European Commission

JRC SCIENCE FOR POLICY REPORT

Collection of available techniques for the prevention or reduction of environmental impacts in non-energy extractive industries (NEEI)

Garbarino, E.
Orveillon, G.
Hamor, T.
Saveyn, H.G.M.
Eder, P.

September 2021

Joint Research Centre

EUR 30827 EN

Contact information
Name: European Commission – Joint Research Centre, Growth & Innovation, Circular Economy & Industrial Leadership
Address: Edificio EXPO, Calle Inca Garcilaso 3, 41092 Seville, Spain
Email: JRC-ENV-RESEARCH@ec.europa.eu

EU Science Hub
https://ec.europa.eu/jrc

JRC125247

EUR 30827 EN

PDF ISBN 978-92-76-41493-3 ISSN 1831-9424 doi:10.2760/622092

Luxembourg: Publications Office of the European Union, 2021

How to cite this report: Garbarino, E., Orveillon, G., Hamor, T., Saveyn, H.G.M., Eder, P., *Collection of available techniques for the prevention or reduction of environmental impacts in non-energy extractive industries (NEEI)*, EUR 30827 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-41493-3, doi:10.2760/622092, JRC125247.

Contents

Abstract

The European Green Deal and its environmental, climate, circular economy and industrial policy actions commit to twin green and digital transitions and to move towards zero pollution for air, soil and water. Achieving these objectives requires access to sustainable raw materials. The objective of the study presented here was to investigate which information already exists in the public domain regarding techniques that could possibly contribute to preventing or reducing the impact on the environment from non-energy extractive activities.

The study starts by analysing the Key Environmental Issues, i.e. the areas where the largest environmental impacts could be expected for the various extractive sub-sectors as a whole in the EU. The report then presents a review of 430 literature references that were used to identify 149 Prevention or Reduction Techniques (PRT) which are currently being applied in the non-energy extractive industries to address these Key Environmental Issues.

This in-depth overview of PRT can be used as an interactive screening toolkit, with PRT identified for the main Key Environmental Issues. However, not all PRT apply to all extractive sub-sectors, types of mineral resources, and extractive operations. Hence, it must be stressed that the application of PRT is very much dependent on site-specific conditions.

In order to maximise the usability of the collected data, additional detailed information is needed with particular reference to PRT relevance for mineral resources and extractive activities and applicability conditions. Furthermore, during the study, the importance of applying a risk-specific approach emerged, particularly in the evaluation of the site- or operation-specific applicability.

Disclaimer

It is to be noted that this study is an exploratory mapping of existing information and it is not a development of a Best Available Techniques (BAT) Reference Document (BREF) or any chapter of a BREF.

The exercise consisted of collecting information on techniques and assigning them into categories, without an assessment of their contribution to the prevention or reduction of negative impacts on the environment from non-energy extractive activities.

Acknowledgements

The authors wish to acknowledge the support of Maria Nyberg, Gerardo Herrera, Debby De Roover, Milan Grohol and Peter Handley of the European Commission, DG GROW, Christian Wimmer, DG ENV, and Rodrigo Chanes Vicente (Ministry of Spain, former seconded national expert in DG GROW).

The authors are grateful to the experts, authorities and organisations that participated in the data collection and actively contributed to the study.
The authors would like to thank the 16 Member States, the NGO, the 5 other institutions and experts, and the 7 industry organisations below that participated actively in this Science for Policy research study, providing very useful data, information and comments during the data and information collection exercise, the webinar and the written consultation.

Member States:
Austria
Belgium
Cyprus
Czech Republic
Denmark
Estonia
Finland
France (BRGM)
Germany
Greece
Hungary
Ireland
Portugal
Slovenia
Spain (Ministry and IGME)
Sweden

Industry associations:
Cembureau
Eurogypsum
Euromines
Euroroc
Federation de Aridos
FinnMin (Finnish mining association)
UEPG

NGOs:
London Mining Network

Other institutions/experts:
Cobalt Institute
European Copper Institute
North Macedonia
Mike Cambridge
OECD

Finally, the authors acknowledge the valuable support of its contractor Wood EI&S GmbH, and in particular of Toon Smets, Keir McAndrew and their whole mining expert team.

Executive summary

The European Green Deal[1] aims at achieving a sustainable EU economy. This is the core of the EU's environmental, climate and industrial policy, setting out the target of climate-neutrality in 2050, zero pollution, and increasing the CO_2 reduction targets to 55% by 2030. Achieving the Green Deal objectives requires access to sustainable raw materials, in particular Critical Raw Materials (CRM) necessary for clean technologies, digital, space and defence applications, by diversifying supply from both primary and secondary sources.

An important part of the Action Plan on CRM[2] (2020) relates to strengthening the sustainable and responsible domestic sourcing and processing of raw materials in the European Union taking into account that non-energy extractive industries (NEEI) sites, if not properly designed and managed, may have significant environmental impacts. Effects depend, inter alia, on the type of mineral, extraction methodology, substances used in mineral treatment, extractive waste characteristics, site-specific environmental conditions and the way extractive waste is managed.

It is against this background that this study investigates which information already exists in the public domain regarding techniques that could possibly contribute to preventing or reducing the impact on the environment from extractive activities in the non-energy extractive industries (NEEI). The project was part of an action on the "Implementation of framework conditions for non-energy minerals", that the Joint Research Centre (JRC) is carrying out in collaboration with DG GROW for the project "RM-EIP II – Support for raw materials policy", within the context of the European Innovation Partnership (EIP) on Raw Materials (RM) and the related Strategic Implementation Plan.

The study starts by identifying the Key Environmental Issues (KEI), i.e. the areas where the largest environmental impacts could be expected in the NEEI. Using expert judgement, a scoring exercise considered the aggregated environmental impacts per extractive sub-sector in Europe as a whole.
The report then presents a review of 430 literature references, of which 59% were gathered from Member State authorities, industry associations, environmental NGOs and other relevant stakeholders via a data and information collection exercise and 41% were collected by means of a complementary literature search. These references are used to extract 2634 techniques for preventing or reducing negative impacts in NEEI. Out of this long list of techniques, 1633 techniques have been retained and grouped to derive 149 Prevention or Reduction Techniques (PRT) that are currently being applied to address the KEI, in particular those KEI with high and medium scores.

This in-depth overview of the currently available techniques for the prevention or reduction of environmental impacts in the non-energy extractive industry can be used as an interactive screening toolkit, with PRT identified for the main KEI. Nonetheless, not all PRT apply to all extractive sub-sectors, types of mineral resources, and extractive operations. Hence, it must be stressed that the application of PRT is very much dependent on site-specific conditions. However, this study is an exploratory mapping of existing information and it is not a development of a Best Available Techniques (BAT) Reference Document (BREF) or any chapter of a BREF. The reported techniques have been collected and assigned into categories, without an evaluation of their actual contribution to the prevention or reduction of negative impacts on the environment.

In order to maximise the usability of the collected data, further information would be needed regarding PRT relevance for mineral resources and extractive activities, as well as applicability conditions. For this purpose, quantitative information on environmental performance and operational data from sites where the PRT are in use would need to be collected from EU mining operators.

Furthermore, during the study, the importance of applying a risk-specific approach emerged, particularly in the evaluation of the site/operation specific applicability. This includes considering sectoral, geographic and climatic variations or site-specific conditions (e.g. the geological characteristics of the deposit).

A summary overview of the KEI, and the PRT identified to address them, is provided in Table A. The Table contains the following columns:

- KEI: a description of the Key Environmental Issue;
- PRT group: an umbrella name for one or a group of related Prevention or Reduction Techniques;

(1) COM(2019) 640 - https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf
(2) COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability

- PRT No.: the identification number of a certain Prevention or Reduction Technique;
- PRT Title: the descriptive title of a Prevention or Reduction Technique;
- Cross-reference: indicates the number of another Prevention or Reduction Technique that contains common elements with, or is identical to, the described PRT, but falls under a different PRT group and/or addresses different KEI.

Table A. Overview of the Key Environmental Issues (KEI) in non-energy extractive industries and Prevention or Reduction Techniques (PRT) to address them, identified in this study

KEI	PRT group	PRT No.	PRT title	Cross-reference (secondary KEI)
Generic PRT				
All KEI	Corporate management	PRT001	Organisational and Corporate Management System	
		PRT002	Environmental Management System	
	Information and data management	PRT003	Extractive site characterisation (incl. baseline study)	
		PRT004	Extractive activities options	
		PRT005	Environmental Impact Assessment	
		PRT006	Public and community engagement	
		PRT007	Environmental monitoring programmes	
Risk-specific PRT to ensure **SAFETY (STABILITY)**				
Structural stability, and related adaptation to climate change	Design for closure	PRT008	Design for closure	
	Additional Organisational and Corporate Management tools	PRT009	Additional Organisational and Corporate Management tools	
	Ground investigation	PRT010	Ground investigation	
	Selection of extraction methods	PRT011	Selection of extraction methods to ensure structural stability, and related adaptation to climate change, in the long term	
	Developing blasting schedules	*PRT012*	*Developing blasting schedules*	*PRT107*
	Water management	PRT013	Water management	
		PRT014	Drainage systems	
	Geotechnical analysis and monitoring	PRT015	Geotechnical analysis	
		PRT016	Geotechnical monitoring	
		PRT017	Geotechnical conformance checks and audits	
Physical stability	Backfill stabilisation techniques	PRT018	Stabilisation of the backfill material	
	Backfilling	PRT019	Backfilling	
Chemical stability	Prevention or minimisation of pollutant leaching	PRT020	Automatic cyanide control	
		PRT021	Reduction of cyanide use	
		PRT022	Pre-aeration of the ore	
		PRT023	Monitoring cyanide concentrations	
	Prevention or minimisation of Acid Mine (or Rock) Drainage (AMD/ARD)	PRT024	AMD/ARD management strategy	
		PRT025	Conceptual site model of AMD processes	
		PRT026	Desulphurisation/sulphuric acid onsite production	
		PRT027	*Progressive rehabilitation*	*PRT043*
		PRT028	*Permanent dry covers*	*PRT045*
		PRT029	*Permanent free water and wet covers*	*PRT046*
Stability	Monitoring of physical and chemical stability	PRT030	Monitoring of physical and chemical stability	
Risk-specific PRT for the prevention or minimisation of **EMISSIONS TO SOIL AND GROUNDWATER**				
Diffused and channelled emissions to soil and groundwater	Soil management	PRT031	Soil management	
	Explosives management	PRT032	Nitrogen and explosives management	
	Basal structures and physical barriers	PRT033	Impermeable natural soil basal structure	
		PRT034	Impermeable artificial basal structure	
		PRT035	Secondary containment	
	Water management	*PRT036*	*Water management*	*PRT013*
		PRT037	*Hydrologic control*	*PRT061 (part of it)*
		PRT038	*Recycling of water*	*PRT060*
		PRT039	*Diversion of water run-off systems*	*PRT062 (part of it)*
		PRT040	*Drainage systems*	*PRT014*
		PRT041	*Landscaping and geomorphic reclamation*	*PRT119*
		PRT042	*Water treatment techniques*	*PRT063, 078*
	Covering	PRT043	Progressive rehabilitation	
		PRT044	Revegetation	
		PRT045	Permanent dry covers	
		PRT046	Permanent free water and wet covers	
	Heap bioleaching	PRT047	Heap bioleaching	

	Groundwater and soil pollution remediation	PRT048	Remediation of contaminated soil - Permeable Reactive Barriers (PRBs)	
		PRT049	Remediation of contaminated soil - phytoremediation	
		PRT050	Remediation of contaminated soil - stabilisation	
		PRT051	Remediation of contaminated soil - encapsulation	
		PRT052	Remediation of contaminated soil - soil washing	
		PRT053	Remediation of contaminated soil - thermal desorption	
		PRT054	Remediation of contaminated soil - (bio)venting	
		PRT055	Remediation of contaminated soil - natural attenuation or in-situ bioremediation	
		PRT056	Remediation of contaminated soil - composting	
	Monitoring of emissions to soil and groundwater	PRT057	Monitoring of emissions to soil and groundwater	
		PRT058	Leakage detection systems	
Risk-specific PRT for the prevention or minimisation of **EMISSIONS TO SURFACE WATER**				
Extractive Influenced Water (EIW) generation	EIW generation prevention or minimisation	*PRT059*	*Water management*	*PRT013*
		PRT060	Re-use or recycle the excess water	
		PRT061	Erosion and sediment control	
		PRT062	Stormwater management	
Suspended particles	Removal of suspended solids or suspended liquid particles	PRT063	Removal of suspended solids or suspended liquid particles	
Anions contaminants	Removal of anions contaminants	*PRT064*	*Oxidation based systems*	*PRT068*
		PRT065	*Reduction based systems*	*PRT069*
		PRT066	*Ion exchange*	*PRT073*
		PRT067	*Filtration of dissolved substances*	*PRT074*
Metals and metalloids	Removal of metals and metalloids	PRT068	Oxidation based systems	
		PRT069	Reduction based systems	
		PRT070	Chemical precipitation	
		PRT071	Co-precipitation with chloride or sulphate metal salts	
		PRT072	Adsorption	
		PRT073	Ion exchange	
		PRT074	Filtration of dissolved substances	
Organic contaminants	Removal of organic contaminants	*PRT075*	*Oxidation based systems*	*PRT068*
		PRT076	*Adsorption*	*PRT072*
Acidity and dissolved substances	Removal of acidity and dissolved substances	PRT077	Active neutralisation	
		PRT078	Passive neutralisation	
Emissions to surface water	Monitoring of emissions to surface water	PRT079	Monitoring of emissions to surface water	
Risk-specific PRT for the prevention or minimisation of **EMISSIONS TO AIR AND RELATED CLIMATE IMPACTS**				
Dust	Prevention or minimisation of dusting from blasting	PRT080	Planning and design of blasting	*PRT105*
	Prevention or minimisation of dusting from exposed surfaces	PRT081	Water or water-based solutions spraying of exposed surfaces	
		PRT082	Wind protection systems	
		PRT083	*Reduction and minimisation of exposed surfaces*	*PRT043, 044, 045, 046, 061, 119*
	Prevention or minimisation of dusting from equipment, roads and facilities	PRT084	Enclosing equipment and facilities	
		PRT085	Water or water-based solutions spraying equipment and roads	
		PRT086	Road and equipment maintenance	
		PRT087	Organisational techniques for transport and handling	
	Prevention and monitoring of dusting from channelled emissions	PRT088	Air collection - dust emissions	
		PRT089	Treatment of channelled dust emissions	
Volatile Organic Compounds (VOC) and other potential pollutants emissions	Prevention or minimisation of emissions of VOC and other potential air pollutants	*PRT090*	*Nitrogen and explosives management*	*PRT032*
		PRT091	Advanced explosive techniques and alternatives to blasting	
		PRT092	Treatment of channelled VOC and other potential air pollutants emissions	
GreenhouseGases (GHG) and other combustion emissions	Prevention and minimisation of GHG and other combustion emissions	PRT093	Decarbonisation	
		PRT094	Increased equipment efficiency	
Emissions to air	Monitoring of air emissions	PRT095	Monitoring of dust, VOC, GHG and other combustion emissions	

Risk-specific PRT for the prevention or minimisation of **OTHER EMISSIONS**				
Noise	Prevention or minimisation of noise emissions	PRT096	Noise and vibration management plan	
		PRT097	Noise protection systems	
		PRT098	*Planning and design of blasting*	*PRT105*
		PRT099	*Staging the charges and blasting quantity*	*PRT106*
		PRT100	*Developing blasting schedule*	*PRT107*
		PRT101	Organisational techniques for noise reduction	
		PRT102	Noise insulation of equipment and facilities	
	Monitoring of noise emissions	PRT103	Monitoring of noise emissions	
Vibrations	Prevention or minimisation of vibrations	PRT104	Ground vibration and overpressure control with appropriate drilling grids	
		PRT105	Planning and design of blasting	
		PRT106	Staging the charges and blasting quantity	
		PRT107	Developing blasting schedules	
		PRT108	Advanced initiation techniques	
		PRT109	Vibration control techniques for equipment and facilities	PRT102 (partly)
	Monitoring of vibrations	PRT110	Monitoring of vibrations	
Odour	Prevention or minimisation of odour emissions	*PRT111*	*Odour treatment techniques*	*PRT043, 044, 092*
	Monitoring of odour emissions	PRT112	Monitoring of odour emission	
Risk-specific PRT for the prevention or minimisation of **BIODIVERSITY AND LAND USE IMPACTS**				
Habitats, plants and wildlife	Prevention or minimisation of impacts on habitats, plants and wildlife	PRT113	Ecological survey	
		PRT114	Strategy for terrestrial habitat preservation	
		PRT115	Strategy for aquatic habitat preservation	
		PRT116	Soil conservation measures	
		PRT117	Other measures for minimisation of biodiversity and land use impacts	
		PRT118	Rehabilitation techniques	
		PRT119	Landscaping and geomorphic reclamation	
Visual, footprint and landscape impacts	Prevention or minimisation of visual, footprint and landscape impacts	PRT120	Topographical and land surveys	
		PRT121	Visual barriers	
		PRT122	Visual impact optimisation	PRT043, 119 (partly)
Impacts on material assets and cultural heritage	Prevention or minimisation of material assets impacts	PRT123	Cultural heritage assessment	
		PRT124	Minimise adverse impacts and implement restoration measures	
		PRT125	Community consultation, engagement and protection	
Risk-specific PRT for the prevention or minimisation of **CONSUMPTION**				
Energy consumption, and related contribution to climate change	Prevention or minimisation of energy consumption	PRT126	Energy use: balance, reporting and audit	
		PRT127	Benchmarking - Best Truck Ratio (BTR) assessment tool	
		PRT128	Generic energy consumption reduction techniques	
		PRT129	Operational energy consumption reduction techniques	
		PRT130	Optimisation of crushing and grinding processes	
		PRT131	Optimisation of material flow	
		PRT132	Friction reduction and wear protection	
		PRT133	Mine automation	
		PRT134	Digitalisation	
		PRT135	*Decarbonisation: Renewable energy - solar*	*PRT093*
Water consumption	Prevention or minimisation of water consumption	*PRT136*	*Water management*	*PRT013*
		PRT137	Water consumption reduction measures	
		PRT138	Water recovery techniques	
Reagents and auxiliary materials	Prevention or minimisation of reagents and auxiliary material consumption	PRT139	Auxiliary materials recovery techniques	
		PRT140	Design, inspection, maintenance of storage tanks	
Risk-specific PRT for the prevention or minimisation of **HAZARDOUS MATERIALS IMPACTS**				
Hazardous materials	Lubricants, fuels, chemical management	PRT141	Use minimisation of hazardous substances	
		PRT142	Elimination and substitution of hazardous substances	
		PRT143	*Nitrogen and explosives management*	*PRT032*
		PRT144	Mobile Manufacturing Units Explosives	
		PRT145	*Leakage detection systems*	*PRT058*
		PRT146	*Secondary containment*	*PRT034, 035*
		PRT147	Lubricants and fuel management	
	Cyanide management	PRT148	Cyanide management	
		PRT149	*Monitoring cyanide concentrations*	*PRT023*

Indication of cross-references in italics and of secondary KEI in grey

Related and future JRC work

Further potential work relates to collecting information on mine automation, process optimisation and digitalisation and to assessing circular use of resources, including the recovery of critical and other raw materials from extractive wastes.

