability.

Water deserves special consideration since communities near the disposal sites, and in Tuzla more generally, experienced intermittent supply (at least until January 2007) and poor water quality. Many use public and private water wells, some of which are considered polluted by the coal ash disposal activities and water-soluble or suspended pollutants from the sites

5.4.4. Wastewaters

The RECOAL team analysed water flow and quality in the drainage areas of the CAD sites Divkovici and Drežnik. The results show very high pH values for ash transport water (12), drainage water (10.5 and tube wells (10) and also highly elevated levels of electric conductivity.

Extremely alkaline ash transport water was found to eliminate both benthic and fish fauna[27]. Measurements of pH downstream of the river Jala showed pH values of about 8.5. However, EC values of 4300-7300 mS cm^{-1} up- and downstream of inlets of ash transport water and landfill leachates confirmed that the thermoelectric power plant represents only one of many pollution sources in the region of Tuzla.

The oxygen saturation in the continuously flowing ash transport water was 100% whereas only 3 % were measured for the landfill leachate of Drežnik. The virtual absence of oxygen in the ash body cause so called "reductive conditions" leading to reduction of arsenic form the oxidation state V to III. Notably, AsIII is more toxic and mobile than the AsV-species. As a result significantly enhanced concentrations of Arsenic were found in bore hole water and landfill leachate of the abandoned site Drežnik compared to the ash transport water from Divkovici II. In contrast the opposite was found for Chromium presumably due to initial leaching of CrVI and reduction of Chromium to the more benign CrIII in the ash body of the abandoned site (Figure 18). Therefore it has to be taken into account that the chemical nature of ash bodies changes over time due to natural attenuation processes as well as site specific processes such as the reduction of the redox status. As a result, leaching of potentially toxic elements can be either enhanced ore reduced as it was shown for arsenic and chromium, respectively. Hence monitoring of landfill leachate from abandoned sites is recommended.

The total concentrations of inorganic pollutants in ash transport water and drainage water are within regulatory limits for wastewater and leachate of most EU countries (Table 10). When using the considerably stricter drinking water standards, several elements (As, B, Cr, Ni) exceeded threshold values by ash transport waters and/or and ash landfill leachate, respectively. The pH remains the most problematic parameter with respect to wastewater classification. However, it would be not allowed to release such highly alkaline wastewater in any EU country.

Evaluation of the ashes according to EU waste classification (based on leaching tests) revealed that only Arsenic exceeded the threshold for classification as an inert waste according to EU regulations (Table 8).

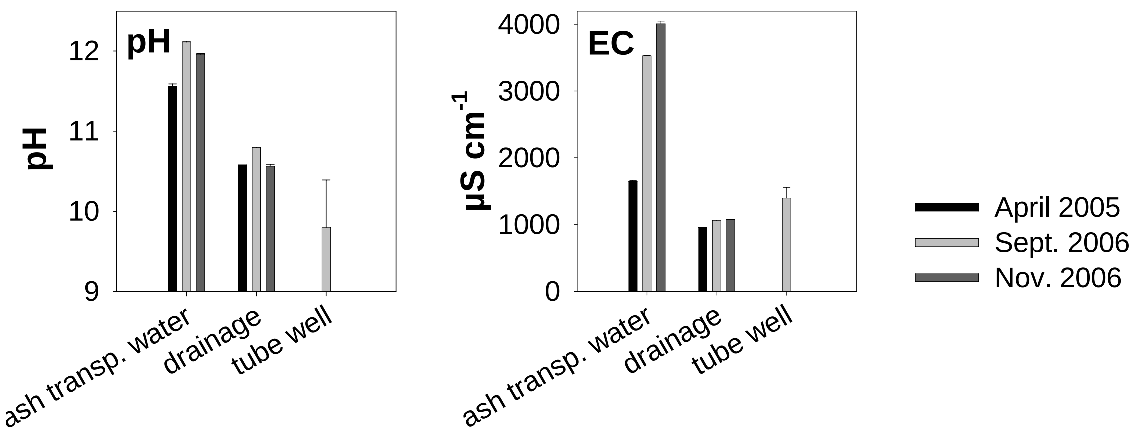


Figure 17. pH, electric conductivity (EC) of ash transport water form the actie site Divkovici and drainage water (landfill leachate) and water from boreholes from the abandoned site Drežnik.

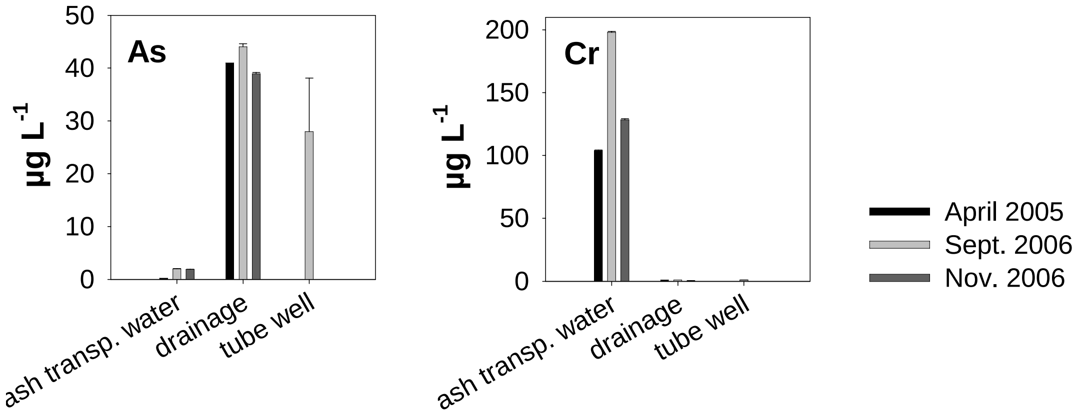


Figure 18. Arsenic and Chromium concentrations in filtered samples of ash transport water from the active site Divkovici and drainage water (landfill leachate) and water from boreholes form the abandoned site Drežnik (Dellantonio et al. 2008).[28]