Page left blank

1 Introduction

1.1 Background of the study

The sustainable production of raw materials from EU sources is the second of the three pillars of the Raw Materials Initiative (RMI)[3]. While the overall potential of non-energy mineral resources in Europe is strong, the access to these resources is becoming more and more difficult, thereby increasing EU dependency on imports. This was addressed in the European Innovation Partnership on Raw Materials Strategic Implementation Plan (EIP-RM SIP) under "Priority Area II.A: Improving Europe's raw materials framework conditions" where three priority areas were defined: Minerals policy framework (II.1); Access to minerals potential in the EU (II.2); and Public awareness, acceptance and trust (II.3). In the EIP-RM SIP Implementation document (2016)[4] it was indicated that the level of implementation for Priority area II.A was "very limited". The situation has improved since 2016, but it is still far from the targets set in the EIP-RM SIP. Information is often scattered and cannot be readily used by stakeholders for better resource management, streamlining the permitting process, or increasing public awareness. A Best Available Technique (BAT) Reference Document (BREF) exists for the management of waste from extractive activities.

It is generally acknowledged that BREFs contribute to increasing environmental protection and sustainable development of industrial sectors, while providing more predictability for the industry during the permitting process.

This study, "Collection of available techniques for the prevention or reduction of environmental impacts in Non-Energy Extractive Industries (NEEI)", aims to provide an overview of existing documents and information on available techniques that stakeholders considered relevant and assigning these latter into categories. It is part of an action on the "Implementation of framework conditions for non-energy minerals", that the Joint Research Centre (JRC) is carrying out in collaboration with DG GROW for the project "RM-EIP II – Support for raw materials policy", within the context of the European Innovation Partnership (EIP) on Raw Materials (RM).

1.2 Policy context

Published documents and initiatives that may contain useful information relevant to the extractive sector are described below, in order to present the policy context.

BREFs developed under the Industrial Emissions Directive (IED) by the European Integrated Pollution Prevention and Control Bureau (EIPPCB):

- BREFs provide information on a range of industrial processes of activities listed in Annex I of the IED (Directive 2010/75/EU).
- They are the result of an exchange of information between experts from EU Member States, industries concerned, environmental NGOs and the European Commission. This exchange is coordinated by the EIPPC Bureau of the JRC. Currently, more than 30 BREFs relevant for sectors covered by the IED have been published[5].
- The contents and scope of a BREF are described in Section 2 of Commission Decision 2012/119/EU on the so-called "Sevilla process" guidance. In particular, Section 2.2 describes the elements that a BREF, such as data on general information about the sector concerned (Chapter 1), applied processes and techniques (Chapter 2), current emission and consumption levels (Chapter 3), techniques to consider in the determination of BAT, the so-called "BAT candidates" (Chapter 4), BAT conclusions (Chapter 5) and emerging techniques (Chapter 6).

(3) European Commission, 2008. Communication from the Commission to the European Parliament and the Council, The raw materials initiative - meeting our critical needs for growth and jobs in Europe

(4) https://ec.europa.eu/growth/sectors/raw-materials/eip/strategic-implementation-plan_en

(5) https://eippcb.jrc.ec.europa.eu/reference/

BREFs and similar documents developed under legislative instruments other than the IED:

The BREF for the Management of Waste from Extractive Industries (MWEI BREF)[6]:

- The MWEI BREF covers the management of extractive waste and the extractive waste facility in the planning and design, operational, closure and after-closure phases according to the Extractive Waste Directive (EWD, Directive 2006/21/EC). The exchange of information was coordinated by the JRC, the "Sevilla process" guidance was followed and the MWEI BREF was published in 2018.
- The MWEI BREF contains 57 BAT, of which 10 generic BAT and 47 risk-specific BAT, addressing 25 generic and risk-specific objectives, and providing information about almost 200 techniques. Generic BAT focus on corporate management, information and data management, and waste hierarchy. Risk-specific BAT comprise BAT identified to prevent or reduce as far as possible specific risks that are identified by a proper Environmental Risk and Impact Evaluation, duly considering the relevant site-specific information. Risk-specific BAT on safety aim at helping to ensure the short-term and long-term structural stability of the extractive waste deposition areas and the physical and chemical stability of extractive waste. Other risk-specific BAT aim at preventing or minimising water status deterioration, air and soil pollution or other risks to human health, flora and fauna, related to noise emissions, odour nuisance, visual and footprint impacts and extractive waste containing Naturally Occurring Radioactive Materials (NORMs).
- The following processes and activities are considered in the MWEI BREF:
  (a) Management of extractive waste from onshore extractive activities.
  (b) Handling/transport of extractive waste (e.g. loading, unloading and on-site transport).
  (c) Treatment of extractive waste: (i) physical and mechanical treatment (e.g. sorting, blending, dewatering, thickening); (ii) chemical treatment (e.g. desulphurisation, cyanide detoxification); (iii) biological treatment (e.g. biological sulphide reduction).
  (d) Deposition of extractive waste: (i) temporary deposition; (ii) permanent deposition.
  (e) Activities directly associated with the management of extractive waste: (i) treatment of Extractive Waste Influenced Water (EWIW); (ii) preparing extractive waste to be placed back into excavation voids.

The Best Available Techniques Guidance Document on upstream hydrocarbon exploration and production (HC REF)[7]: HC REF was developed on behalf of DG ENV by an external contractor, Wood. It was published in 2019.

The Medium Combustion Plant Directive (MCPD, Directive 2015/2193/EU):

- The MCPD regulates emissions of SO_2, NO_X and dust to air. It aims to reduce those emissions and the resultant risks to human health and the environment. It also requires monitoring of carbon monoxide (CO) emissions. The emission limit values set in the MCPD apply from 20 December 2018 for new plants and 2025 or 2030 for existing plants, depending on their size. The MCPD addresses the potential need for Member States to apply stricter emission limit values in areas where this can improve local air quality in a cost-effective way. The Commission will help Member States by providing information on the lowest emissions achievable with the most advanced techniques. Technical information is provided by an information exchange between stakeholders[8].

European Green Deal

The European Green Deal Communication (2019)[9] launched a new growth strategy that aims to transform the EU into a fair and prosperous society, improving the quality of life of current and future generations, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. It also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts. The European Green Deal commits the Commission to review the measures to address pollution from

(6) MWEI BREF https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/best-available-techniques-bat-reference-document-management-waste-extractive-industries
(7) HC REF https://ec.europa.eu/environment/integration/energy/pdf/hydrocarbons_guidance_doc.pdf
(8) Ricardo Energy & Environment (2019). Final Technology Report. MCP Information exchange (Report for DG Environment ENV.C.4/FRA/2015/0042) https://ec.europa.eu/environment/industry/stationary/mcp.htm
(9) COM(2019) 640 - https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

large industrial installations and how to make them fully consistent with climate, energy and circular economy policies. The European Green Deal includes the following actions:

- The proposal for a Regulation establishing the framework to achieve climate neutrality by 2050 and amending Regulation (EU) 2018/1999 (European Climate Law)[10] (March 2020). This proposal specifies that when setting the trajectory for achieving climate neutrality, the Commission shall consider, among others, best available technologies. Reaching this target will require actions by all sectors, including investing in environmentally-friendly technologies and supporting industry to innovate.
- The adoption of the European Industrial Strategy[11] (March 2020), whose main drivers to empower industry and SMEs are the green transition, supported by the European Green Deal, the digital transition[12], supported by the European digital strategy, and the competitiveness on the global stage.
- The proposal of a Circular Economy Action Plan[13] (March 2020), which presents actions to design sustainable products and to further promote circularity in industrial processes in the context of the review of the IED, including the integration of circular economy practices in BREFs.
- The presentation of the European Biodiversity Strategy for 2030[14] (May 2020), which is aimed at establishing protected areas, restoring degraded ecosystems and addressing the global biodiversity crisis.
- A new Zero Pollution Action Plan for water, air and soil[15] (presented in 2021), which is aimed at preserving biodiversity and reducing pollution in water, reviewing air quality standards, reducing pollution from industrial installations, improving prevention of accidents and presenting a new chemicals strategy for sustainability for a toxic-free environment.
- A commitment to review EU measures to address pollution from large industrial installations and how to make them fully consistent with climate, energy and circular economy policies, entailing a revision of the IED by 2021. Among others, the extractive industry has been identified as a sector where improvements might be possible.

Other specific documents and actions for NEEI and raw materials in Europe:

- The Action Plan on Critical Raw Materials (CRM)[16] (2020) recognises that the access to resources and sustainability is key for the EU's resilience in relation to raw materials. It points out the role of raw and advanced materials in the transition to the Green and Digital Economy where a main building block is about strengthening the sustainable and responsible domestic sourcing and processing of raw materials in the European Union. The EU principles for sustainable raw materials to be published in 2021 will reflect such good practices applied in Europe. The EC Guidance Document on "Non-energy mineral extraction and Natura 2000[17] and a summary document of this guidance[18] (2019).
- The JRC policy report: A review of European Union legal provisions on the environmental impact assessment of non-energy minerals extraction projects[19] as another part of a broader action on the "Implementation of framework conditions for non-energy minerals".
- The elaboration of guidelines for best risk management approaches in the extractive sector[20] launched by DG ENV in 2019. In order to develop them, the Commission is organising an exchange of information aimed at identifying key activities, collecting information on risk management approaches through the entire extractive life cycle, specifying environmental and operational monitoring needs, assessing the economics of the application of best risk management approaches and proposing best risk management approaches.

(10) https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588581905912&uri=CELEX:52020PC0080
(11) https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en
(12) https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age_en
(13) https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf
(14) https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/eu-biodiversity-strategy-2030_en
(15) https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/eu-biodiversity-strategy-2030_en
(16) COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability
(17) http://ec.europa.eu/environment/nature/natura2000/management/docs/neei_n2000_guidance.pdf
(18) https://op.europa.eu/en/publication-detail/-/publication/1ad3394e-de79-11e9-9c4e-01aa75ed71a1
(19) Hamor et al. (2021). A review of European Union legal provisions on the environmental impact assessment of non-energy minerals extraction projects.
(20) https://ec.europa.eu/environment/waste/mining/risk_management.htm

2 Scope of the study

The scope of this study is to provide an overview of existing documents on available techniques for the prevention or reduction (Prevention or Reduction Techniques - PRT) of environmental impacts in the NEEI (see the Glossary) through the extractive cycle, excluding extractive waste, and to group them into an extensive selection of PRT that cover the sector in a comprehensive and balanced way.

The main information and documents for the different sub-sectors of the NEEI have been gathered from Member State authorities, industry associations, environmental NGOs and other relevant stakeholders via a data and information collection exercise, launched by the JRC and GROW in October 2019 (see Annex 2). These documents have also been complemented by the results from a techno-scientific literature search. Furthermore, the JRC has been supported in this PRT collection exercise by an external contractor, Wood.

A background paper was prepared as a working document for a written consultation (organised from October 2020 to January 2021) to collect feedback from stakeholders on the preliminary results from the study. Furthermore, and in addition to the written consultation, an online workshop was organised on 3 December 2020 to present, discuss and exchange with stakeholders on the preliminary results presented in the background paper (see Annex 5).

The background paper, the inputs provided by stakeholders during the workshop and the outcomes of the written consultation represented the basis for finalising the study on "*Collection of available techniques for the prevention or reduction of environmental impacts in Non-Energy Extractive Industries (NEEI)*".

This collection of PRT is an exploratory mapping of existing information and it is not a development of a BREF or any chapter of a BREF. The exercise consisted merely of collecting information on techniques and assigning them into categories, without an evaluation of their contribution to the prevention or reduction of negative impacts on the environment from non-energy extractive activities.

It is important to underline that a "technique" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned. Moreover, "available techniques" means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions. These available techniques should be effective in achieving a high general level of protection of the environment as a whole.
The concept of PRT may be presented under other but similar names, sometimes focussed on either the technologies or the ways of designing, building, maintaining, operating or decommissioning an installation, including, but not limited to, Best Available Techniques (BAT), Best Environmental Technologies, Best Environmental Practices and Best Environmental Management Practices. It should also be underlined that not everything that is claimed to be a PRT or similar, would actually meet the definition of BAT from the IED[21]

More in detail, inclusions in the study and exclusions from the study are specified below. The definitions set out in the EWD have been used as guidance (see the Glossary).

"Extractive industries" means all establishments and undertakings engaged in surface or underground extraction of mineral resources for commercial purposes. Extraction by drilling boreholes, or treatment of the extracted material are included (see Art. 3(6) of the EWD).

Elements included in the scope of the study
The list of mineral resources, extractive activities, life cycle phases and key environmental impacts considered in the scope of the study includes:

([21]) According to Art. 3(10) of Directive 2010/75/EU (IED), Best Available Techniques are defined as *the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole:*
- *'techniques' includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;*
- *'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;*
- *'best' means most effective in achieving a high general level of protection of the environment as a whole.*

Non-energy mineral resources:

- Metallic minerals[22]: Base metals (Cu, Ni, Pb, Sn, Zn); Precious metals (Ag, Au, Pt); Iron ores and others (Fe, Co, Mn, Mo, V, W, ilmenite or titanium minerals or Ti); Bauxite.
- Industrial minerals[23]: Limestone and gypsum; Clay and kaolin; Potash; Feldspar; Phosphate rock; Peat (as non-energy mineral, for example for use in horticulture and agriculture); Other industrial minerals (e.g. magnesite).
- Construction minerals[24]: Aggregates; Construction and ornamental stones.

Extractive activities:

- Extraction: surface; subsurface; borehole mining; solution mining.
- This includes also activities such as construction of access roads, site preparation and clearing. Rehabilitation is also included in the extraction phase being based on a design for closure approach, ie. rehabilitation is designed in the planning and design phase, it is carried out during operation (in the case of progressive rehabilitation) or during closure and after-closure.
- Treatment: comminution (size reduction, e.g. crushing and grinding); size control (screening, mineral sorting and classification); beneficiation (physical separation - chemical separation - biological separation); upgrading (which refers to removal of water, dewatering, sedimentation, drying; see also the Glossary).
- Transport and handling: loading and unloading; hauling.
- Storage, including temporary storage.

Life cycle phases:

- Planning and design.
- Operation (see extractive activities above, including management and maintenance).
- Closure and after-closure.

Environmental issues: defined taking into account information from relevant legislation[25, 26]:

- Safety: structural stability (which refers to not collapsing or breaking and includes considerations on seismicity and impacts of extreme events), and related adaptation to climate change, physical stability (which refers to not moving or spreading, as, for example, in certain backfilling activities), chemical stability (which refers to not leaching or dissolving).
- Emissions to soil and groundwater (channelled emissions, e.g. stack or point source emissions, and diffuse emissions, e.g. non-channelled).
- Emissions to surface water: anion contaminants (such as sulphates, nitrates, phosphates and chloride); acidity and dissolved substances (TDS); suspended particles (TSS); organic contaminants (BOD, COD, TOC); metals and metalloids. During the consultation, a stakeholder pointed out that not only acidity, but also excessive alkalinity may be an environmental issue to be considered.
- Emissions to air, and related climate impacts: dust; VOC and other potential air pollutants; GHG (mainly CO_2) and other combustion emissions (combustion products such as NO_x or SO_2).
- Other emissions: noise emissions, vibrations, odour emissions.
- Biodiversity and land use impacts: impacts on habitats, plants, wildlife, visual, footprint and landscape impacts, impacts on materials assets and cultural heritage (including geological and mining heritage).

(22) https://ec.europa.eu/growth/sectors/raw-materials/industries/minerals/metallic_en
(23) https://ec.europa.eu/growth/sectors/raw-materials/industries/minerals/industrial_en
(24) https://ec.europa.eu/growth/sectors/raw-materials/industries/minerals/construction_en
(25) Directive 2006/21/EC on the management of waste from extractive industries; Directive 2014/52/EU on the assessment of the effects of certain public and private projects on the environment; Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment; Directive 2010/75/EU on industrial emissions; COM Implementing Decision 2012/119/EU of 10 February 2012 laying down rules concerning guidance on the collection of data and on the drawing up of BAT reference documents and on their quality assurance. The most complete and updated list of the relevant EU legislation is available in Hámor et al., 2021.
(26) Study – Legal framework for mineral extraction and permitting procedures for exploration and exploitation in the EU (Minlex study) https://publications.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en; RMIS http://rmis.jrc.ec.europa.eu/

— Consumption: energy consumption, and related contribution to climate change, water consumption, consumption of auxiliary materials: reagents and auxiliary materials.

— Hazardous materials (use, storage, transfer): lubricants, fuels, chemicals (including cyanide).

Elements not included in the scope of the study

The activities in the extractive industry explicitly not included in the scope of this study comprise:

— All elements already covered in the MWEI BREF.

— Exploration, considering that a specific dedicated study would be needed on this topic.

— Pyrometallurgy, smelting, thermal manufacturing processes (other than the burning of limestone), metallurgical processes and refining, based also on the definitions in Art. 3(8) of the EWD.

— Occupational health and safety.

— Energy fuels and minerals (such as coal, lignite, peat for energy production, uranium ore, hydrocarbons, oil shale).

Methodology

The methodology applied for providing an overview of the PRT of environmental impacts in the NEEI included the following steps:

— Preliminarily identifying the Key Environmental Issues (KEI) for the mineral resources and extractive activities under the scope of the study, along its life cycle phases, through expert judgement. A scoring exercise was performed by a contracted consultant's (Wood) internal mining experts, and commented the JRC (see Section 3.1 and Annex 1). This scoring considered the aggregated environmental impacts per extractive sub-sector in Europe as a whole. It was not meant to represent a site-specific situation, which needs to be properly analysed by means of an EIA, following a risk-specific approach.

— Gathering the information that Member State authorities, industry associations, NGOs and other stakeholders considered relevant on PRT via a data and information collection exercise, and complementing it by a techno-scientific literature search (see Section 4.1 and Annex 2).

— Extracting a list of techniques for preventing or reducing negative impacts in NEEI from the collected references. This list includes their title, the relevant (group of) mineral resources, extractive activities and the key environmental issue to which each technique applies, based on a review of the collected literature references (see Section 4.2).

— Grouping these techniques into one or more PRT, based on the information reported in the collected literature references, without any assessment or evaluation of their actual contribution to the prevention or reduction of negative impacts on the environment (see Section 4.3).

— Using the preliminarily identified KEI, and in particular the ones with high and medium scores, in assisting with the scoping of the PRT.

During the online workshop and the written consultation, stakeholders acknowledged that, despite the ample time allocated for data collection, not all relevant literature sources may have been shared with the JRC for this study. Stakeholders particularly pointed out that the gathered information and literature may not contain up-to-date information from technology providers and operators on available techniques already applied in the extractive sector (e.g. advances in autonomous robotics). Therefore, the collection of PRT may lack information on advanced techniques in the field of mine automation, process optimisation and digitalisation. Despite this, several Member States considered that the study provides an in-depth overview of the PRT in use in NEEI. Thus, even if the list is not exhaustive, it may be considered as a valuable compilation of techniques to prevent and reduce environmental impacts. More in detail, the study, and particularly the Annexes, can be used as an interactive screening toolkit of PRT that may apply depending on the site-specific conditions. In fact, not all PRT apply to all extractive sectors and types of mineral resources, extractive activities and operations, and the need of applying a risk-specific approach to analyse the PRT applicability clearly emerged during the study (see Section 3.1).

3 Preliminary identification of the Key Environmental Issues (KEI) in the non-energy extractive sector

3.1 Description of the process to identify KEI

In order to focus the data collection of PRT Key Environmental Issues (KEI) have been identified for the mineral resources groups and extractive activities under the scope of the study.

The activities and environmental aspects listed in Section 2 have been considered throughout the following life cycle phases: planning and design, operation, closure and after-closure. For each combination of mineral, activity and environmental aspect, a scoring of high, medium, or low was provided through expert judgement (see Annex 1). The KEI scoring was performed by Wood's internal mining experts and commented by the JRC. External experts or other stakeholders were not involved in the initial scoring exercise, but were given the possibility to provide feedback during the general consultation on the background paper.

In order to assess information on aggregated environmental impacts and as a framework to allocate a quantitative scoring to each environmental issue, the following KEI assessment criteria have been used:

- Are the environmental issues and associated parameters relevant for the activity or process concerned?
- Is the process and its pollution and consumption a significant part of pollution and consumption in the EU extractive sub-sector, currently or trending?

The scoring was assessed through expert judgement by considering the aggregated environmental impacts per extractive sub-sector in Europe as a whole. In particular, cumulative effects of sub-sectors, for example the combined effects of many smaller activities and environmental issues, determine the importance of the KEI and scoring result. It was, for example, considered that the aggregates sector comprises about 25.000 extraction sites in the EU-27 and the assigned scoring reflects this assumption. The actual environmental impact of a single quarry might be lower, or conversely higher, than the assigned scoring to the whole sub-sector suggests, as the "site-specificity" might need to be further assessed and the potential impacts to be better defined and understood by means of a proper risk evaluation.

The KEI scoring is thus not applicable to a single extractive activity, where the site-specific conditions need to be properly considered and evaluated by means of a proper Environmental Impact Assessment (EIA), following a risk-specific approach[27].

Risk-specific approach
As emphasized by stakeholders during the consultation, site-specific conditions for each individual extractive site need to be properly understood and defined. A risk-specific approach needs to be applied. It can help reflecting the vast diversity in extractive activities, mineral resources, sectors, geography, climatic and site specific conditions in Europe. It helps focusing on the KEI for each specific extractive activity and adapting the deployment of techniques according to the evaluation of the environmental risks and possible impacts.

The risk-specific approach is based on rigorous risk assessment and management principles[28]. More in detail, a proper and comprehensive EIA considers the full spectrum of hazards and risk elements, including source-pathway-receptor linkages, for a given extractive site. It is a structured, dynamic and often iterative process, which is part of the risk management, where all the environmental risks and impacts from the extractive activity are identified, analysed and evaluated over the whole life cycle. As a stakeholder pointed out during the consultation, the understanding of the potential pollution is linked to the extractive site characterisation, including baseline and geochemical background studies.

Depending on the outcome of the EIA (according to Directive 2011/92/EU), together with information derived from the extractive waste management plan (according to Directive 2006/21/EC) in the case of an integrated design considering both the extractive site and the extractive waste deposition area, one or more generic and/or risk-specific techniques/PRT are identified as applicable for a specific situation. These PRT aim to minimise each

(27) Hamor et al. (2021). A review of European Union legal provisions on the environmental impact assessment of non-energy minerals extraction projects. *WP6 "Implementation of framework conditions for primary raw materials (non-energy minerals)", Task 6.2*
(28) ISO 31000:2009. Risk management -- Principles and guidelines, International Organization for Standardization

overall risk, and to prevent or reduce, as far as possible, any adverse effects on the environment and human health.
Specific European actions are ongoing to elaborate guidelines for best risk management approaches in the extractive sector[29] and to publish a specific study on EIA of non-energy minerals extraction projects[30].

Based on these considerations, as suggested by stakeholders during the workshop and the written consultation, this study is obviously not to be used as an EIA. It can be rather used as an interactive toolkit for screening a non-exhaustive list of PRT that may apply depending on the outcomes of a proper EIA, where the site specific conditions of each extractive site are duly taken into consideration.

Categories used in the scoring exercise
These two criteria guided the expert input to perform a scoring of the KEI for each combination of mineral resource and type of activity. As part of the scoring approach, the mining experts allocated each combination of extractive activity and (group of) mineral resource to one of the following categories:

- Grey: not covered, i.e. there is no aggregated impact in relation to the specific environmental issue and parameter. The combinations falling under the grey coloured category are combinations of activities and mineral resources that in reality do not occur and/or activities for which the specific aggregated environmental impact in the EU is considered as not significant. Examples include chemical separation for construction and ornamental stones, solution mining for clay, comminution of peat, emissions of organic contaminants from size control of aggregates or vibrations and noise emissions from storage.
- Green: low importance (1), i.e. the environmental issue is not relevant for the activity; although an aggregated impact could occur, this is considered as small or trivial for the activity in the EU extractive sub-sector.
- Amber: medium importance (2), i.e. the environmental issue is relevant for the activity, the aggregated impact is considered as medium for the activity in the EU extractive sub-sector; the associated risks have been assessed by Wood as usually considered and treated in order to reduce the potential environmental impacts.
- Red: high importance (3), i.e. the environmental issue is very relevant for the activity, the aggregated impact is considered as high for the activity in the EU extractive sub-sector; the associated risks have been assessed by Wood as typically considered and treated in order to reduce the potential environmental impacts.

Although the KEI identification mainly relied on expert judgment (see the explanation above and in Annex 1), the identification of relevant literature assisted with the assessment and scoring of the KEI, for example by either validating or complementing the expert judgement. The following literature references have been, for example, considered: IFC 2007. Safety Guidelines for Mining; IFC 2007. Guidelines for Construction Materials Extraction; Jain et al. 2015; European Commission 2018. MWEI BREF; Manhart et al. 2019; Finnish Environment Institute 2013; Australia 2016. Preventing acid and metalliferous drainage.

(29) Elaboration of guidelines for best risk management approaches in the extractive sector launched by DG ENV in 2019 https://ec.europa.eu/environment/waste/mining/risk_management.htm
(30) Hamor et al. (2021). A review of European Union legal provisions on the environmental impact assessment of non-energy minerals extraction projects. *WP6 "Implementation of framework conditions for primary raw materials (non-energy minerals)", Task 6.2*

3.2 Preliminary assessment of the KEI

The disaggregated table with the scores for each combination of (group of) mineral resource, extractive activity and environmental issue is provided as Table 3 in Annex 1. More aggregated summaries of Table 3 have also been prepared for extraction, treatment, transport and handling and storage (see, respectively, Table 4, Table 5, Table 6 and Table 7 in Annex 1).

Figure 1 presents the distribution of the medium (2) and high (3) scores assigned to the environmental issues across the extractive activity categories and mineral resources. The values have been weighted to reflect the different number of mineral resources groups per sub-sector (i.e. 2 for construction minerals, 7 for industrial minerals and 4 for metallic minerals). The highest aggregated impacts relate to the extraction and treatment phases and with the highest scores for the metallic ores, followed by the industrial minerals and construction materials, respectively.

Extraction and treatment of metallic minerals represents 51% of the aggregated impacts that scored high. Transport, handling and storage overall are not considered as having a high aggregated impact (0.4% of the high scores), but rather medium aggregated impact (representing 36% of the medium scores).

Figure 1. Distribution of total weighted medium (2) and high (3) scores across extractive activities and mineral resources

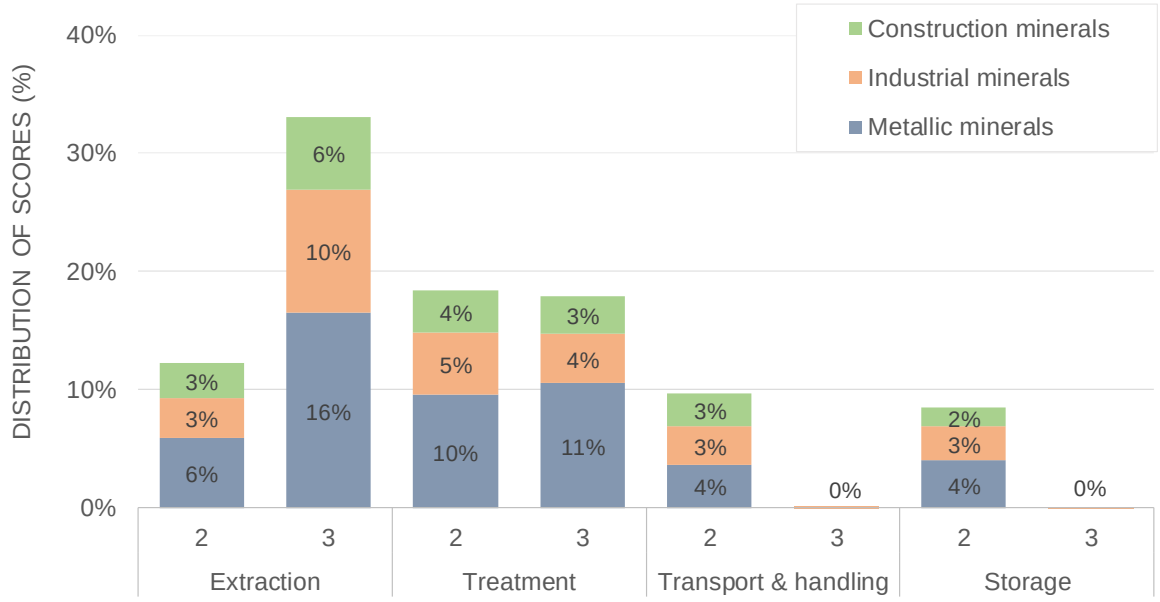


Figure 2 and Figure 3 provide an overview of the KEI for each of the extractive activities and for each of the mineral resources. All figures focus on the medium and high scores; the low scores have not been considered in the analysis.

Figure 2. Distribution of total weighted medium (2) and high (3) scores across the environmental issues for each extractive activity (see the List of abbreviations).

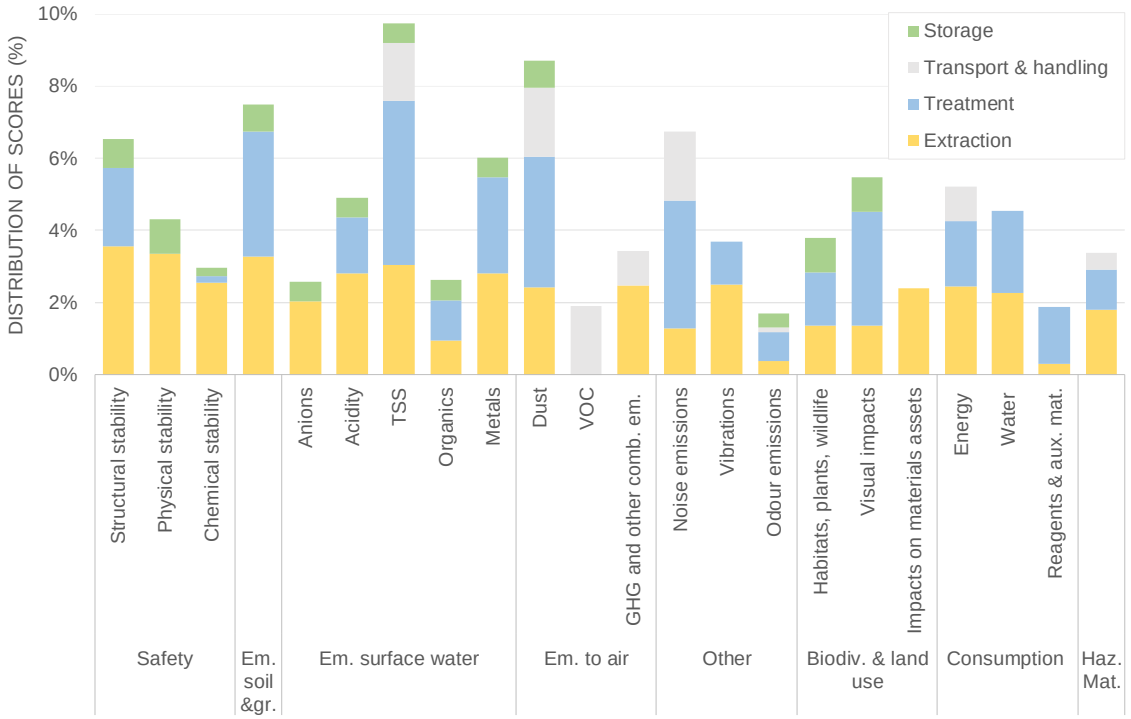
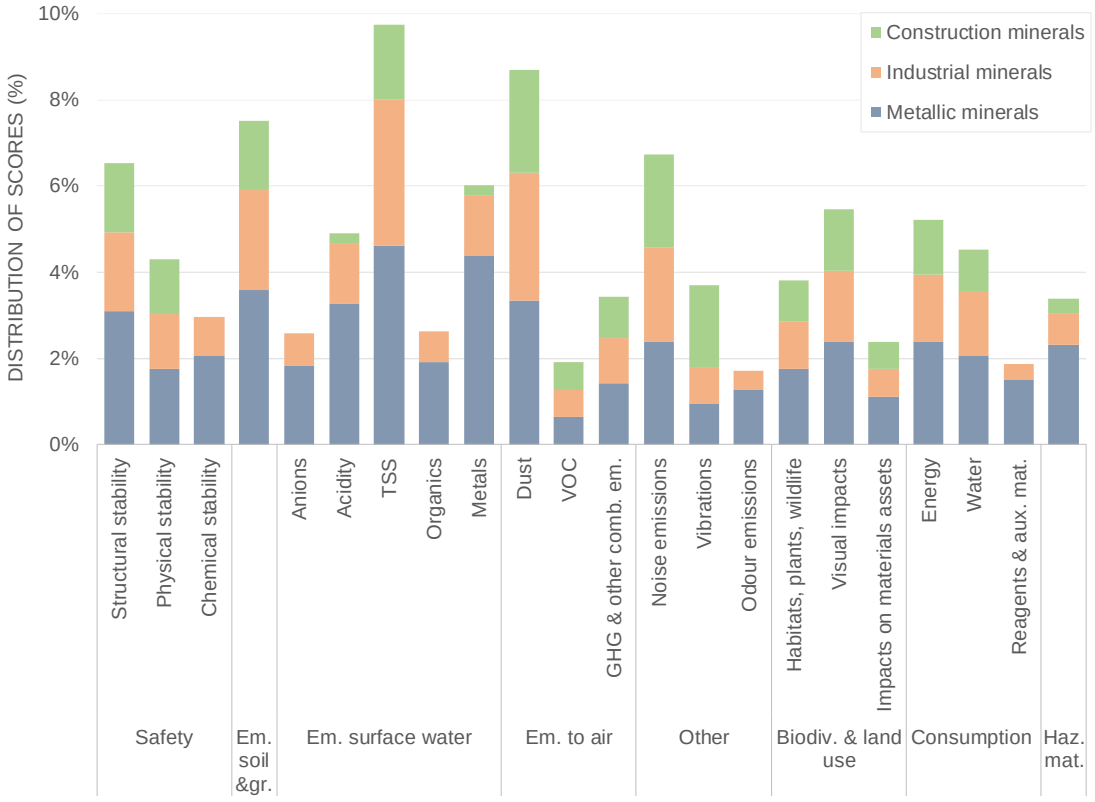


Figure 3. Distribution of total weighted medium (2) and high (3) scores across the environmental issues for each mineral resource (see the List of abbreviations).

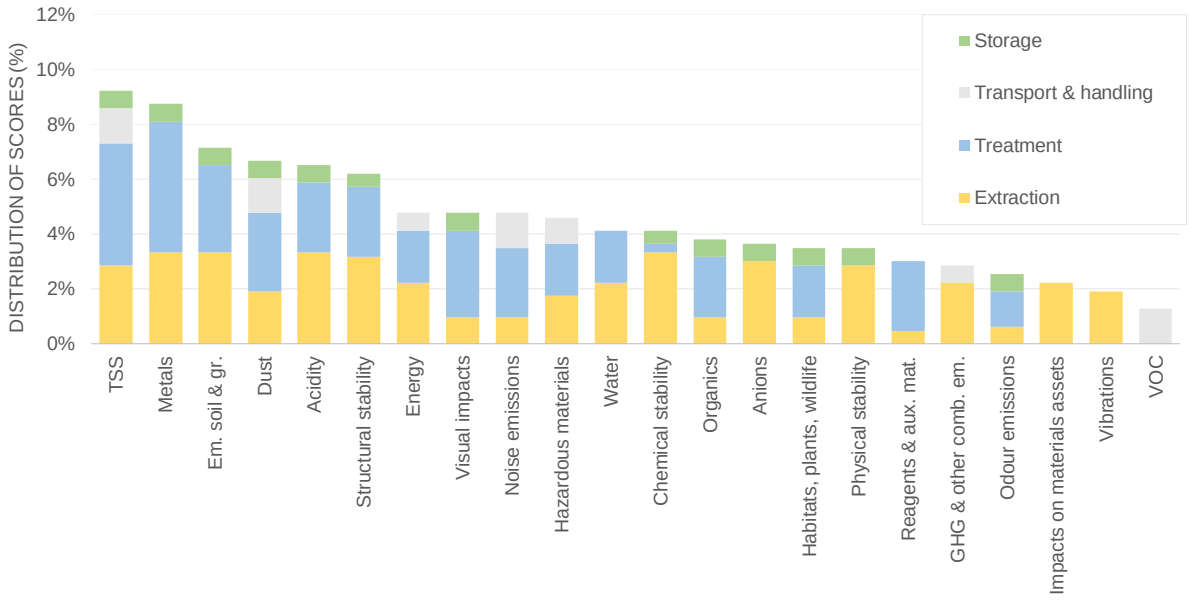


The distributions of total weighted medium and high scores across the environmental issues for the extractive activities in the case of metallic minerals, industrial minerals and construction minerals are shown, respectively, in Figure 4, Figure 5 and Figure 6. It can be concluded that:

— Metallic minerals score highest (high and medium scores) on emissions to surface water (TSS, metals, acidity), emissions to soil and groundwater, dust emissions and structural stability (see Figure 4).

- The high and medium aggregated impacts during extraction are observed across the following environmental issues, e.g. in decreasing order: emissions to surface water (metals), emissions to surface water (acidity), chemical stability and structural stability. The high and medium aggregated impacts during treatment processes relate to, in decreasing order of KEI scores, emissions to surface water (TSS and metals), emissions to soil and groundwater, visual, footprint and landscape impacts, dust emissions, and structural stability.
- For metallic minerals similar trends for the medium and high aggregated impact scores are observed as for the industrial minerals. However, other issues have been scored as high compared to the majority of industrial minerals, for example the energy use during metallic mineral treatment.