Table 8. Regulatory limits (drinking water, waste water, leaching limits of waste for landfill) of selected parameters are compared with the mean total concentrations (digested) and filtered (< 0.2 µm) fractions from waste water samples (taken in November 2006) and water extractable fractions of CCR from all sites (standard errors in brackets)

Parameter	Measurements, Tuzla					Thresholds		
	effluents (November 2006)				water extract	drinking water[1]	waste water[2]	leaching limits of inert wastes[3]
	transport water		leachate					
	total	filtered	total	filtered	(1:10)			(1:10 water extract)
	µg l^{-1}				µg kg^{-1}	µg l^{-1}		µg kg^{-1}
As	29 (10)	2 (0.04)	72 (11)	39 (0.5)	680 (100)	10	100	500
Cr, total	264 (17)	128 (1)	< 1	< 1	210 (53)	50	500	500
pH	12 (0.01)		10.6 (0.02)			6.5-9.5	6.5-8.5	-

[1] Council directive 98/83/EG on quality of water intended for human consumption

[2] Thresholds for waste water and landfill leachate for discharge into rivers, Austrian waste water emission directive

[3] Council directive 1999/31/EC on the landfill of waste

5.4.5. Suitable land use

Perceived demand to use the coal ash disposal sites for agriculture significantly influenced RECOAL's research programme. Thus much of the work focused on testing the safety of different food and animal feed crops grown in ash or a mixture of ash and other materials. Local interviews show, however, that the agricultural use of the disposal sites has decreased over recent years, partly due to concerns over the safety of current agricultural practices and pollutants entering the food chain. An improvement in the regional economic situation and employment opportunities could render cultivation of the sites unnecessary. Recommending cultivation on the disused coal ash disposal sites is likely to raise significant local conflicts unless its safety is demonstrated to local citizens who have concerns about the possibility of pollutants migrating into the food chain.

Aside from demands for agricultural land, there is a more general demand for flat areas suitable for creating a healthy environment and expanding the productive area of the city (explained in the current Spatial Plan[29]). Members of the local communities expressed the need for recreational space, particularly green space near their homes for children and young people to use. Some of the interviewees highlighted that whatever is done with the disposal sites public interest should be the priority.

The advantages of establishing green space would be two-fold. First it would help protect the community from industrial pollution by acting as a barrier and/or pollutant adsorbing 'sponge'. Second, having attractive and varied green space would improve the community's self-esteem. The association of trees as being healthy was commonly mentioned by interviewees and contrasted with the 'unhealthy' dirt found at the coal ash disposal sites. Women in particular highlighted the importance of woodland, orchards and parks for their personal or family well-being. Thus the restoration of the CAD sites as open woodland would be welcomed by many within the local communities.

5.5. Experiments on risk reduction and reintegration measures

5.5.1. Establishment of a soil cover

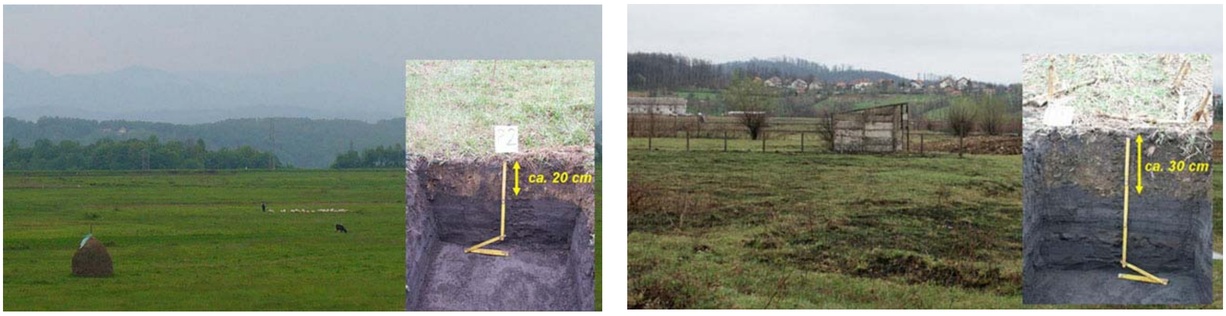
On Drežnik and Plane the soil cover established during the early 1990s successfully prevented coal ash dust from dispersing. However, since then cultivation practices such as tillage and ploughing have undermined the effectiveness of such cover bringing coal ash back to the surface (Figure 20).

The risk associated with this measure is the potential migration of pollutants from the ashes into the soil cover. For example, elevated concentrations of nickel and chromium were found in the soil samples from Drežnik and Plane (Figure 21). However, the large concentrations of Cr and Ni in the cover soils point to a geogenic origin as undisturbed and mixed soil layers showed similar concentrations. Luckily, Cr is very little transferred by plant root uptake into the aerial plant parts and plays in foodstuffs a limited role in human toxically compared to problem elements such as Cd.[30]

Soil is available locally. For instance, soil excavated from an opencast coal mine in Sikulje, about 15 km from Tuzla, was used in RECOAL's field experiments. In choosing a suitable soil cover costs will have to be weighed against the quality of the product. Maintenance of the soil cover may be required depending on the practices developed on it. Applying a soil cover to the other sites and improving the existing cover at Drežnik and Plane may provide the basis for the stabilisation of the CAD sites and their reforestation or cultivation.

Material and transport costs are currently the main barriers impeding the establishment of an appropriate (sufficiently deep) and safe soil cover. Against these costs, it is important to consider the non-quantifiable factors that make this treatment valuable. The soil cover provides the basis for the establishment of a healthy vegetation cover, stabilisation of the sites and prevention of dust dispersion. Adding a soil cover thus provides the basis for any further use of the sites; considering their proximity to populated areas, this could be industrial units, recreational or agricultural use.

In the long-term it is important to consider the potential harmful effects that the soil cover is unable to neutralise. For instance, the soil cover in Drežnik and Plane has not prevented totally[31] the uptake of pollutants by crops and natural vegetation, and may have introduced pollutants into the food chain. Agricultural tilling practices brought the ashes back to the surface again (Figure 21). Hence, clear guidelines for local residents and institutions are needed to advise on the management and maintenance of a safe site cover and the possible land uses that such soil cover may enable (see Section 5.4).
Soils selected for covering ash disposal sites for the purpose of agricultural after use should be of high quality and particularly they should not contain any contaminants with levels exceeding those for agricultural use.



a) Plane b) Drežnik

Figure 19. Disposal sites Plane and Drežnik, appearance and profiles, (Grünewald 2005).

Figure 20 Coal ash brought up due to ploughing (photo: M Markovic, I Kisić).

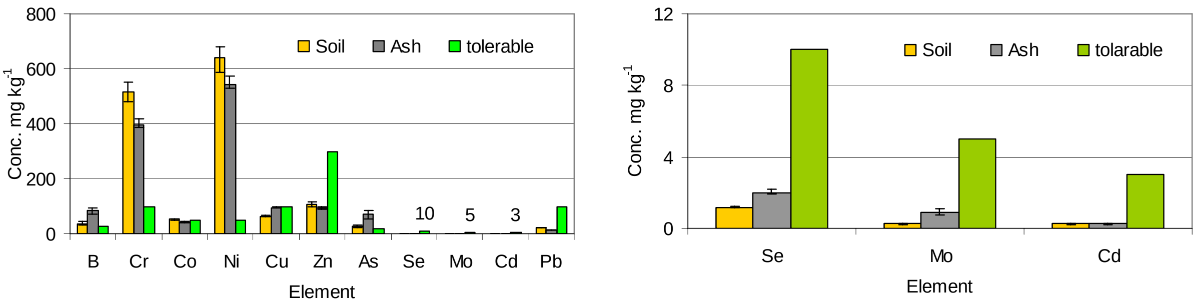
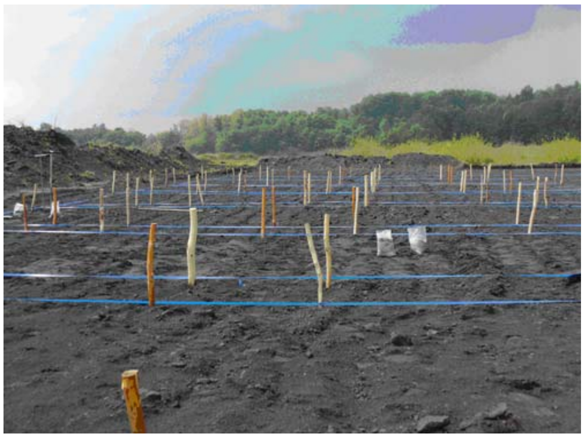


Figure 21.Overview of concentrations of certain pollutants in the soil cover (Source: RECOAL field study on Drežnik); tolerable: levels for agricultural soils (Blume et al. 2004).

5.5.2. Ash amendment

RECOAL assessed the applicability of compost, produced from locally available municipal and industrial organic residues as an amendment to ash to improve substrate fertility. The purpose of this treatment is to establish a vegetation cover on barren CAD sites and prevent dust erosion. This remediation technology is likely to be easily applicable and have lower costs than other alternatives.

a) Compost production on-site (Babic 2006)



b) Establishment of test pots (Repmann 2006)

c) The various individual plots of field experimental site Divkovici I in May 2007 (Repmann 2007)

Figure 22. Field experimental site Divkovici I.

The compost consisted of sawdust and sewage sludge from nearby sources[32] (Figure 22a) and was tested in a field experiment in Divkovici I. Additional experiments were carried out in greenhouses (Figure 23).