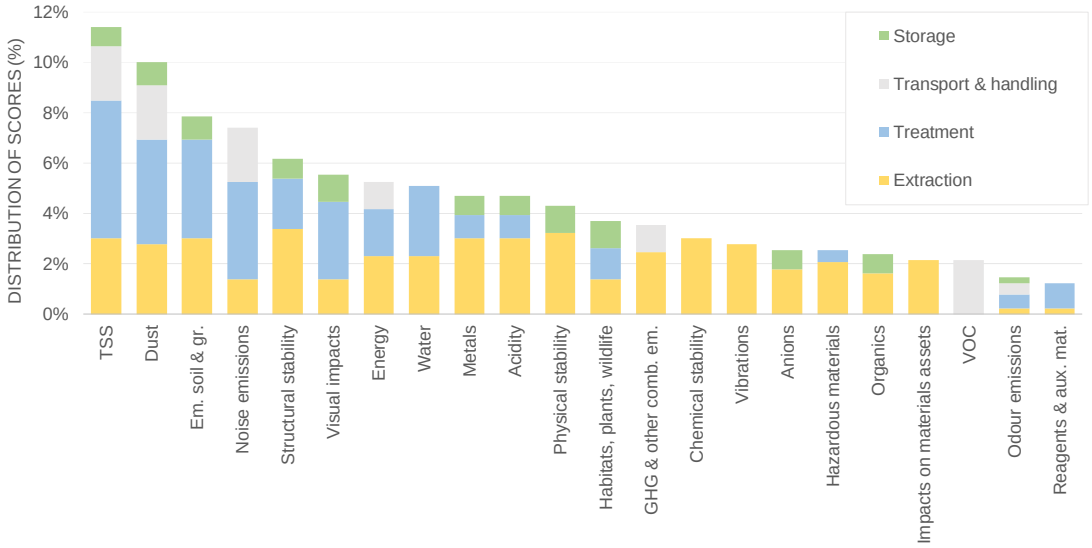
Figure 4. Distribution of total weighted medium (2) and high (3) scores across the environmental issues for the extractive activities - metallic minerals (see the List of abbreviations).



— Industrial minerals score highest (high & medium scores) on emissions to surface water (TSS), dust emissions, emissions to soil and groundwater, noise emissions and structural stability (see Figure 5).

- Though some high aggregated impacts occur during treatment processes, such as impacts of comminution, size control and beneficiation on both emissions of suspended particles to surface water and of dust to air, the majority of the highest scores for industrial minerals relate to surface and subsurface extraction.
- Apart from the odour emissions resulting from peat, no high scores have been allocated to transport and storage of industrial minerals, only low or medium scores.
- The high and medium aggregated impacts during extraction are observed across the following environmental issues, e.g. in decreasing order: structural stability, emissions to soil and groundwater, chemical stability, emissions to surface water (TSS, acidity and metals), physical stability, dust emissions, and vibrations. The high and medium aggregated impacts during treatment processes relate to, in decreasing order of scores, emissions to surface water (TSS), dust emissions, emissions to soil and groundwater, visual impacts and water consumption.

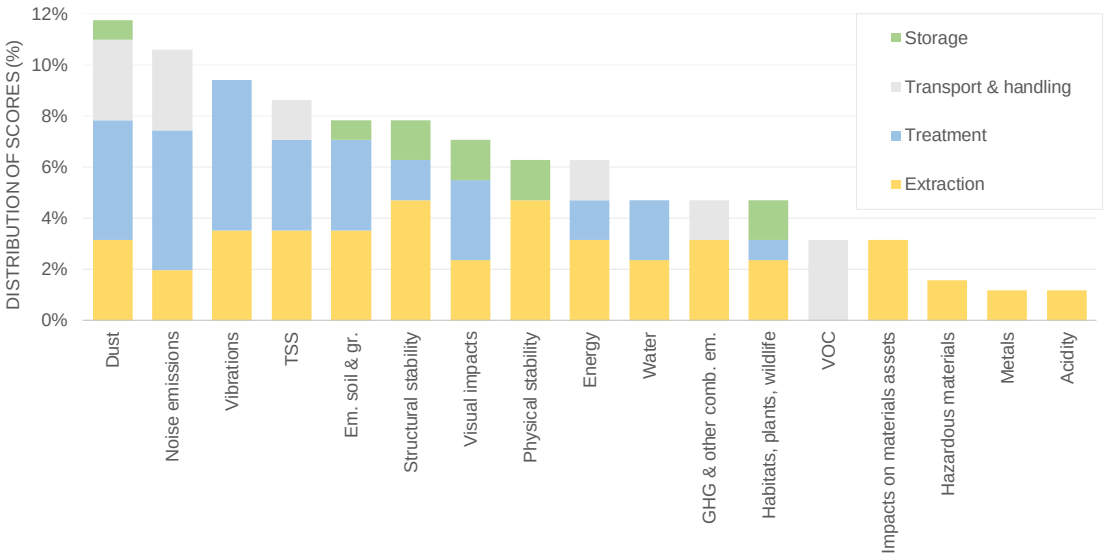
Figure 5. Distribution of total weighted medium (2) and high (3) scores across the environmental issues for the extractive activities - industrial minerals (see the List of abbreviations).



— Construction minerals score highest (high and medium scores) on dust emissions, noise and vibrations, emissions to surface water (TSS), structural stability and emissions to soil and groundwater (see Figure 6).

- Especially during surface and subsurface extraction as well as during the comminution, size control and physical separation processes, the highest aggregated impact scores can be observed for both aggregates and construction and ornamental stones. The high and medium aggregated impacts during extraction are observed across a range of environmental issues, e.g. in decreasing order: stability issues (structural and physical), vibrations, emissions to groundwater and surface water (TSS), dust emissions, and energy consumption etc. The high and medium aggregated impacts during treatment processes relate to, in decreasing order of KEI scores, vibrations, noise emissions, dust emissions, emissions to surface water (TSS) and emissions to soil and groundwater.
- Though the extraction of aggregates and of construction and ornamental stones leads to similar levels of emissions to air and surface water, in general, it is considered that the treatment of aggregates could lead to higher levels of emissions to air (dust), noise and vibrations (comminution, size control and physical separation).

Figure 6. Distribution of total weighted medium (2) and high (3) scores across the environmental issues for the extractive activities - construction minerals (see the List of abbreviations).



— Energy and water consumption have similar levels of medium and high scores for metallic, industrial and construction minerals.

— Industrial minerals and metallic minerals have medium and high scores across all environmental issues considered.

From the identification or scoring of the KEI, it can be concluded that:

— The KEI scoring reveals that the differences in scoring results are larger between the various extractive activities than between the groups of mineral resources (see Table 3 in Annex 1). Variations between mineral resources reflect specificities such as the use of explosives for extraction of phosphate rock leading to nitrate emissions, the high level of vibrations during physical separation of aggregates using vibrating screens, odour emissions from the handling, transport, and storage of peat.

— The highest number of 'high and medium' scores are allocated to the extraction phase, covering most of the mineral resources.

— Some of the environmental issues and the scoring thereof are linked to each other. The impacts on structural stability affecting the structural integrity of the extractive areas for example, can be caused by different aspects, such as seismicity or extreme events, include climate events. They can also impact other environmental issues, for example emissions to groundwater, surface water and physical stability of any stored by-products, or concentrate. Also, the emissions of NO_x (combustion emissions) are linked to the use of energy, e.g. diesel fuels.

— Structural stability, and the related adaptation to climate change, considers impacts in the short and in the long term during life cycle phases, including closure and after-closure and this influences the assigned scoring.

— Energy consumption and related GHG and other combustion emissions to air are considered most relevant for treatment processes, the extraction phase, but also for hauling. Electric motors are often used for separation and other treatment processes, and, therefore, these are not causing major issues for combustion emissions.

— Particular attention is paid to the aggregated impacts scored as medium and high in the PRT identification. The mining experts observed that the level of the disaggregation for the scoring of the KEI did not always result in different scoring results across groups of minerals. It can be thus expected that also the PRT will likely address more than one group of minerals.

— Though rehabilitation in itself intends to restore the land and create positive impacts on biodiversity (reversing the negative impacts), water quality and landscape, the activities to do this can lead to a (temporary) aggregated impact and have been considered as such. Hence, for example, structural and physical stability present high scores during this phase.

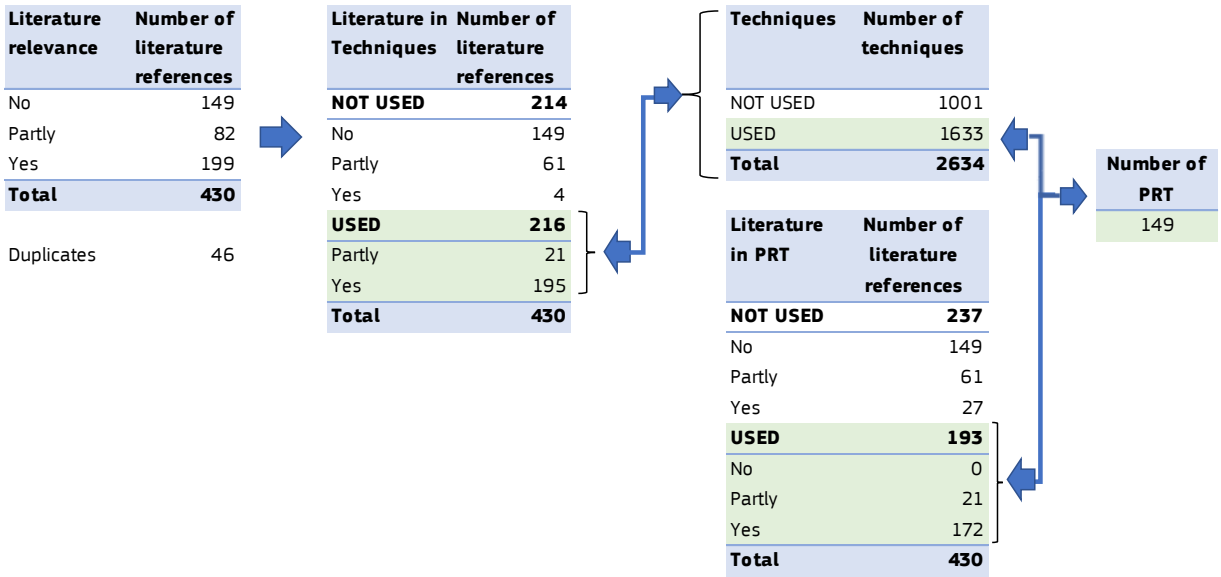
4 Overview on available techniques for the prevention or reduction (PRT) of environmental impacts

4.1 Analysis of the literature references considered relevant and used for deriving techniques

Information and documents on PRT for the NEEI were gathered from Member State authorities, industry associations, environmental NGOs and other relevant stakeholders via a data and information collection exercise. They were complemented by a literature search. The data collection process and an in-depth analysis of the exchanged information are reported in Annex 2.

In summary, 430 unique references (excluding 46 duplicates provided by stakeholders) were collected, out of which 216 references were used to extract 1633 techniques, which were in turn bundled into 149 PRT (see Figure 7). Certain references were not used because they were not publicly available or out of the scope of this study or because they contained generic information on case studies, legislation, permitting and measuring procedures rather than specific information on PRT (for more details, see Annex 2)

Figure 7. Summary of the collected literature references



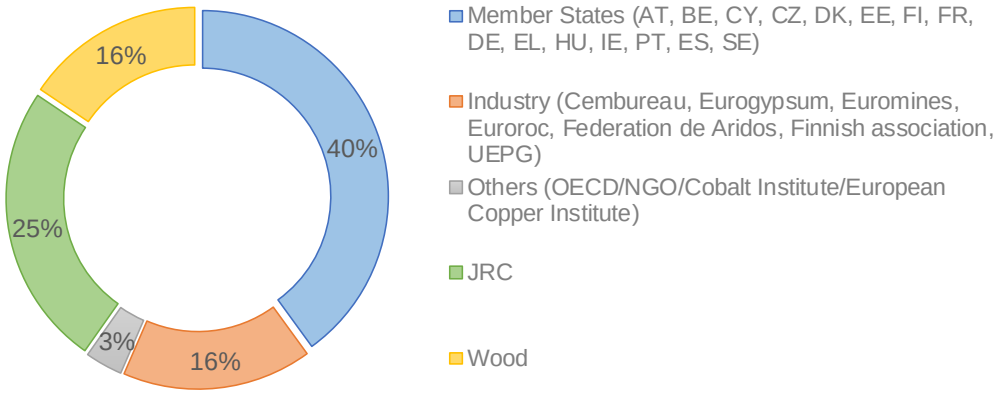
- 244 references were classified as sources from EU Member States (category A, 56%); 150 from non-EU countries (category B, 35%); and 36 on other similar relevant activities from EU Member States (category C, 8%).
- 266 of references reviewed were in English (62%), 164 in non-English languages (38%), covering Czech, Danish, Dutch, Estonian, Finnish, French, German, Greek, Hungarian, Macedonian, Portuguese, Russian, Swedish and Spanish. In addition, contacts in native languages were made with experts in Bulgaria, China, Italy, Poland and Romania.
- 25 references reviewed date from before the year 2000, all other references are more recent, with 163 from the last 5 years (2015-2019).

Moreover, 193 references (89% directly relevant and 11% partly relevant) were finally used in the PRT (see Figure 7), out of which:

- 111 references were classified as sources from EU Member States (A, 58%); 76 from non-EU countries (B, 39%); and 6 on other similar relevant activities from EU Member States (C, 3%). Sources from EU Member States especially apply in ES, SE, the whole EU, PT, FI, EE, DE, CY and IE, while sources from non-EU countries mainly apply in Australia, USA, Canada, Russia and Asia as well as worldwide.
- 41% consist of guidance documents, 18% consist of technical reports and 13% consist of webpages.

Among the total 430 references gathered, 40% was provided by Member States (of which 86% by ES, EL, DE, PT, SE and FI), 16% by industry (of which 72% by the construction mineral associations), 3% by others and 41% complemented by literature search (see Figure 8).

Figure 8. Literature references provided by different stakeholders



During the consultation, stakeholders suggested additional literature references, which have not been included in the analysis, but listed in Figure 19 in Annex 5 for future references and studies.

4.2 Overview of the techniques extracted from the literature references

A list of 2634 techniques for preventing or reducing negative impacts was extracted from the 430 references based on a review of the available literature identified (see Figure 7). Relevant information was extracted, such as the title of the technique, the relevant group of mineral resources, extractive activities and the key environmental issue to which the technique applies. Duplicates of the same technique but targeting different environmental issues were included.

1633 techniques out of 2634 (62%) were used to derive the PRT. The remaining 1001 techniques were not taken into consideration because of the following main reasons:

- About 33% of the discarded techniques refer to the treatment of the Extractive Influenced Water (EIW, which may also be referred as Mine Water), including Acid Mine Drainage/Acid Rock Drainage (AMD/ARD) management and treatment. The EIW was included in the scope of the MWEI BREF only when mixed with the EWIW. Anyhow, as the techniques described in the MWEI BREF for the treatment of EWIW (see BAT 45-47 in European Commission, 2018) may be similar and also apply to the EIW treatment, there was no need of an in-depth analysis to identify already well-defined techniques. The BAT on prevention or minimisation of emissions to surface water included in the MWEI BREF, together with examples of abated pollutants or targeted parameters, have been summarised in Table 18 in Annex 5, in order to highlight where potential information for the PRT for emissions to surface water may be retrieved. However, during the consultation, stakeholders pointed out the need of better developing the PRT for emissions to surface water, particularly with reference to nitrogen removal as a stand-alone technique. This in-depth analysis may be carried out in future potential guidance or reference documents.
- Some techniques focus on elements not included in the scope of the study, such as the extractive waste management or exploration activities.
- Some techniques were derived from BREF already published by the European Commission, such as the BREF for emissions from storage, and there was no need to analyse them in detail.

— Several techniques describe commonly applied process and techniques for the extraction, treatment, handling and transport and storage of non-energy mineral resources rather than techniques to prevent or reduce environmental impacts. For example, gravity concentration or flotation were considered as usually applied mineral processing techniques and not as PRT.

— Similar techniques but with slightly different titles may have not been grouped into the same PRT.

— The main goal of the exercise was to propose an extensive selection of PRT that cover the sector in a comprehensive and balanced way. This selection was not meant to be exhaustive and it particularly focused on the PRT targeting KEI with medium (2) and high (3) scores (see Section 3.2). Therefore, not all the identified techniques, particularly the very specific ones, were included in the final PRT.

4.3 Overview of the PRT

Based on the list of techniques, it was considered how certain techniques could be grouped into one or more PRT. There are, for example, variations of similar techniques that were aggregated into a single PRT proposal, whilst for other techniques, a presentation of a particular technique in a single PRT appeared more appropriate.

Furthermore, the preliminary identification of the KEI (see Section 3), and in particular the aspects with high (3) and medium (2) scores, assisted with scoping the PRT (see Figure 7).

The PRT titles, including the indication of the cross-references to the same techniques impacting other environmental aspects, the targeted main and secondary KEI (see Table 13 in Annex 3), are listed in Table 1.

Additional information on the proposed PRT is reported in Annex 4 Table 14. It includes collected literature references, a short description, generic information on quantitative indicators/criteria or applicability restrictions, and sites where the PRT is applied (A-B-C categories, see Annex 3), together with the level of implementation (as assigned by the Wood mining experts).

It is necessary to underline that this study is a purely informative document, where the information from literature was grouped and classified based on the information reported in the literature references, without any assessment or evaluation. The exercise consisted merely of collecting information on techniques and assigning them into categories, without an assessment of their actual contribution to the prevention or reduction of negative impacts on the environment from non-energy extractive activities.