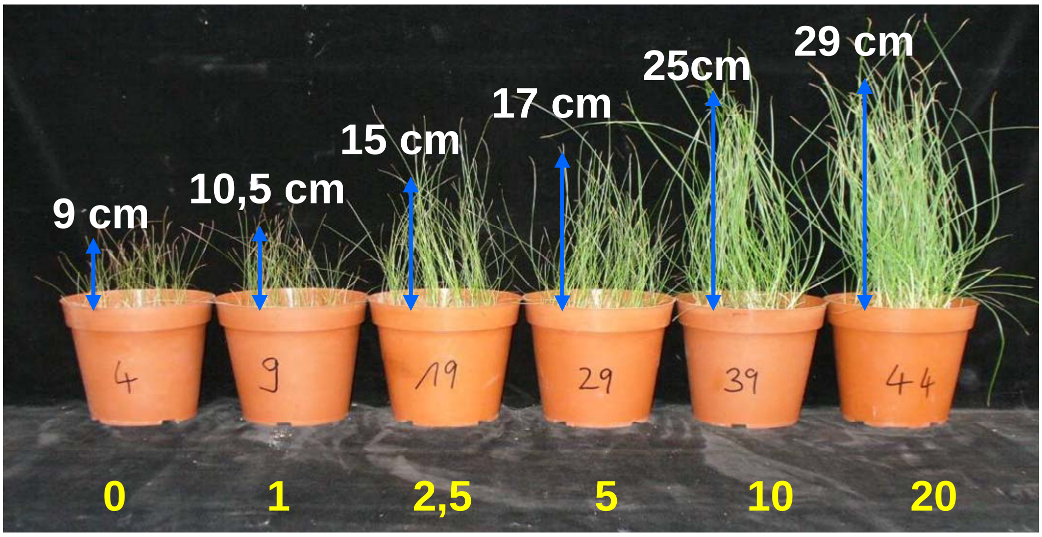


Figure 23. Performance of grass (red fescue) grown in various compost treatments (greenhouse BTUC) ranging from 0 to 20 L m^{-2}, (Repmann 2006).

The experiments evaluated the application of different amounts of compost per square metre (rates ranging from 1 L/m^2 to 20 L/m^2) and the growth of grass on these substrates. These experiments demonstrated that the compost applications up to a depth of 20 cm improve the growth and cover in the crops tested. Figure 24 shows the performance of a specific grass mixture – containing mainly red fescue (*Festuca rubra*) and sheeps fescue (*Festuca ovina*) – grown on different treatments (from no application of compost to the maximum application).

Plot 7: Control plot - no treatment

Plot 2: 1 litre of compost added per m^2

Plot 11: 10 litres of compost added per m^2

Plot 49: 20 litres of compost added per m^2

Figure 24 Growth of grass in various treatments on RECOAL's experimental site at Divkovici I; (Repmann 2007)

The application of compost not only sustained the growth of grass but also increased the production of biomass (Figure 25) and the coverage of the land (Figure 26). Accordingly, the application of 10 to 20 L/m^2 is likely to be sufficient to achieve enough grass coverage to prevent ash erosion.

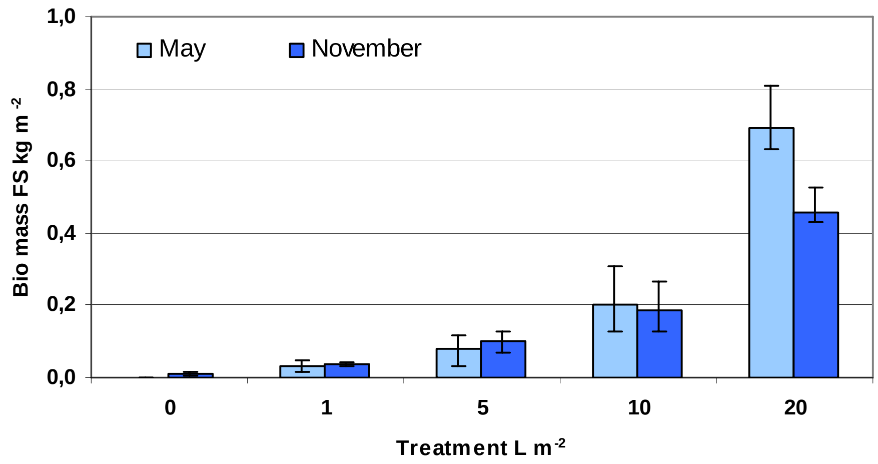


Figure 25. Biomass production for all tested treatments on experimental site Divkovici I.

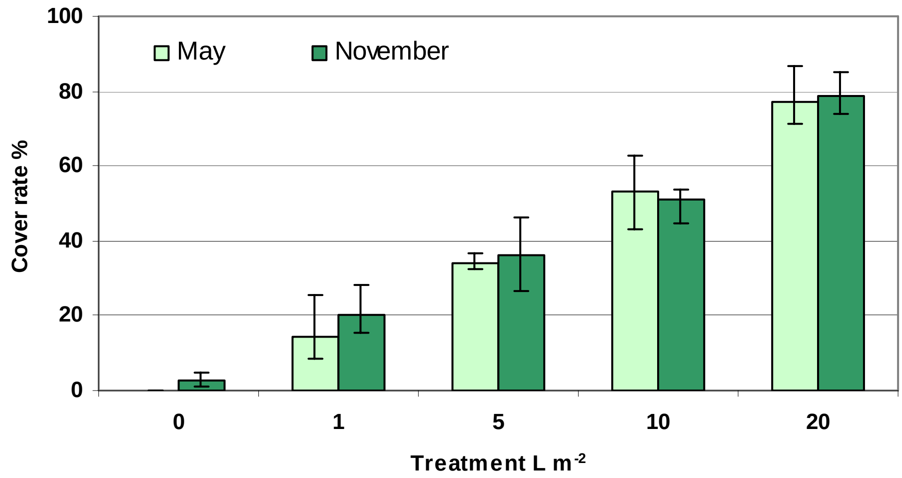


Figure 26. Percentage of plant cover achieved for all tested treatments on experimental site Divkovici I.

In addition, the compost improved the fertility of the ash substrates with respect to N, P and K and the microbial activity[33] in the amended ashes. However, although the pollutant uptake by plants in treated ashes was reduced when compared with untreated ashes, some of the pollutants were present in the grass grown on the amended ashes in concentrations above those considered normal. Hence, the grass grown on the ashes would not be considered suitable for fodder, and such use be discouraged to minimise the risk of transfer into the food chain particularly with respect to direct ash intake (ingestion) during grazing.

Material costs for applying an amendment may be considerably lower than that of adding good quality soil. If no sources are located nearby, then transport costs drive the costs of any of the applications. In the RECOAL field experiments, the amendment was more economical than the soil application. However, the amendment does not support the same range of vegetation covers as soil, and in fact was only deemed suitable for grasses. Thus, amendment application may not meet local expectations in terms of the remediation results, especially the landscape characteristics, benefits and safety of use that a good quality and deep soil cover could bring.

5.5.3. Cultivar alternatives

The current cultivation of plots on Drežnik and Plane disposal sites motivated the project to evaluate the performance of several commonly used cultivar varieties in terms of their productivity and potential contamination. The evaluation included the following crops: Corn, Potato, Wheat, Barley, Alfalfa and Red Clover. Each crop and cultivar tends to respond to pollution differently, tolerating and taking up different amounts and kinds of pollutants present in the air, growing substrate and water.

Greenhouse studies were set up in order to determine the metal uptake in locally grown crops and to check the performance of different varieties of a crop. The pot experiments used three different cultivars of barley, lucerne and bean grown on pure ash taken from Jezero. Seventeen elements were tested such as copper, cadmium, cobalt, chromium, nickel, arsenic and boron. Some of these elements were above the range of normal background values according to the literature (Table 9).

Table 9. Summary of greenhouse study results for metal uptake in locally grown crops

Analysis of:	Elements above average:
Pure ash (Jezero)	As, B, Cr, Cu, Ni
Bean	As, B, Cr, Cs, Se, Mo, Ni, Pb, Co, Cu
Lucerne	As, B, Cr, Cs, Se, Mo, Ni
Barley	As, B, Cr, Cs, Se

Our analysis of the data revealed differences in the pollutant uptake between different crops and cultivars. Beans were most affected, whereas barley varieties appeared to be more tolerant to pollution. According to these results, the most recommended crop on the CAD sites is barley, cultivar Tvrtko, which appears to be the least likely to take up metals from the ash. Other cultivars of barley (Knin and Tomislav), lucerne (different Mirna cultivars) and bean take up more pollutants. The results confirm the well-known observation that grassy species (Monocots, graminaceous plants) are known to tolerate higher metal levels in soil and take up less amounts of disadvantageous trace elements than herbal plants (Dicots).

In another experiment, winter barley and soybean were grown in soil ash substrates in different proportion, imitating the natural conditions of cultivation on Plane and

Drežnik. At the date of writing the experiment has not been finalised, but preliminary results indicate that the addition of good quality uncontaminated soil to the ashes improves considerably the safety of crops. However, the addition of soil was not enough to prevent the pollutant uptake - particularly in barley - despite the improvement in the growing conditions.

Field experiments were established in Drežnik and Divkovici to evaluate the safety of CAD sites cultivation in real conditions. In Drežnik, the safety of five different crops (potato *(Solanum tuberosum)*, bean *(Fasoelus vulgaris)*, corn *(Zea mays)*, barley *(Hordeum sativum)* and lucerne - alfalfa *(Medicago sativa)* were grown on a soil cover and monitored on a daily basis. Results suggest that Boron and Arsenic, and in some cases cadmium, pose safety risks for the cultivation of edible crops on the CAD sites. In Divkovici, cultivation took place directly on the ashes after the addition of an amendment.

The economic analysis showed that agricultural crops such as winter wheat, barley and oat were not profitable but could form part of subsistence farming. The establishment of pastures on the other hand could be economically viable but the grass/feed would need to be checked for its pollutant levels (initial results indicate a high risk of contamination). Applying good quality unpolluted soil and compost to the site may reduce the risk of contamination from the ash deposits. In addition, grassland could be established quickly to stabilise the soil cover and also improve the landscape characteristics.

5.5.4. Crop rotation systems

Some locals cultivate small plots in parts of the older coal ash disposal sites using small tractors for soil tillage and ploughing. The flatness of the land facilitates the access of the machinery. However, tillage and ploughing has resulted in the rupture of the soil cover, and as a result the coal ash starts to accumulate on the surface, so that the dust dispersion problem re-emerges.

Building on existing local knowledge, RECOAL scientists put their emphasis on identifying appropriate cultivation systems. Two key points will contribute to safe cultivation:

- Prevent tillage on the disposal sites.
- Ensure that the surface is covered during the warm period of the year, thus preventing dust dispersion.

Only crops that do not require tillage are recommended. For example, two rotation alternatives that could be employed, from spring to winter, are:

1. Alfalfa – Alfalfa – Alfalfa – Winter wheat
2. Red Clover – Red Clover – Winter Barley – Oat (which requires the Oat to be planted with the Red Clover in spring).