Table 1. PRT titles, including the indication of cross-references (*in italics*), main and secondary KEI

KEI	PRT group	PRT No.	PRT title	Cross-reference	Secondary KEI
Generic PRT					
All KEI	Corporate management	PRT001	Organisational and Corporate Management System		
		PRT002	Environmental Management System		
	Information and data management	PRT003	Extractive site characterisation (incl. baseline study)		
		PRT004	Extractive activities options		
		PRT005	Environmental Impact Assessment		
		PRT006	Public and community engagement		
		PRT007	Environmental monitoring programmes		
Risk-specific PRT to ensure **SAFETY (STABILITY)**					
Structural stability, and related adaptation to climate change	Design for closure	PRT008	Design for closure		Physical stability, Emissions to soil and groundwater, Emissions to surface water, Emissions to air - dust
	Additional Organisational and Corporate Management tools	PRT009	Additional Organisational and Corporate Management tools		All
	Ground investigation	PRT010	Ground investigation		Emissions to soil and groundwater
	Selection of extraction methods	PRT011	Selection of extraction methods to ensure structural stability, and related adaptation to climate change, in the long term		Physical stability, Emissions to soil and groundwater, Emissions to surface water
	Developing blasting schedules	*PRT012*	*Developing blasting schedules*	*PRT107*	
	Water management	PRT013	Water management		Emissions to soil and groundwater, Emissions to surface water, Water consumption, Consumption of auxiliary materials
		PRT014	Drainage systems		Physical stability, Emissions to soil and groundwater, Emissions to surface water, Biodiversity and land use - habitats, plants, wildlife, Water consumption

	Geotechnical analysis and monitoring	PRT015	Geotechnical analysis		Emissions to soil and groundwater
		PRT016	Geotechnical monitoring		Physical stability, Emissions to soil and groundwater
		PRT017	Geotechnical conformance checks and audits		Physical stability, Emissions to soil and groundwater
Physical stability	Backfill stabilisation techniques	PRT018	Stabilisation of the backfill material		Structural stability
	Backfilling	PRT019	Backfilling		Structural stability, Emissions to soil and groundwater, Emissions to surface water
Chemical stability	Prevention or minimisation of pollutant leaching	PRT020	Automatic cyanide control		Emissions to soil and groundwater, Hazardous materials
		PRT021	Reduction of cyanide use		Emissions to soil and groundwater, Hazardous materials
		PRT022	Pre-aeration of the ore		Emissions to soil and groundwater, Hazardous materials
		PRT023	Monitoring cyanide concentrations		Emissions to soil and groundwater, Hazardous materials
	Prevention or minimisation of AMD/ARD	PRT024	AMD/ARD management strategy		Emissions to soil and groundwater, Emissions to surface water – acidity & metals
		PRT025	Conceptual site model of AMD processes		Emissions to soil and groundwater
		PRT026	Desulphurisation/sulphuric acid onsite production		Emissions to surface water - acidity & metals
		PRT027	*Progressive rehabilitation*	*PRT043*	
		PRT028	*Permanent dry covers*	*PRT045*	
		PRT029	*Permanent free water and wet covers*	*PRT046*	
Stability	Monitoring of physical and chemical stability	PRT030	Monitoring of physical and chemical stability		Physical stability, Emissions to soil and groundwater
Risk-specific PRT for the prevention or minimisation of **EMISSIONS TO SOIL AND GROUNDWATER**					
Diffused and channelled emissions to soil and groundwater	Soil management	PRT031	Soil management		Structural stability, Emissions to surface water - TSS, Emissions to air – dust, Biodiversity and land use - habitats, plants, wildlife
	Explosives management	PRT032	Nitrogen and explosives management		Emissions to surface water, Emissions to air - VOC, Noise emissions, Vibrations
		PRT033	Impermeable natural soil basal structure		Chemical stability

	Basal structures and physical barriers	PRT034	Impermeable artificial basal structure		Chemical stability
		PRT035	Secondary containment		Emissions to surface water, Water consumption, Hazardous materials
	Water management	*PRT036*	*Water management*	*PRT013*	*Emissions to surface water - TSS*
		PRT037	*Hydrologic control*	*PRT061 (part of it)*	
		PRT038	*Recycling of water*	*PRT060*	
		PRT039	*Diversion of water run-off systems*	*PRT062 (part of it)*	*Structural stability*
		PRT040	*Drainage systems*	*PRT014*	
		PRT041	*Landscaping and geomorphic reclamation*	*PRT119*	
		PRT042	*Water treatment techniques*	*PRT063, 078*	
	Covering	PRT043	Progressive rehabilitation		Emissions to surface water, Emissions to air – dust, Biodiversity and land use - habitats, plants, wildlife & visual impacts
		PRT044	Revegetation		Emissions to surface water, Emissions to air – dust, Biodiversity and land use - habitats, plants, wildlife
		PRT045	Permanent dry covers		Chemical stability, Emissions to air – dust,
		PRT046	Permanent free water and wet covers		Chemical stability
	Heap bioleaching	PRT047	Heap bioleaching		
	Groundwater and soil pollution remediation	PRT048	Remediation of contaminated soil - Permeable Reactive Barriers (PRBs)		
		PRT049	Remediation of contaminated soil - phytoremediation		
		PRT050	Remediation of contaminated soil - stabilisation		
		PRT051	Remediation of contaminated soil - encapsulation		
		PRT052	Remediation of contaminated soil - soil washing		
		PRT053	Remediation of contaminated soil - thermal desorption		
		PRT054	Remediation of contaminated soil - (bio)venting		
		PRT055	Remediation of contaminated soil - natural attenuation or in-situ bioremediation		
		PRT056	Remediation of contaminated soil - composting		
	Monitoring of emissions to soil and groundwater	PRT057	Monitoring of emissions to soil and groundwater		Chemical stability, Water consumption
		PRT058	Leakage detection systems		Hazardous materials

Risk-specific PRT for the prevention or minimisation of **EMISSIONS TO SURFACE WATER**					
EIW generation	EIW generation prevention or minimisation	*PRT059*	*Water management*	*PRT013*	
		PRT060	Re-use or recycle the excess water		Water consumption
		PRT061	Erosion and sediment control		Structural stability, Emissions to soil and groundwater, Emissions to air - dust, Biodiversity and land use - habitats, plants, wildlife & visual impacts, Water consumption
		PRT062	Stormwater management		Structural stability, Emissions to soil and groundwater, Water consumption
Suspended particles	Removal of suspended solids or suspended liquid particles	PRT063	Removal of suspended solids or suspended liquid particles		Emissions to soil and groundwater, Water consumption
Anions contaminants	Removal of anions contaminants	*PRT064*	*Oxidation based systems*	*PRT068*	
		PRT065	*Reduction based systems*	*PRT069*	
		PRT066	*Ion exchange*	*PRT073*	
		PRT067	*Filtration of dissolved substances*	*PRT074*	
Metals and metalloids	Removal of metals and metalloids	PRT068	Oxidation based systems		
		PRT069	Reduction based systems		
		PRT070	Chemical precipitation		
		PRT071	Co-precipitation with chloride or sulphate metal salts		
		PRT072	Adsorption		
		PRT073	Ion exchange		
		PRT074	Filtration of dissolved substances		
Organic contaminants	Removal of organic contaminants	*PRT075*	*Oxidation based systems*	*PRT068*	
		PRT076	*Adsorption*	*PRT072*	
Acidity and dissolved substances	Removal of acidity and dissolved substances	PRT077	Active neutralisation		
		PRT078	Passive neutralisation		
Emissions to surface water	Monitoring of emissions to surface water	PRT079	Monitoring of emissions to surface water		Emissions to soil and groundwater, Water consumption

Risk-specific PRT for the prevention or minimisation of **EMISSIONS TO AIR AND RELATED CLIMATE IMPACTS**					
Dust	Prevention or minimisation of dusting from blasting	*PRT080*	*Planning and design of blasting*	*PRT105*	*Energy consumption*
	Prevention or minimisation of dusting from exposed surfaces	PRT081	Water or water-based solutions spraying of exposed surfaces		
		PRT082	Wind protection systems		Noise emissions
		PRT083	*Reduction and minimisation of exposed surfaces*	*PRT043, 044, 045, 046, 061, 119*	
	Prevention or minimisation of dusting from equipment, roads and facilities	PRT084	Enclosing equipment and facilities		Noise emissions, Odour emissions
		PRT085	Water or water-based solutions spraying equipment and roads		
		PRT086	Road and equipment maintenance		Energy consumption
		PRT087	Organisational techniques for transport and handling		Emissions to air - VOC & GHG and other combustion emissions, Energy consumption
	Prevention and monitoring of dusting from channelled emissions	PRT088	Air collection - dust emissions		
		PRT089	Treatment of channelled dust emissions		
VOC and other potential pollutants emissions	Prevention or minimisation of emissions of VOC and other potential air pollutants	*PRT090*	*Nitrogen and explosives management*	*PRT032*	
		PRT091	Advanced explosive techniques and alternatives to blasting		Emissions to soil and groundwater, Emissions to air - dust & GHG and other combustion emissions, Noise emissions, Vibrations
		PRT092	Treatment of channelled VOC and other potential air pollutants emissions		Odour emissions
GHG and other combustion emissions	Prevention and minimisation of GHG and other combustion emissions	PRT093	Decarbonisation		Energy consumption
		PRT094	Increased equipment efficiency		Energy consumption
Emissions to air	Monitoring of air emissions	PRT095	Monitoring of dust, VOC, GHG and other combustion emissions		
Risk-specific PRT for the prevention or minimisation of **OTHER EMISSIONS**					
Noise		PRT096	Noise and vibration management plan		Vibrations
		PRT097	Noise protection systems		

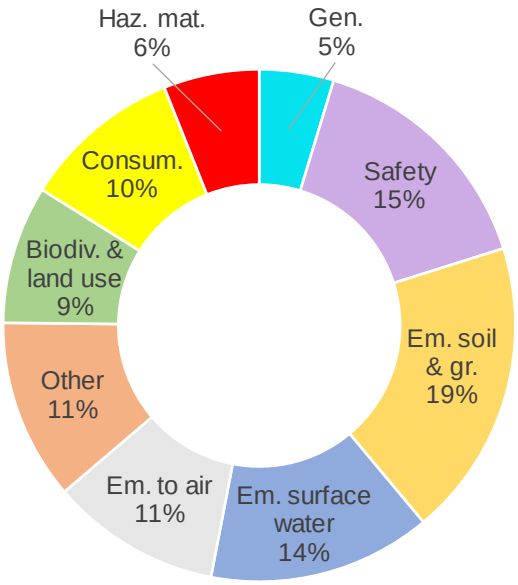
	Prevention or minimisation of noise emissions	*PRT098*	*Planning and design of blasting*	*PRT105*	
		PRT099	*Staging the charges and blasting quantity*	*PRT106*	
		PRT100	*Developing blasting schedule*	*PRT107*	
		PRT101	Organisational techniques for noise reduction		
		PRT102	Noise insulation of equipment and facilities		Vibrations
	Monitoring of noise emissions	PRT103	Monitoring of noise emissions		
Vibrations	Prevention or minimisation of vibrations	PRT104	Ground vibration and overpressure control with appropriate drilling grids		
		PRT105	Planning and design of blasting		Structural stability, Emissions to air – dust & GHG and other combustion emissions, Noise emissions, Biodiversity and land use - habitats, plants, wildlife & impacts on materials assets
		PRT106	Staging the charges and blasting quantity		Structural stability, Emissions to air – dust & GHG and other combustion emissions, Noise emissions
		PRT107	Developing blasting schedules		Structural stability, Emissions to air – dust & GHG and other combustion emissions, Noise emissions
		PRT108	Advanced initiation techniques		Emissions to air - dust & GHG and other combustion emissions, Noise emissions
		PRT109	Vibration control techniques for equipment and facilities	PRT102 (partly)	Emissions to air - dust, Noise emissions
	Monitoring of vibrations	PRT110	Monitoring of vibrations		
Odour	Prevention or minimisation of odour emissions	*PRT111*	*Odour treatment techniques*	*PRT043, 044, 092*	
	Monitoring of odour emissions	PRT112	Monitoring of odour emission		Emissions to air - VOC
Risk-specific PRT for the prevention or minimisation of **BIODIVERSITY AND LAND USE IMPACTS**					
Habitats, plants and wildlife	Prevention or minimisation of	PRT113	Ecological survey		Biodiversity and land use - visual impacts
		PRT114	Strategy for terrestrial habitat preservation		Biodiversity and land use - visual impacts
		PRT115	Strategy for aquatic habitat preservation		

	impacts on habitats, plants and wildlife	PRT116	Soil conservation measures		Emissions to soil and groundwater, Emissions to surface water - TSS, Biodiversity and land use - visual impacts
		PRT117	Other measures for minimisation of biodiversity and land use impacts		Emissions to soil and groundwater, Biodiversity and land use - visual impacts
		PRT118	Rehabilitation techniques		Emissions to soil and groundwater, Emissions to air – dust, Biodiversity and land use - visual impacts
		PRT119	Landscaping and geomorphic reclamation		Physical stability, Emissions to soil and groundwater, Emissions to air – dust, Biodiversity and land use - visual impacts
Visual, footprint and landscape impacts	Prevention or minimisation of visual, footprint and landscape impacts	PRT120	Topographical and land surveys		Biodiversity and land use - habitats, plants, wildlife
		PRT121	Visual barriers		
		PRT122	Visual impact optimisation	PRT043, 119 (partly)	
Impacts on material assets and cultural heritage	Prevention or minimisation of material assets impacts	PRT123	Cultural heritage assessment		Biodiversity and land use - habitats, plants, wildlife
		PRT124	Minimise adverse impacts and implement restoration measures		Biodiversity and land use - habitats, plants, wildlife
		PRT125	Community consultation, engagement and protection		Biodiversity and land use - habitats, plants, wildlife
Risk-specific PRT for the prevention or minimisation of **CONSUMPTION**					
Energy consumption, and related contribution to climate change	Prevention or minimisation of energy consumption	PRT126	Energy use: balance, reporting and audit		Emissions to air - VOC & GHG and other combustion emissions
		PRT127	Benchmarking - Best Truck Ratio (BTR) assessment tool		Noise emissions
		PRT128	Generic energy consumption reduction techniques		Emissions to air - GHG and other combustion emissions
		PRT129	Operational energy consumption reduction techniques		Emissions to air - GHG and other combustion emissions
		PRT130	Optimisation of crushing and grinding processes		Emissions to air - dust & GHG and other combustion emissions
		PRT131	Optimisation of material flow		Emissions to air - dust & GHG and other combustion emissions
		PRT132	Friction reduction and wear protection		Emissions to air - dust

		PRT133	Mine automation		Structural stability, Physical stability, Chemical stability, Emissions to soil and groundwater, Emissions to surface water, Emissions to air, Consumption of auxiliary materials
		PRT134	Digitalisation		Emissions to air - GHG and other combustion emissions
		PRT135	*Decarbonisation: Renewable energy - solar*	*PRT093*	
Water consumption	Prevention or minimisation of water consumption	*PRT136*	*Water management*	*PRT013*	
		PRT137	Water consumption reduction measures		Emissions to surface water
		PRT138	Water recovery techniques		Emissions to surface water
Reagents and auxiliary materials	Prevention or minimisation of reagents and auxiliary material consumption	PRT139	Auxiliary materials recovery techniques		
		PRT140	Design, inspection, maintenance of storage tanks		Emissions to soil and groundwater
Risk-specific PRT for the prevention or minimisation of **HAZARDOUS MATERIALS IMPACTS**					
Hazardous materials	Lubricants, fuels, chemical management	PRT141	Use minimisation of hazardous substances		
		PRT142	Elimination and substitution of hazardous substances		Emissions to surface water
		PRT143	*Nitrogen and explosives management*	*PRT032*	
		PRT144	Mobile Manufacturing Units Explosives		Emissions to air - dust
		PRT145	*Leakage detection systems*	*PRT058*	*Emissions to surface water, Emissions to air, Odour emissions*
		PRT146	*Secondary containment*	*PRT034, 035*	*Emissions to air*
		PRT147	Lubricants and fuel management		Emissions to soil and groundwater, Emissions to surface water
	Cyanide management	PRT148	Cyanide management		Chemical stability, Emissions to soil and groundwater
		PRT149	*Monitoring cyanide concentrations*	*PRT023*	

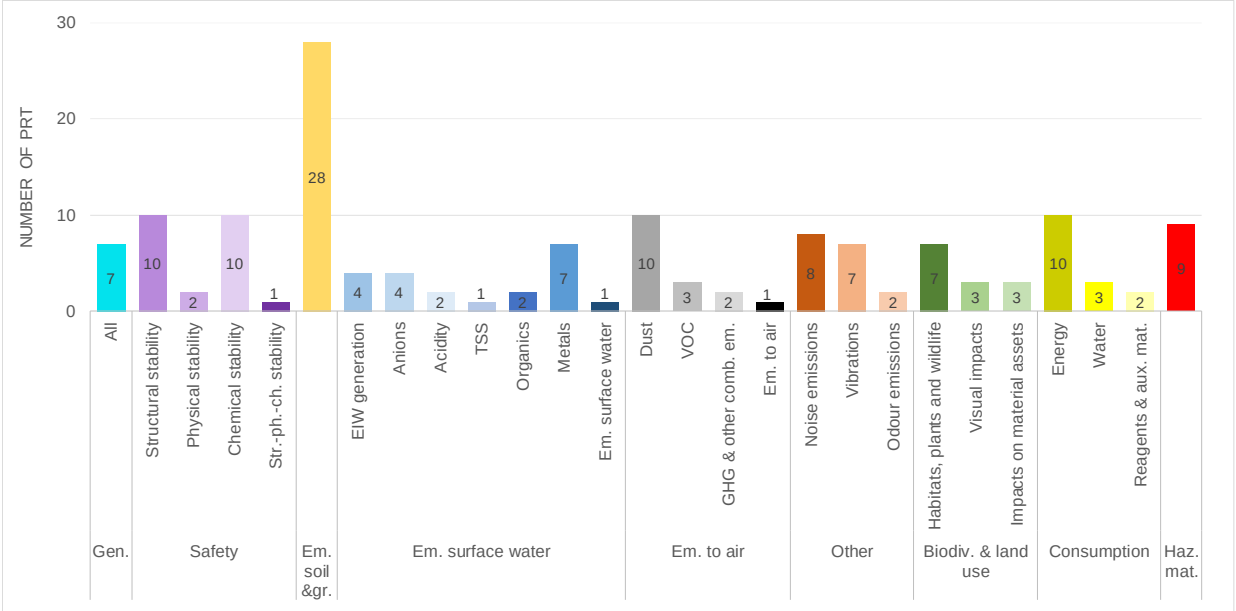
The proposed PRT cover all main KEI groups, as shown in Figure 9.
The higher number of PRT (19%) is proposed for emissions to soil and groundwater, the smaller number for hazardous materials (6%) or the generic KEI (5%).

Figure 9. PRT share for each main KEI group (see the List of abbreviations).



The number of PRT for each main KEI is shown in Figure 10. For example, PRT on safety represent 15% of the total PRT proposed, with 10 PRT on structural stability, 2 PRT on physical stability, 10 PRT on chemical stability and 1 PRT on monitoring for the three types of stability issues.

Figure 10. Number of PRT per main KEI. Colours reveal the number of PRT for each KEI category included in each main KEI (see the List of abbreviations).