According to the observations made during RECOAL's research the introduction of these methods would not only improve the safety of cultivation practices but also improve the environmental conditions for the local population. Based on existing research results, RECOAL would not recommend the cultivation of more labour-intensive crops such as corn or potato, due to the working/disturbing of the soil, the amount of exposed soil, and the crops/cultivars' uptake of pollutants. Focusing on grassland may also help resolve the conflict of opinions and interests between those who cultivate the sites and those who consider that farming the sites is endangering the whole community.

5.6. Wind barriers and landscape measures

Wind barriers are an effective method to prevent the dispersion of dust from the disposal sites. According to interviews, carried out with stakeholders and local residents as part of the RECOAL project, the presence of hedges and wooded landscapes also would have high acceptance among local residents and citizens from Tuzla. The dominant species of trees growing in the areas surrounding the disposal sites are Willows, Poplars, Maple, Beech, Alder, Hazel, Hornbeam, Elder, Ash and Horse Chestnut. Using native species in shelterbelts would help establish a stable wind barrier (species are used to local biotic and abiotic conditions) and preserve/improve local ecosystems. Attending to their landscape characteristics, RECOAL recommends the use of Poplar *(Populus alba)* and Hazel *(Corylus Avellana)*. Poplar trees are fast growing, reaching up to 25m of height in a relatively short time. Hazel may complement the barrier created by the poplar by occupying the space near the surface where the Poplar crown narrows. Robinia was also found to grow well and may be a suitable species. Figure 27 Example of a design for a tree belt offers a proposal for the design of a Poplar-Hazel wind barrier.

Reforestation of the disposal sites would be an initially costly but potentially highly effective and multi-purpose solution for the long term benefiting local residents and ecosystems. For instance, the reforestation with poplar may bring additional benefits such as timber and firewood production. Woodland (including areas of grassland) and tree belts can create a dramatic improvement in the landscape, not only through stopping dust dispersal but also through offering an attractive and healthy land use. All the different uses associated with shelterbelts and woodland (timber and firewood production, recreation, habitat creation) could enhance the relationship of local residents with the place.

Poplar trees will be planted in four rows. The rows should be perpendicular to the dominant wind direction1. The distance between each row and between trees should be six metres. Every second line will be shifted three metres, so that the trees stand in triangles, providing a better coverage. Hazel will be planted on the wind coming side, in two rows, also shifted and separated by 6 metres. This amounts to 277 trees/ha, two thirds Poplar and one third Hazel. The estimated cost of such a tree belt is 3000 €/ha. A belt as the one described above, once the Poplar trees have reached at least 20 metres, will provide coverage to a protected area of 450 metres. The following figure shows the distribution of trees of the wind belt.

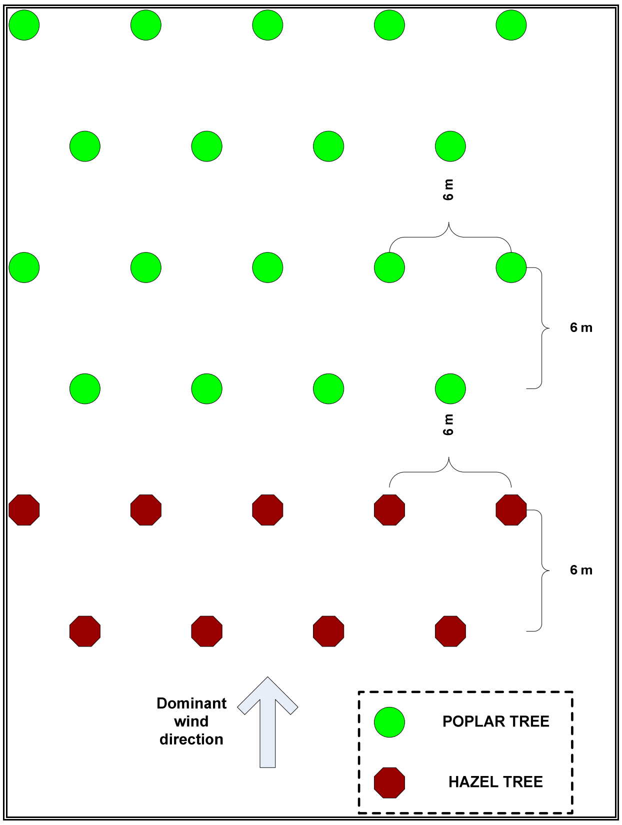


Figure 27 Example of a design for a tree belt

5.6.1. Installation of water-aeration steps

Aeration of alkaline wastewater for passive remediation was previously suggested by geoscientists from Newcastle University[34]. The process causes an increase in the carbon-dioxide saturation (production of H_2CO_3 acid) which neutralises the highly alkaline effluents.

First, the efficacy of carbon-dioxide to reduce wastewater pH was tested in a laboratory scale experiment with a pump system. The pH could be effectively reduced form 11 to 8.5.

Under field conditions six sequentially arranged aeration steps installed at Drežnik caused the pH to decrease by about 0.3 pH units. Hence, a larger number of aeration steps is required to further reduce the pH of alkaline landfill leachate to the required pH level of 8.5 to meet wastewater regulation standards.

5.6.2. Filter materials for filterbed systems and constructed wet lands

Filter materials have been tested on bench and field scales. Selected materials may be used in column or bed-like filter systems. Appropriate locally available materials are generally preferred (savings from reduced transport costs).