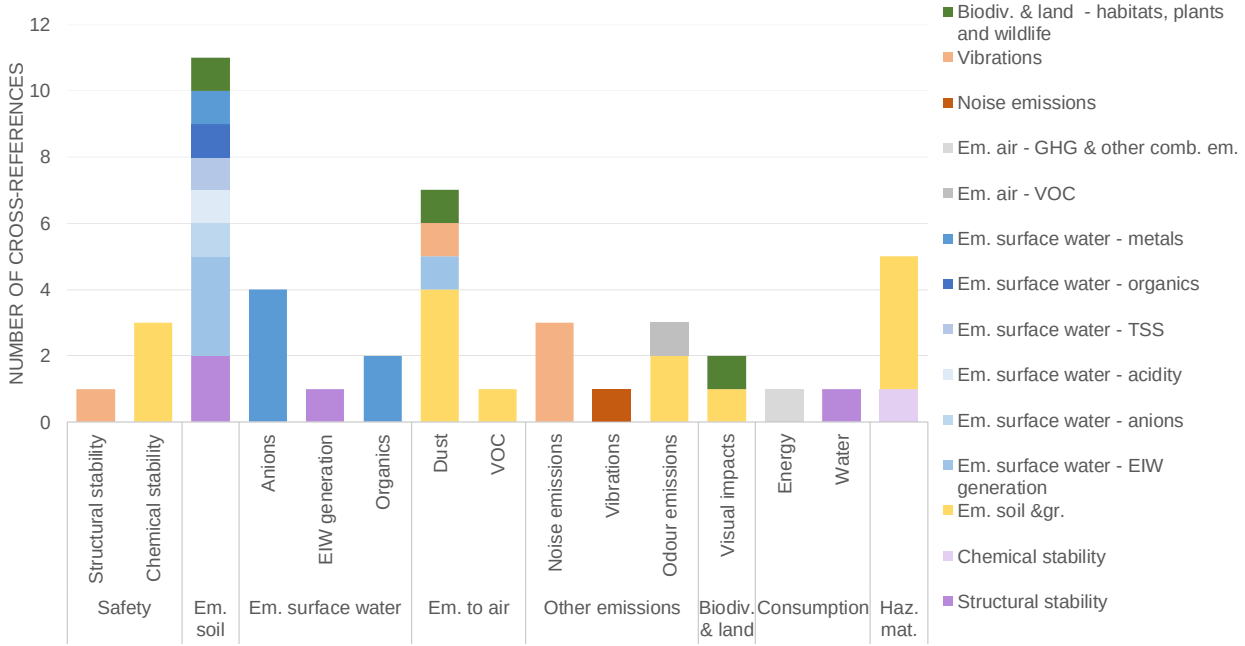


Based on the information reported in the collected literature references, and as pointed out as a conclusion of the scoring exercise, the same PRT can impact more than one KEI (such as vibrations and noise emissions) at the same time, which both represent main targeted KEI. To reflect this, cross-references were included (see Table 1). For example:

- Developing blasting schedules can be applied to prevent or reduce vibrations or noise emissions or to help ensuring structural stability (see PRT 107, 100 and 102 in Table 1).
- Nitrogen and explosives management can be applied to prevent or reduce emissions to soil and groundwater, emissions to air, particularly VOC and other potential pollutants emissions, and hazardous materials impacts (see PRT 032, 090 and 143 in Table 1).
- Covering systems such as progressive rehabilitation, permanent dry covers, permanent free water and wet covers can be applied to prevent or reduce emissions to soil and groundwater, but also AMD/ARD (see PRT 027, 028, 029, 043, 045 and 046 in Table 1).
- Water management can be applied to help ensuring structural stability, and related adaptation to climate change, and to prevent or reduce emissions to soil and groundwater, emissions to surface water, particularly EIW generation, and water consumption (PRT 013, 036, 059 and 136 in Table 1).

As mentioned above, a number of PRT can address more than one main KEI, in which case they are cross-referenced. Cross-references are reported in Table 1 and summarised in Figure 11. For example, a PRT under structural stability (i.e. developing blasting schedules) is cross-referenced to the same PRT under vibrations. Moreover, PRT such as planning and design of blasting, staging the charges and blasting quantity and developing blasting schedule prevent or reduce vibrations but also noise emissions and are cross-referenced in this latter case. Furthermore, the PRT to prevent or reduce anions or organics in the emissions to surface water are the same as the PRT described to prevent or reduce metals and they were thus cross-referenced.

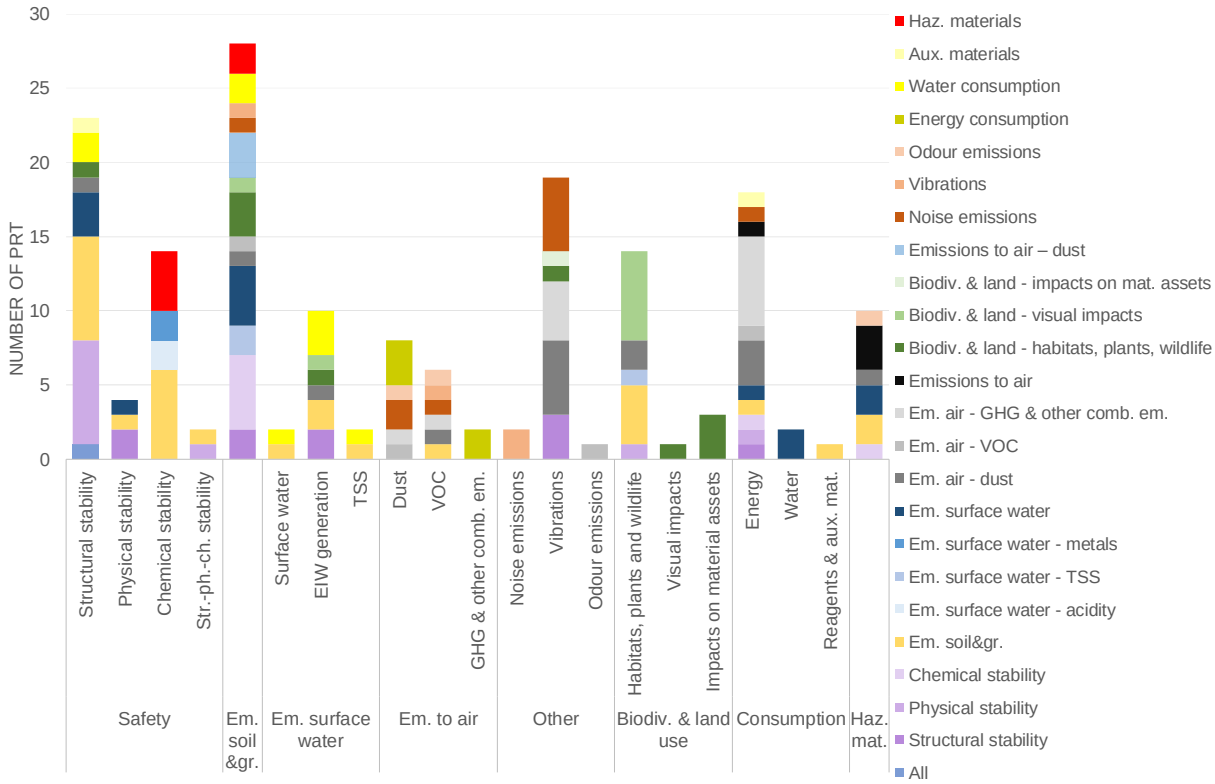
Figure 11. Analysis of the cross-referenced PRT. For those KEI containing cross-referenced PRT (i.e. PRT addressing more than one main KEI), colours reveal which main KEI include the description of the PRT (for example, the PRT on developing blasting schedules is described in PRT107 under vibrations. As this PRT also targets structural stability, PRT012 is included under this KEI, as a cross-reference to PRT107) (see the List of abbreviations).



Different techniques have been grouped in the various PRT. These techniques can target different KEI. Besides identifying the main KEI targeted by each PRT, other KEI, the so called *secondary KEI*, have been assessed by

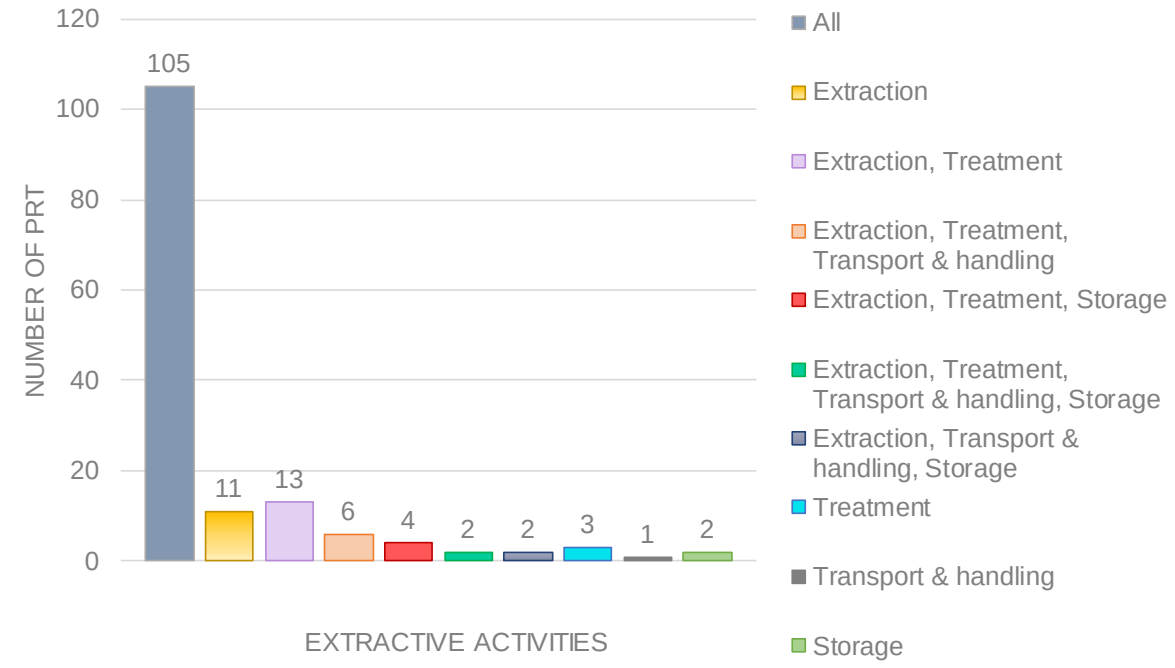
expert judgement for each technique (see Table 13 in Annex 3 for each technique and Table 1 for the proposed PRT). During the consultation, stakeholders also provided input on secondary KEI, which have been included in Table 1. Secondary KEI have not been reported in cross-referenced PRT, to avoid double counting while summing up the number of PRT that apply for each combination of KEI (high and medium scores), extractive activity and mineral resource group (i.e. each cell of the disaggregated KEI Table 3 in Annex 1). The links between the main targeted KEI and the secondary ones are shown in Figure 12.
As an example, PRT aimed at ensuring structural stability can secondarily ensure physical stability. Moreover, PRT applied to prevent or reduce biodiversity impacts on habitats can also help preventing or reducing emissions to soil and groundwater, emissions to surface water (TSS) or visual impacts.

Figure 12. Links between main KEI and secondary KEI. For those PRT also targeting secondary KEI, colours reveal, for each main targeted KEI, which the other targeted secondary KEI are (for example, some PRT ensuring structural stability ensure secondarily physical stability, while some other PRT ensuring structural stability prevent secondarily emissions to soil and groundwater or to air, and so on) (see the List of abbreviations).



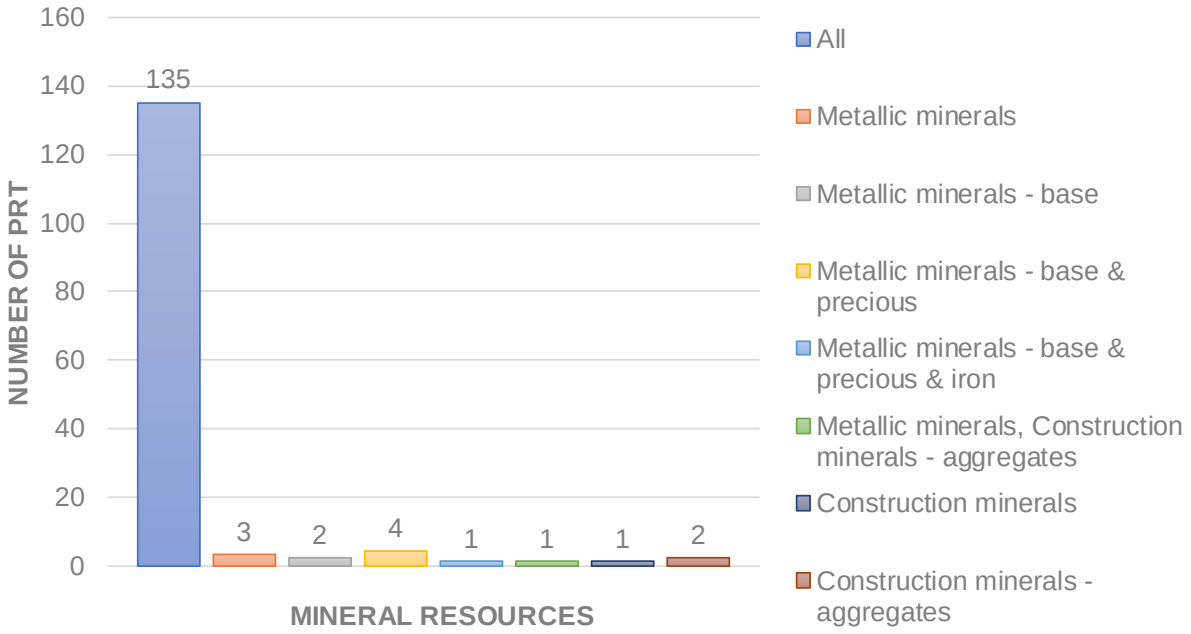
Based on the information reported in the collected literature references, most of the PRT cover more than one extractive activity (see Figure 13 and Table 13 in Annex 3). In these references, 70% of the PRT are indicated as cross-cutting and relevant for all extractive activities, 7% are reported as specifically relevant for extraction, 9% for extraction and treatment, 8% for extraction, treatment, transport and handling and/or storage. Only 2% are indicated as addressing particularly treatment and only 1% transport or storage. The level of details in the collected references does not allow to further describe a detailed relevance for different extractive activities and for this reason many PRT are classified as cross-cutting.

Figure 13. PRT relevant to different extractive activities, based on the information reported in the collected literature references



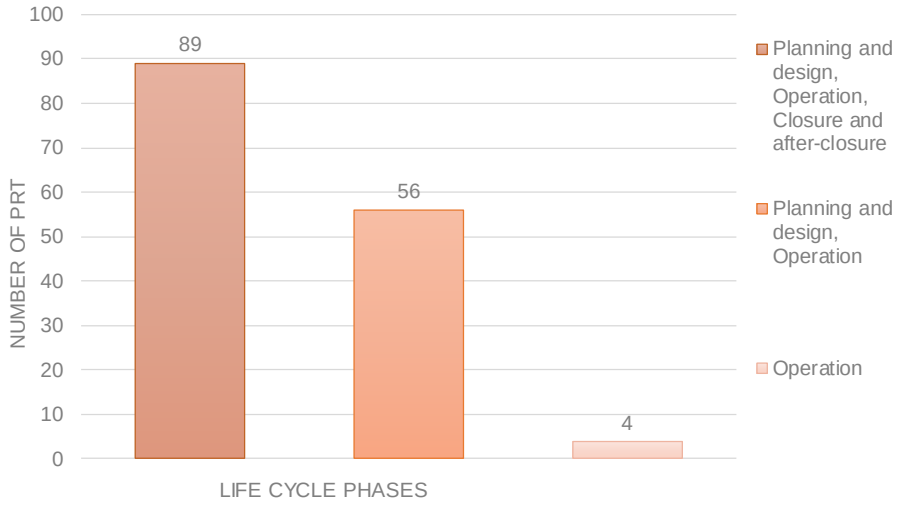
Moreover, based on the information reported in the collected literature references, most of the PRT are indicated to cover more than one mineral resource group, including specific mineral resources such as base metals or aggregates (see Figure 14 and Table 13 in Annex 3). In these references, more than 90% of the PRT are reported as cross-cutting to all mineral resources and 7% are relevant to specific metallic mineral categories. The level of details in the collected references does not allow to further describe a detailed relevance to different mineral resources and for this reason most of the PRT are classified as cross-cutting.

Figure 14. PRT relevant to different non-energy mineral resources, based on the information reported in the collected literature references



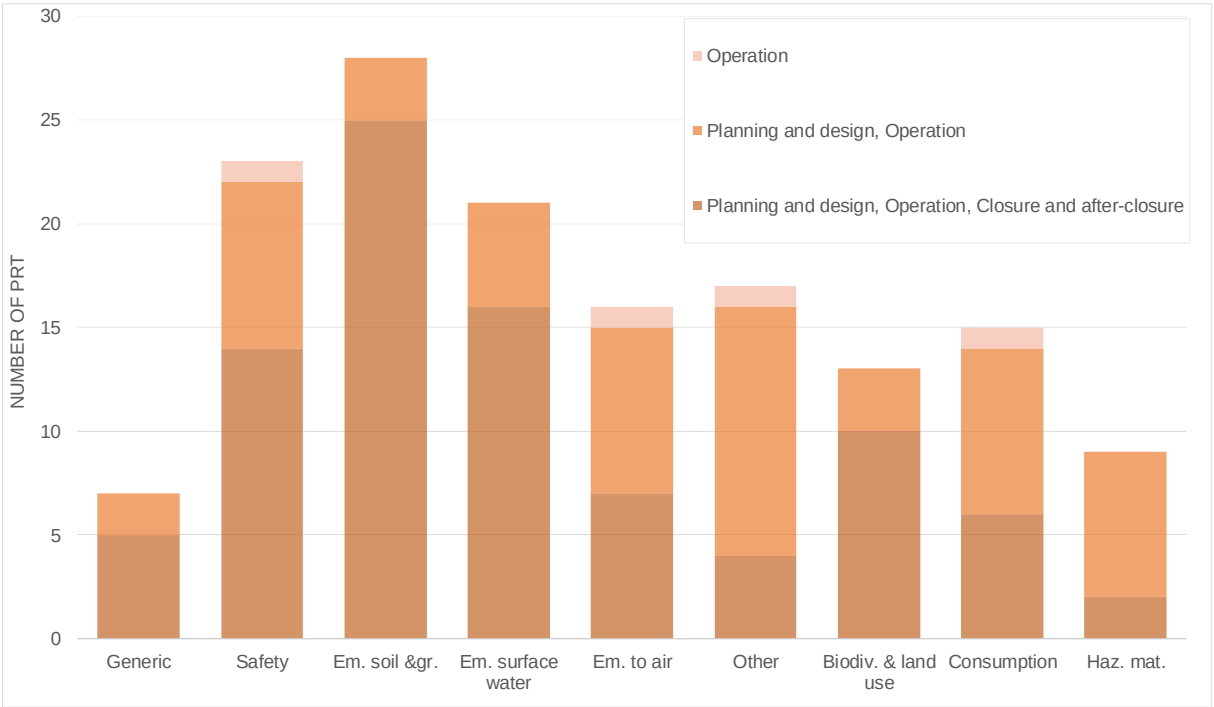
Based on the information reported in the collected literature references, most PRT are indicated as covering more than one life cycle phase (see Figure 15 and Table 13 in Annex 3). In these references, almost 60% of the PRT are reported as cross-cutting to all phases (planning and design, operation, closure and after-closure) and 38% as being applied during planning and design and operation. Only 3% of the PRT are reported as being applied during the operation phase only. PRT being applied exclusively in closure and after-closure have not been identified in these literature references.

Figure 15. PRT applied during different life cycle phases, based on the information reported in the collected literature references



In the case of other emissions (noise, vibrations and odour emissions) and hazardous materials, many PRT are indicated as not relevant during closure and after-closure, but only during planning and design and operation. For other KEI, such as safety, emissions to soil and groundwater, emissions to surface water or biodiversity and land use impacts, PRT are reported in the literature references as mostly relevant for all life cycle phases, including closure and after-closure (see Figure 16).

Figure 16. PRT applied during different life cycle phases across the main KEI groups, based on the information reported in the collected literature references (see the List of abbreviations).



Finally, based on the information reported in the collected literature references, most PRT derive from multiple sources of information (A: EU Member States, B: non-EU countries, C: similar activities in EU) (see Figure 17 and Table 13 in Annex 3). Among the 149 PRT:

- Only 5% derive solely from EU Member States literature references. These PRT target safety, emissions to soil and groundwater, other emissions, consumption and hazardous materials (see Figure 18).
- The majority proceeds from literature references from EU Member States and non-EU countries (A+B, 38%) and from EU Member States, non-EU countries and similar activities (A+B+C, 37%). These PRT address all KEI.
- 9% derive from literature from non-EU countries (B) and target all KEI except from emissions to surface water (see Figure 18).
- 10% proceed from non-EU countries and/or similar activities (B+C, C) and target all main KEI except from emissions to soil and groundwater, biodiversity and land use and hazardous materials (see Figure 18).

Figure 17. PRT classified according to the different sources of information, based on the information reported in the collected literature references

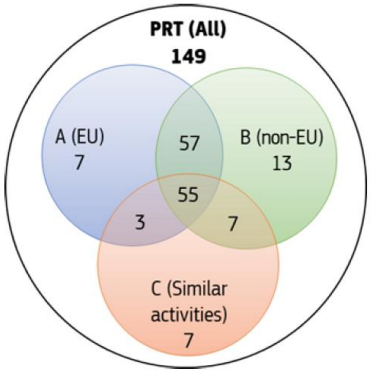
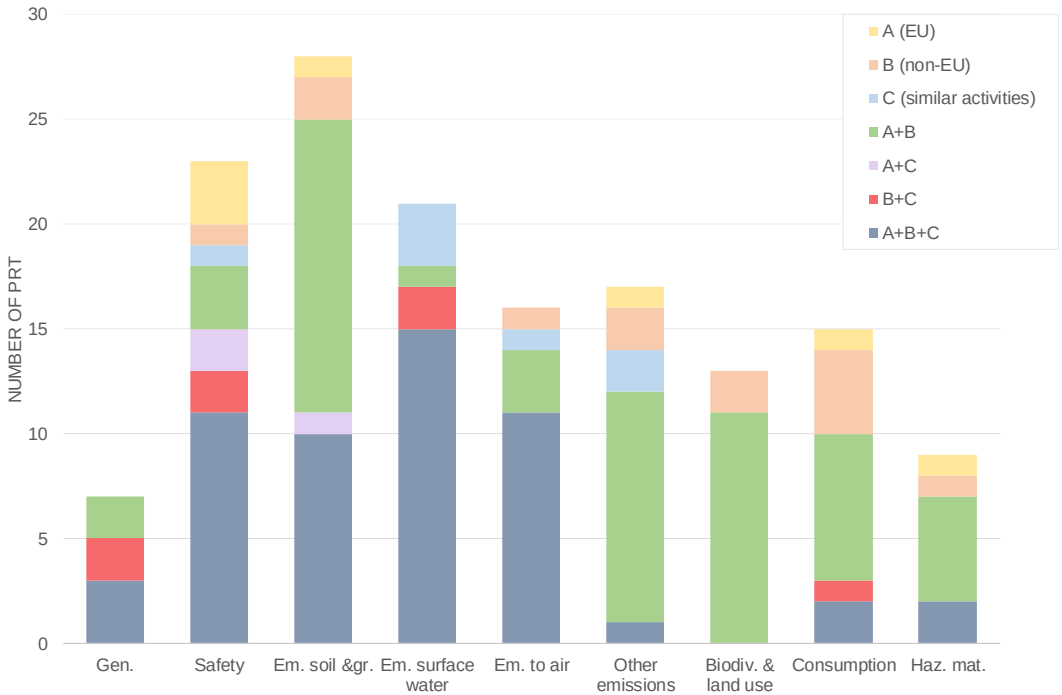


Figure 18. PRT classified for sources of information across the main KEI groups, based on the information reported in the collected literature references (see the List of abbreviations).



Based on the information reported in the collected literature references, it was also assessed if the proposed PRT included generic information on quantitative indicators or criteria, e.g. environmental performance and operational data from well-performing extractive activities of non-energy mineral resources, monitoring frequency (see Table 14 in Annex 4). In these references, 70% of the PRT (excluding cross-references) are reported as not including any quantitative indicator. Moreover, 30% are reported as including some quantitative indicators of which 64% on environmental performance and 25% on both environmental performance and operational data (see Table 2).

Table 2. PRT containing information on quantitative indicators, based on the information reported in the collected literature references

Quantitative indicators	PRT (n.)
PRT with quantitative indicators on:	**36**
Environmental performance	23
Operational data	1
Environmental performance and operational data	9
Qualitative information	3
N/A	**86**
Cross-references	**27**
Total	**149**

Moreover, it was assessed if, based on the information reported in the collected literature references, the proposed PRT include considerations relevant to applicability (such as the possibility of applying the techniques across different geographical areas and extractive sub-sectors, e.g. generally applicable or applicable depending on site-specific conditions, including the limiting factors for application and technical restrictions) (see Table 14 in Annex 4). Out of the 149 PRT:

- 21% are indicated as "generally applicable" and 23% as "widely applicable".
- 2% are indicated as based on the results of a proper Environmental Impact Assessment (EIA).
- 34% are reported as containing some consideration on applicability or technical restriction, including making reference to site specific conditions.
- 20% are reported as cross-references and 4% do not include any indication.

As emphasized by stakeholders during the consultation, site-specific conditions for each individual extractive site need to be properly defined by carrying out a comprehensive EIA, following a risk-specific approach. Depending on the EIA outcomes, one or more generic and/or risk-specific PRT are applied for a specific situation to prevent or reduce the identified environmental impacts (see Section 3.1).

In the collected literature references, consideration and restrictions on applicability appear to be more frequently included under PRT addressing emissions to soil and groundwater, to surface water and to air. In these references, PRT for safety, other emissions, biodiversity and land use, consumption and hazardous materials are reported as widely or generically applicable (see Figure 19). The level of details in the collected references does not allow to further detail the applicability conditions.

Based on a specific assessment of the Wood mining experts on the information reported in the collected literature references, generic information was also provided on the levels of implementation of the PRT by semi-quantitatively analysing if less than 10%, or between 10 and 50% or more than 50% of extractive industries are concerned by the specific environmental risk addressed by the technique (see Table 14 in Annex 4). Among the 149 PRT:

- 7% are indicated as being applied when less than 10% of extractive industries are concerned by the specific environmental risk addressed. This refers particularly to emissions to surface water (metals), emissions to air and related climate impacts (GHG and other combustion emissions), vibrations, energy consumption and hazardous materials (see Figure 20).
- 36% are indicated as being applied when 10-50% of extractive industries are concerned by the specific environmental risk addressed.
- 58% are indicated as being applied when more than 50% of extractive industries are concerned by the specific environmental risk addressed.

Figure 19. PRT presenting some applicability considerations across the main KEI groups, based on the information reported in the collected literature references (see the List of abbreviations).

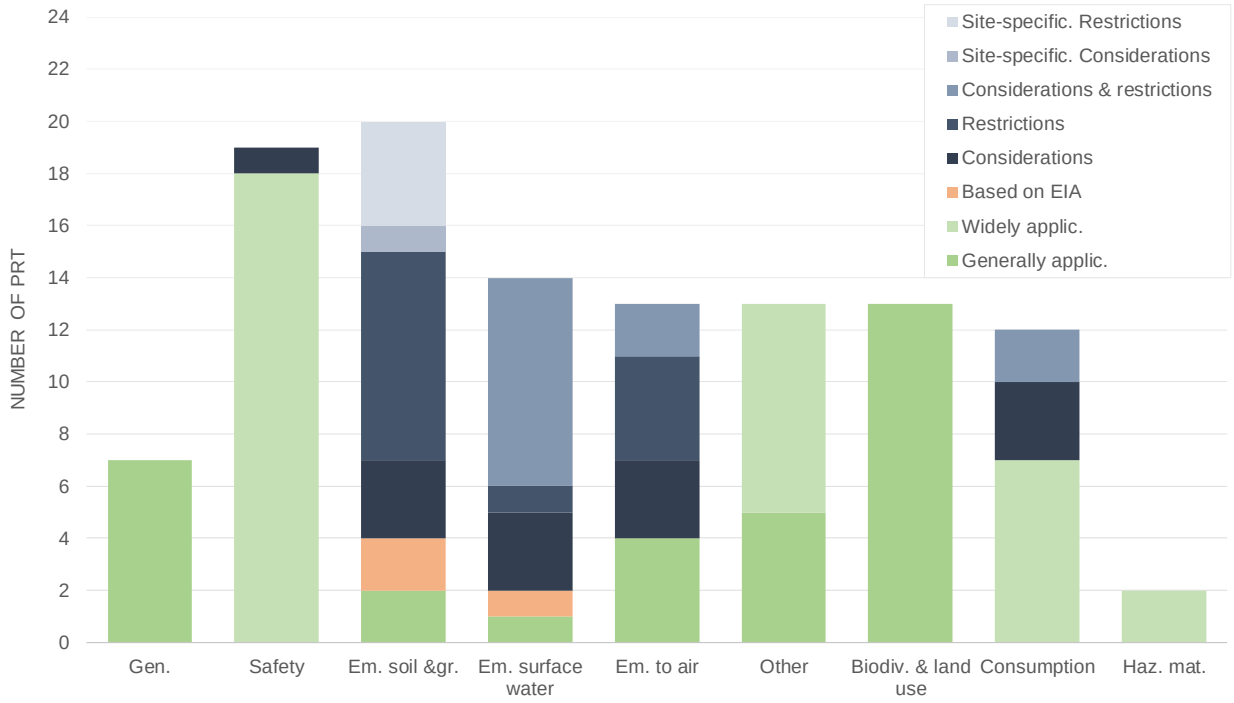
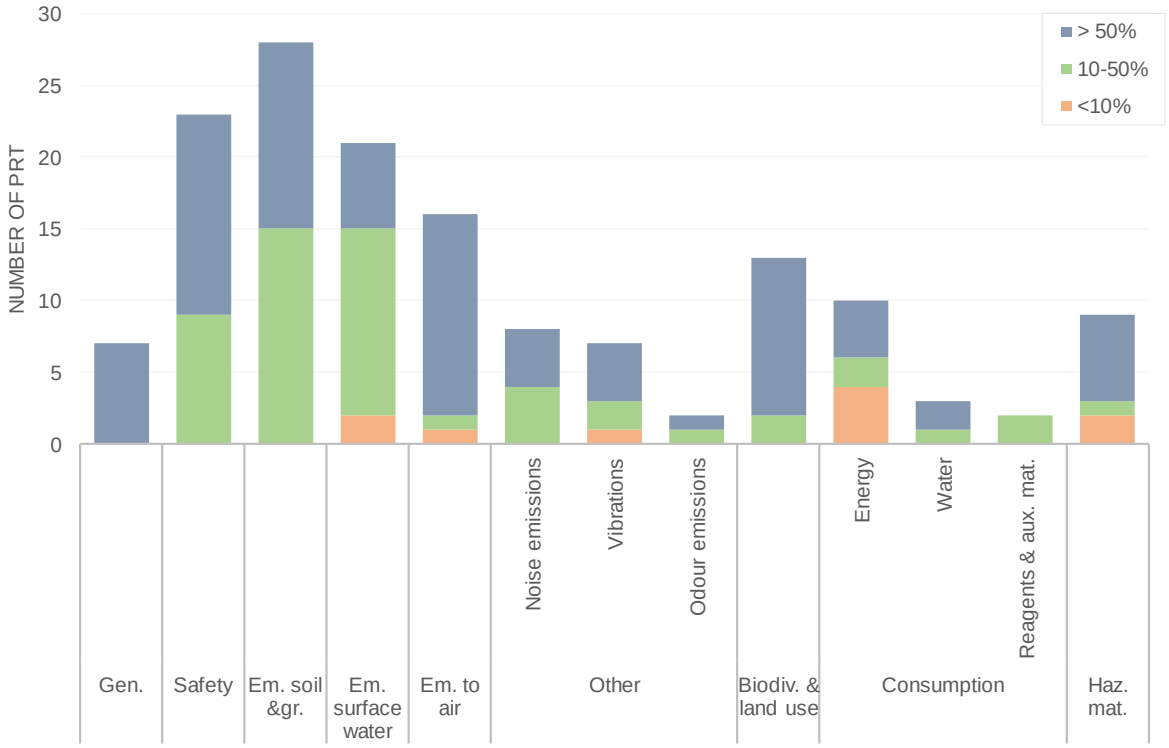


Figure 20. PRT classified for levels of implementation across the main KEI, based on the information reported in the collected literature references (see the List of abbreviations).



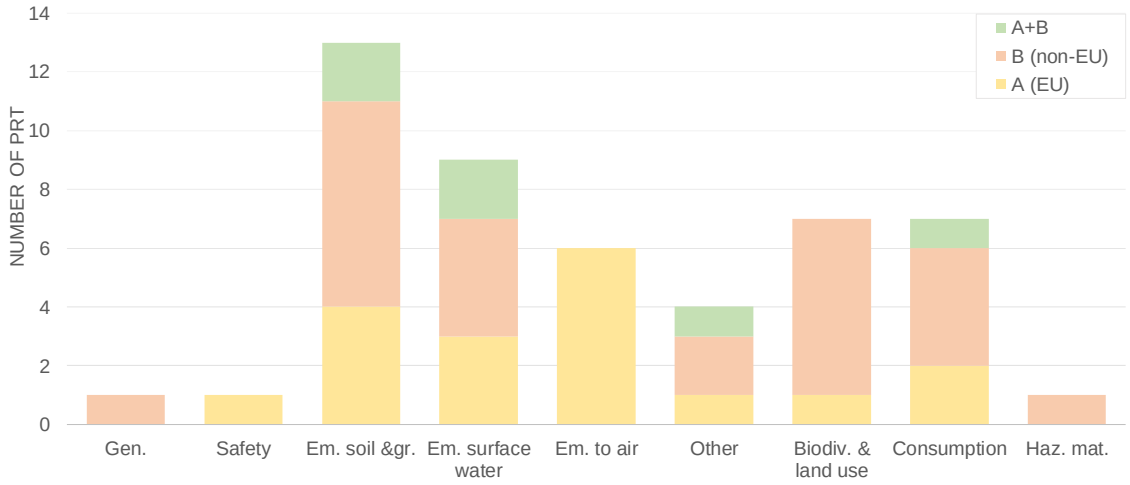
Based on the information reported in the collected literature references, additional information was reported on the origin of different sources of information used for deriving PRT in this study (A-B-C categories, see Annex 3 and Table 14 in Annex 4). Out of 121 PRT (excluding cross-references):

- 59% do not include any information on sites where the techniques are applied.
- 15% present example sites in EU Member States (A), particularly in FI, IE, EE and SE (see Figure 21).
- 5% present example sites in EU Member States and non-EU countries (A+B), particularly FI, Australia and USA see Figure 21).
- 21% present example sites in non-EU countries (B), particularly in Australia, USA and Canada see Figure 21).

For emissions to air and safety, the reported sites where the techniques grouped in the PRT are only in EU Member States. For generic KEI and hazardous materials, the reported sites are only in non-EU countries (see Figure 22).

Figure 21. Origin of the different sources of information used for deriving PRT in this study

Figure 22. PRT classified according to the different sources of information across the main KEI groups (see the List of abbreviations).



5 Analysis of existing information and the proposed PRT for NEEI

The analysis of the collected information and the proposed PRT for the NEEI is presented in Section 5.1, taking into account the feedback received from stakeholders during the consultation. Section 5.2 focuses on the European Green Deal commitments. As suggested by stakeholders, Section 5.3 provides information on advanced technologies and recent breakthroughs in improving environmental performance in the extractive sector, to be considered in future studies.

5.1 Analysis of the information and PRT

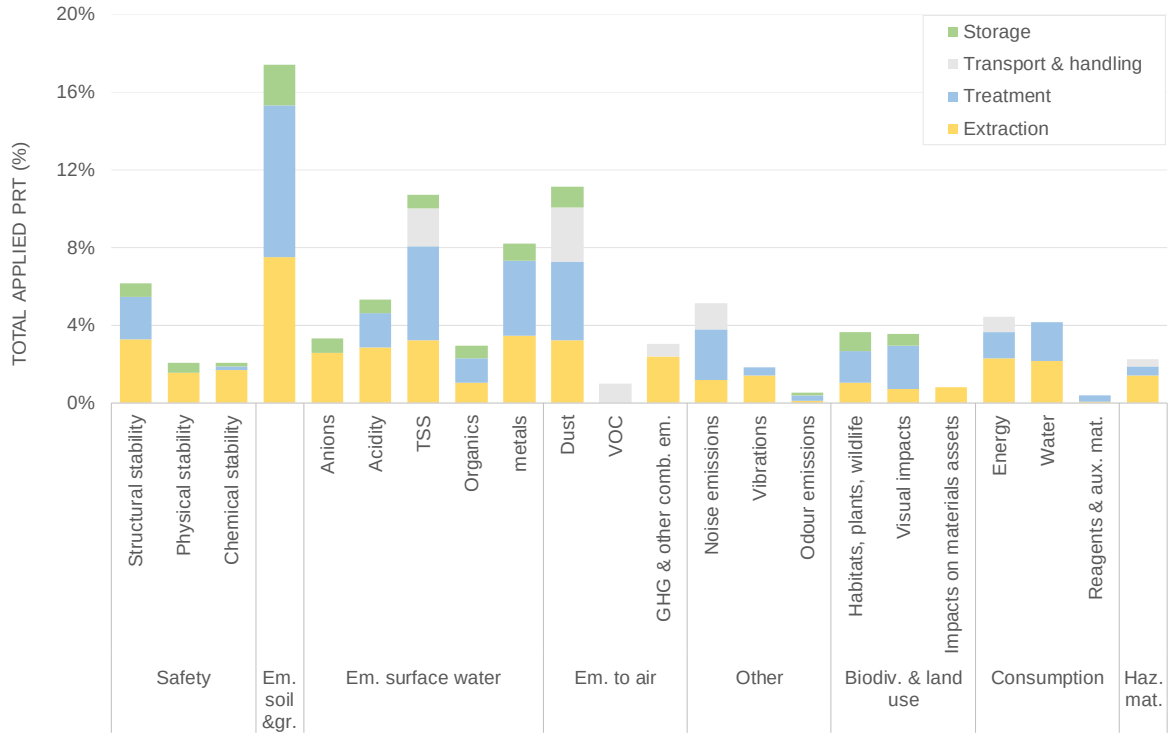
Main and secondary KEI

The high and medium KEI are covered by at least one PRT per main environmental aspect, i.e. stability, emissions to soil and groundwater, emissions to surface water, etc.

The PRT that apply to each combination of key environmental issues, extractive activities and mineral resources (i.e. to each cell of the disaggregated KEI table) have been identified in Table 15 in Annex 4. Both main and secondary KEI targeted by each PRT were considered in building this matrix. This also allowed allocating the different PRT to various environmental aspects that would have been neglected by considering only the main KEI. In this latter case, however, the high and medium KEI are still covered by at least one PRT per main environmental aspect.

Figure 23 shows the distribution of the total number of PRT applicable for each combination of environmental issues, extractive activities and mineral resources across the main KEI, focusing on aspects scoring as of high and medium importance. As in the scoring assessment (see Section 3.2), this total number was weighted to reflect the different number of mineral resources. The distribution in Figure 23 is less homogeneous if compared to the one of total medium and high scores (Figure 2): 10% vs 14% for safety, 17% vs 8% for emissions to soil and groundwater, 30% vs 26% for emissions to surface water, 8% vs 12% for both other emissions and consumption, 9% vs 12% for biodiversity. Only emissions to air and hazardous materials present similar shares (14% and 2-3% respectively).