At Drežnik a column system was installed to test different sorbents' capability and capacity to retain pollutants. We noted that locally available brant (red shist) was able to reduce the pH and was effective in reducing Arsenic but was not able to filter out Boron. The use of bauxite, on the other hand, reduced the pH value and toxicity, and also reduced effectively both arsenic and boron content to drinking water standards. Attention needs to be paid to testing the ability of sorbent materials to respond to the changes of pH in the effluent (i.e. whether they remain effective at improving water quality when pH levels change).

5.6.3. Passive treatment of alkaline waste in a constructed wetland

Constructed wet lands have been designed to purify waste waters with large nutrient and organic loads by microbial decomposition. Similar treatment systems were also applied to remediate acid mine drainage in the UK. The wetland acts as a buffer to increase pH to normal ranges.

However, it has been recently shown that passive remediation systems have also the ability to treat near-neutral and moderately contaminated leachates from CCR disposal sites.[35] Moreover, natural wetland ecosystems effectively buffer highly alkaline waste waters.[36]

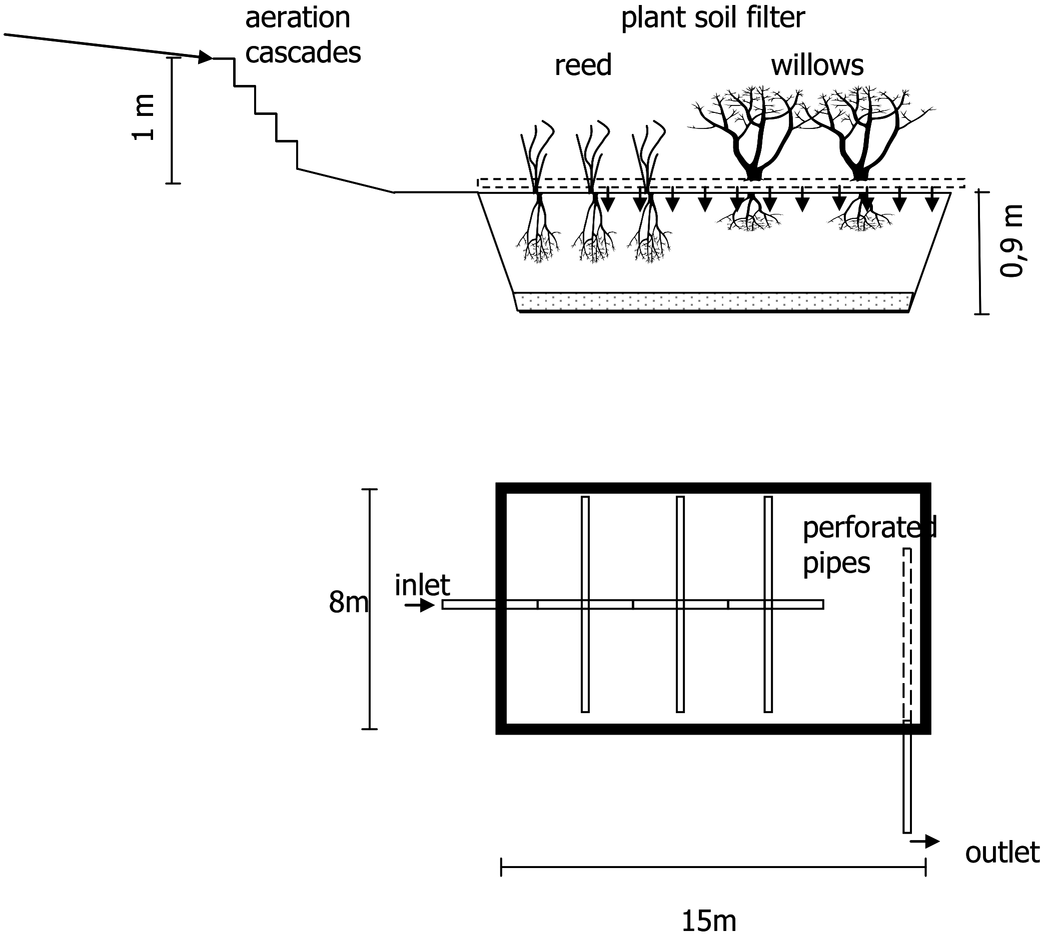


Figure 28. Scheme of the constructed wet land installed at Drežnik

RECOAL designed and tested a soil-vegetation system to retain dissolved and particle-bound pollutants as well as to buffer pH from CAD leacheate from Drežnik. This 'passive' system seems particularly appropriate when the pollution is moderate. There are different types of constructed wetlands; for instance, they can be designed as either having a vertical or lateral wastewater flow. To define the technical design criteria it is convenient to follow the established literature and national norms.[37]

The passive treatment tested by RECOAL was a vertical system with a 30 cm thick soil layer on top and a layer of coarse gravel below to assure effective water drainage. The soil-filter layer supported plant growth (willows and reed) which reduced the wastewater stream through evapotranspiration. Appropriate soil material filters dissolved pollutants, particles (including adsorbed and occluded pollutants) and reduced the alkaline pH by buffer reactions. The system has to be maintained in well-aerated condition as complete water logging leads to a consumption of the oxygen by microbial activities. This triggers undesired chemical processes such as dissolution of pollutant-adsorbing iron-oxides, and reduction of AsV to the more toxic and mobile AsIII species.

The system was irrigated with the CAD wastewater using an agricultural drip irrigation system; this proved to be problematic if the drip-holes were small because of the risk of clogging with particles. Therefore, alternative systems should be tested.

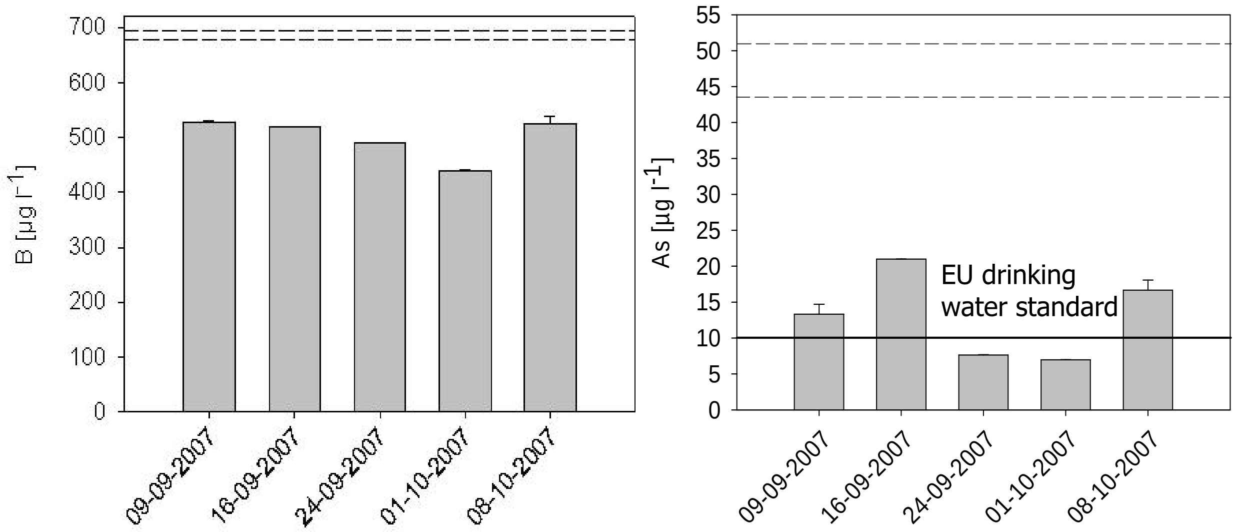


Figure 29. Boron and Arsenic concentrations at the system inlet (dashed lines) and after passive treatment in a constructed wetland at different sampling dates (bars). pH (not shown) decreased from 10.5 to 8.5.

5.7. Conclusions on the Tuzla case study

Energy production from coal produces large amounts of coal ash that needs to be land-filled if it cannot be used as a raw material for other industrial processes or products. In the case of Tuzla's large power plant (TEP) and associated CAD sites, significant environmental and social impacts are felt in the locality. RECOAL has contributed data and knowledge to highlight certain risks and aspects of the CAD sites and scoped possible low-cost management solutions. Other aspects, such as health impacts and effects on the local biota, and ecosystems more generally, remain less well researched and understood.

Concerns and demands from local citizens relate to the variety of pollution impacts of the thermo-electric power plant and the (perceived lack of) decision-making on long-term sustainable remediation solutions and pollution abatement systems. Specifically, dust dispersion is a highly visible factor that not only appears to impacts on residents' health but also affects and alters daily life and has led to a perception of living in a 'second-rate' environment.

While water supply appears to have improved in recent months, there are still serious concerns over the wastewater quality. RECOAL's research confirmed the very high alkalinity of water (pH values range from 10-12, especially for the ash transport water and CAD discharge) and increased electric conductivity which affects the solubility and reaction potential of pollutants present in the coal ash. While many microelements and heavy metals were found to be below regulatory threshold values (i.e. present at 'normal' concentrations), several pollutants (Arsenic, Boron, Chromium and in some cases Cadmium) were in some instances elevated or even above regulatory threshold levels. Analysis of radioactivity levels of the coal ash deposits showed that levels were within normal background radiation.

The RECOAL project explored and analysed locally available and affordable options for treating coal ash transport water and landfill leachate. The focus was on reducing the pH and reduction of Arsenic and Boron by using locally available and cheap treatment methods. We scoped a step-aeration system in combination with different types of sorbent materials of which the locally available red schist ('brant') and bauxite from a more distant location showed promising results for pH reduction and retention of some problem elements. Brant is a cheaper option than bauxite but is less effective in reducing Boron, and also significantly increased Chromium levels. Field tests with a column filtering system showed that pollutant levels could be reduced by 50+ percent and thus that a filtering system can provide an effective water treatment option.

In terms of land use, tests on soils and different land cover options showed that agricultural and pastoral use of the CAD sites, at least in the first 20 or so years could pose significant risks to transferring pollutants into the human food chain. Longer-term tests and different combinations of amendments and a reasonable depth of good quality topsoil are required if such use was deemed highly desirable. Tentatively, we recommend the use of crops that provide thick coverage and do not require tilling or deep ploughing. Alternatively, applying ash amendments (unpolluted organic materials) can help establish a vegetation cover very quickly to prevent the dispersion of coal ash dust. Green space, and especially some tree cover was identified as a highly desirable land use amongst locals and could provide multiple benefits (e.g. amenity, recreational space, wood fuel, building materials, wind break).

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