Figure 23. Distribution of total weighted number of PRT that apply to each combination of environmental issues, extractive activities and mineral resources (high and medium scores) across the main KEI (see the List of abbreviations).



Notwithstanding the above mentioned inhomogeneity, the main targeted KEI are almost the same, but with a slightly different order, for the different mineral resources (see Figure 4 vs Figure 24 for metallic minerals, Figure 5 vs Figure 25 for industrial minerals and Figure 6 vs Figure 26 for construction minerals). For example, in the case of metallic minerals, the main targeted KEI are, in decreasing order of magnitude, TSS, metals, emissions to soil and groundwater, dust, acidity and structural stability in Figure 4 and emissions to soil and groundwater, metals, TSS, dust, acidity and structural stability in Figure 24.

Emissions to surface water exhibit the highest total weighted number of PRT applying to each combination (Figure 23). This depends on the high number of cross-references and secondary KEI assigned. More PRT titles were proposed for emissions to soil and groundwater (see Figure 9). For emissions to surface water, PRT were grouped in broad categories (such as removal of suspended solids or suspended liquid particles, oxidation based systems, reduction based systems, chemical precipitation, etc.). For example, PRT063 for TSS removal includes different sedimentation techniques, such as gravity separation in settling ponds, clarification in tanks, coagulation and flocculation, air flotation, media filtration, membrane filtration for suspended particles, hydro-cycloning. As anticipated, it was indeed considered that the techniques for the treatment of EWIW (BAT45-47) already described in the MWEI BREF (European Commission, 2018) may be similar and also apply to EIW and there was no need of re-defining them (see the analysis in Table 18 in Annex 5 highlighting where potential information for the PRT for emissions to surface water may be retrieved). However, a more in-depth analysis on PRT for emissions to surface water may be carried out in future potential guidance or reference documents.

Figure 24. Distribution of total weighted number of PRT that apply to each combination of environmental issues, extractive activities and mineral resources (high and medium scores) across the main KEI - metallic minerals (see the List of abbreviations).

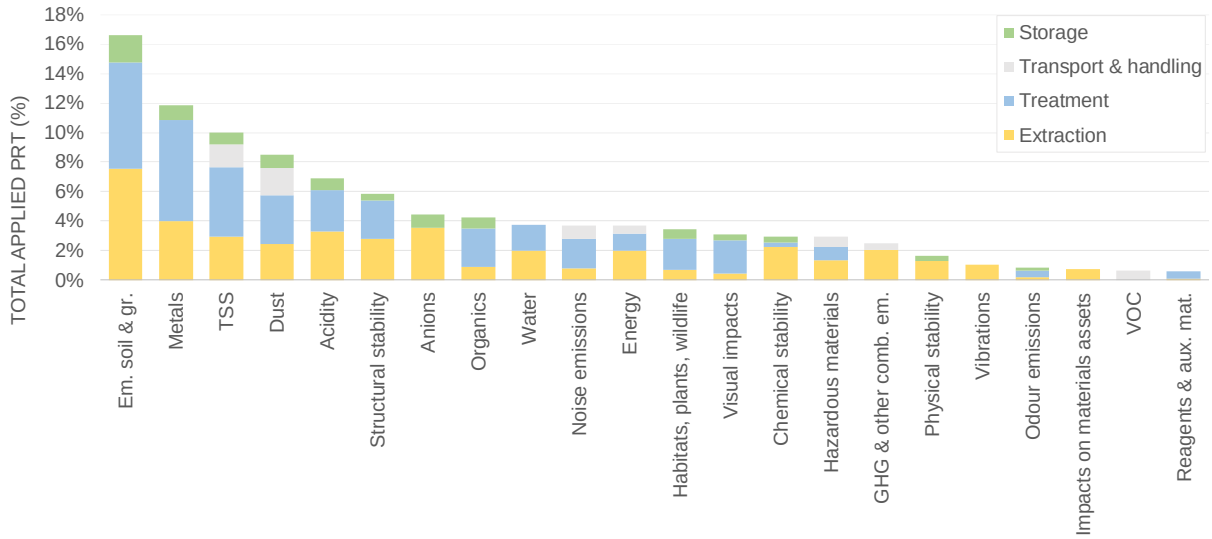


Figure 25. Distribution of total weighted number of PRT that apply to each combination of environmental issues, extractive activities and mineral resources (high and medium scores) across the main KEI - industrial minerals (see the List of abbreviations).

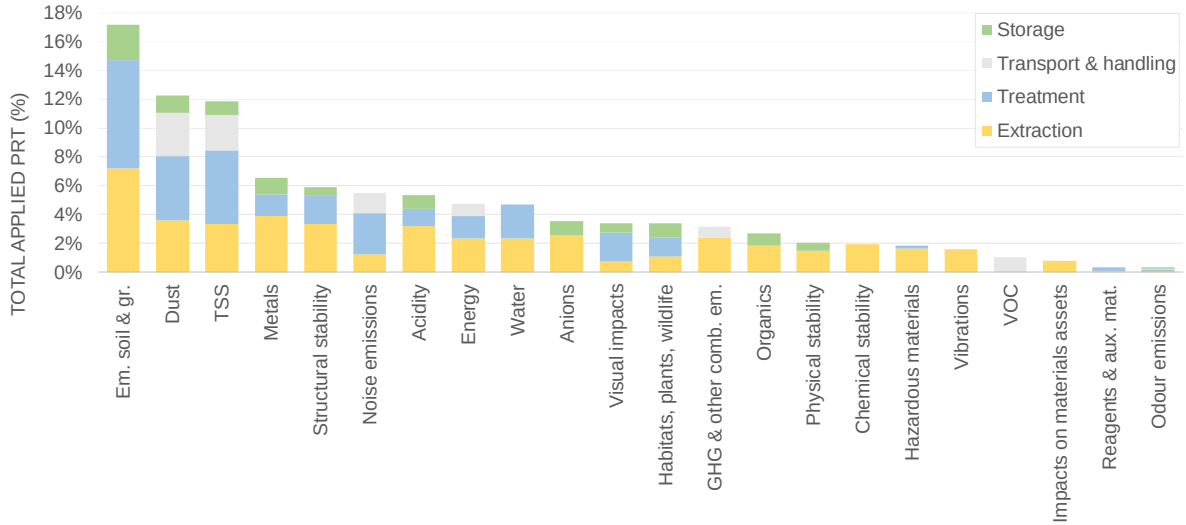
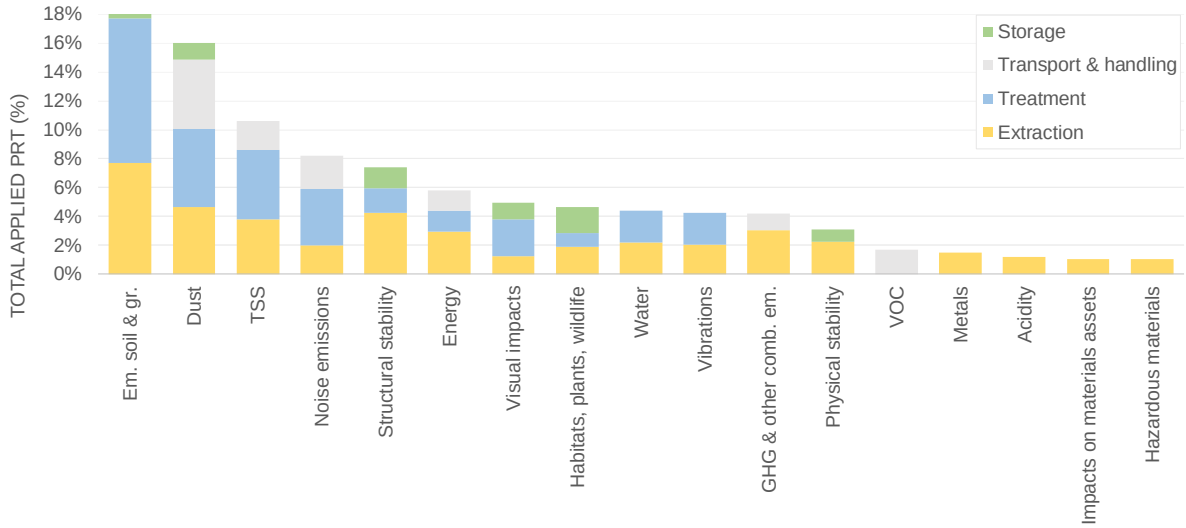


Figure 26. Distribution of total weighted number of PRT that apply to each combination of environmental issues, extractive activities and mineral resources (high and medium scores) across the main KEI - construction minerals (see the List of abbreviations).



For some high or medium KEI, however, a limited number of PRT was identified (see Figure 23 and Figure 27). This is, for example, the case for:

- The use of reagents and auxiliary materials during solution mining and beneficiation (chemical and biological separation), for some metallic and industrial minerals.
- Prevention or minimisation of emissions of VOC and other potential air pollutants during transport, for all minerals.
- Ensuring physical stability during extraction and storage, for all minerals.
- Prevention or minimisation of vibrations during treatment (comminution, size control, beneficiation – physical separation and upgrading, see also the Glossary), for construction minerals.
- Prevention or minimisation of odour emissions during extraction, treatment, transport and handling and storage of peat.

— Prevention or minimisation of visual impacts during extraction, for all minerals.

— Energy consumption, with particular reference to mine automation, and especially for the following techniques i) Automated underground mining equipment; ii) Automated surface mining equipment; iii) Process and software automation; iv) Automation and information management (see also Section 5.3).

This indicates that the impact categories of KEI is not necessarily in relation to the number of prevention and mitigation options available in the literature.

For some of the KEI that were considered as having a potentially high importance or impact, no or limited information was identified in the literature compiled. For future work, it is particularly recommended, also based on the received stakeholder feedback, to collect information and identify techniques that are currently applied to prevent or reduce:

— Saline drainage, metal leaching and resulting chemical stability issues.

— Odour emissions from the extraction, treatment, transport, handling and storage of peat and metal ores.

— Structural stability issues resulting from primary crusher underground.

— Chemical stability issues from solution mining.

— Specific standards related to monitoring of emissions to air and water.

— Information on the reduction or substitution of specific auxiliary materials for treatment processes, such as flocculants.

— Energy consumption, with particular reference to:

  - Process optimisation, and especially on the following techniques i) Process knowledge, continuous monitoring and analytics; ii) Artificial intelligence and simulation in process optimisation; iii) Performance optimisation of beneficiation; iv) Advanced process control systems and techniques; v) Process optimisation program for the entire operation (see Section 5.3).

  - Control and optimisation of underground mine ventilation in order to improve energy efficiency and, secondarily, to prevent and minimise noise emissions).

  - Control and optimisation systems for different extraction methods in surface and underground mining, in order to increase material efficiency of the extraction.

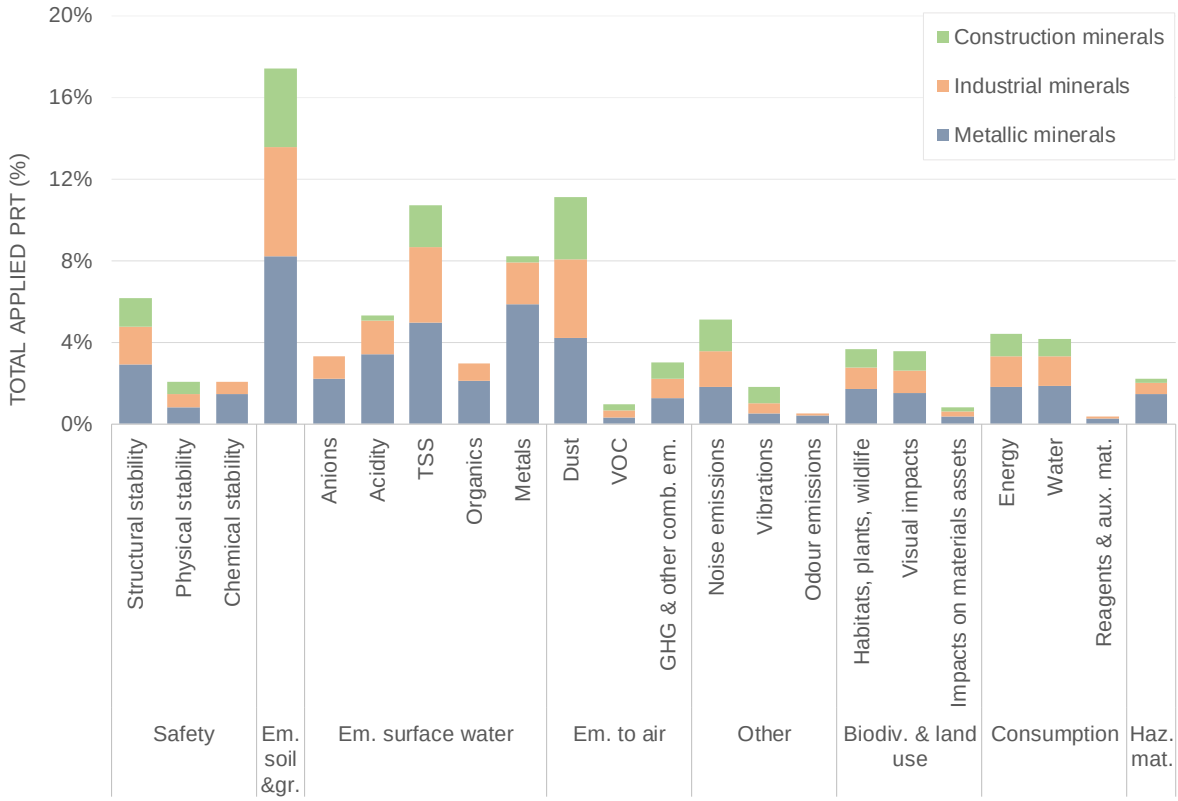
— Consumption, particularly related to the management of chemicals.

During the consultation, a stakeholder pointed out that the collection of information on safety and accident prevention needs to be improved in order to address the potential for an accident or hazardous/ emergency situation arising from activities across the installation. In the current analysis, the potential for, e.g. fire, explosion or spillage of chemicals is considered in the PRT for risk management (e.g. in PRT001, Organisational and Corporate Management system, PRT002 EMS, including operational and emergency procedures, but also in PRT140 Design, inspection, maintenance of storage tanks) and may be analysed further in future potential guidance or reference documents.

All medium impact KEI are covered by either more general PRT or by PRT targeting a specific environmental aspect (in combination with activity and mineral) – for example techniques related to energy consumption during extraction activities or noise emissions during extraction and treatment activities.

Low KEI appear sometimes targeted by the same PRT of the high and medium scores (see Table 15 in Annex 4). This implies that further assessment on the PRT relevance seems needed, also through targeted data collection in future potential guidance or reference documents.

Figure 27. Distribution of total weighted count of PRT that apply to each disaggregated KEI (high and medium scores, targeted and secondary KEI considered) across the environmental issues for each mineral resource (see the List of abbreviations).



Relevance

According to the information provided in the collected literature references, many proposed PRT are applicable to several groups of mineral resources, various extractive activities (e.g. extraction, treatment, transport and handling and storage) and different specific categories of extractive activities (e.g. surface and subsurface, comminution, size control, beneficiation, upgrading, loading and unloading, hauling). Specific considerations on the relevance for the non-energy mineral resources and the extractive activities are reported below.

Non-energy mineral resources:

The level of disaggregation of the KEI identified under the preliminary assessment by expert judgement (see Table 3 in Annex 1) is not always to the same level of detail as the minerals coverage in the PRT and as indicated in the collected literature references (see Table 15 in Annex 4). As pointed out in Section 4.3, in these references more than 90% of the PRT are reported as cross-cutting to all mineral resources and only 7% are, for example, indicated as relevant to specific metallic mineral categories.
As mentioned before, according to the information provided in the collected literature references, some PRT were classified as relevant for combinations of extractive activities and minerals resources that the experts judged "with low importance" or "not occurring in reality and/or for which the specific environmental impact in the EU is considered as not significant" (see green and grey cells in Table 3 in Annex 1 and in Table 15 in Annex 4). Examples for this latter case are:

— For metallic minerals: solution mining for iron ores and bauxite.

— For industrial minerals:

- Borehole and solution mining and beneficiation (chemical and biological separation) for limestone and gypsum, clay and kaolin and feldspar.
- Borehole mining and beneficiation (chemical and biological separation) for potash.

- Subsurface, borehole and solution mining, comminution, size control and beneficiation (physical, chemical and biological separation) for peat.
- Beneficiation (biological separation) for phosphate rocks and others.

— For construction minerals: solution mining, beneficiation (chemical and biological separation) for all construction minerals. Subsurface extraction for aggregates. Borehole mining, size control and beneficiation (physical separation) for construction and ornamental stones.

Extractive activities:
It was considered that the level of disaggregation in terms of extractive activities in the KEI appeared an appropriate grouping for the proposed PRT and many of the techniques are applicable and presented in this level of detail as in the KEI (see Table 3 in Annex 1). The expert panel concluded that most PRT are applicable to more than one group of mineral resource. When it comes to extractive activities, PRT are often less transferable.
However, as pointed out in Section 4.3, it should be considered that, based on the information reported in the collected literature references, about 70% of the PRT are indicated as cross-cutting to all extractive activities and only few PRT (7% for extraction and 2% for treatment) are reported as relevant for a specific activity.

Concerning the PRT relevance both for mineral resources and extractive activities:

— 9% of the responses provided by stakeholders during the consultation highlights the lack of data and points out the need for further classification based on the type of the extractive activity (e.g. extraction, treatment, transport and handling, storage), the type of the operation (e.g. subsurface/surface, underground/surface operations) and the rock type (e.g. soft, sedimentary, stratified rocks/hard rocks).

— No specific information in the description of the PRT was found within the collected literature references, or better specified by stakeholder during the consultation, to enable a more specific classification, i.e. the level of detail in the collected references does not allow to further describe a detailed relevance to different extractive activities or mineral resources and for this reason most of the PRT are classified as cross-cutting (see also Section 4.3).

— In order to maximise the usability of the collected data, as underlined by stakeholders, further information is needed with particular reference to PRT relevance for different minerals and extractive activities.

Life cycle phases
As pointed out in Section 4.3, based on the information reported in the collected references, almost 60% of the PRT are indicated as cross-cutting to all phases. PRT that apply exclusively during closure and after-closure need to be investigated by collecting further literature information and targeted data collection in future potential guidance or reference documents.

Quantitative indicators
Based on the information reported in the collected literature references, only 30% of the PRT (excluding cross-references) are indicated as containing some quantitative indicators or criteria, mainly on environmental performance.

Therefore, quantitative indicators on environmental performance and operational data from well-performing non-energy extractive activities still need to be collected and classified for most PRT by additional literature search and targeted data collection from stakeholders, ideally by carrying out the previously mentioned potential guidance or reference documents exercise.

Applicability
As pointed out in Section 4.3, based on the information reported in the collected literature references:

— 34% of the proposed PRT are indicated as containing some consideration on applicability or technical restrictions, including taking into account site-specific conditions.

— 44% are indicated as "generally applicable" and "widely applicable", also in case of risk-specific PRT. Based on a risk-specific approach, the applicability of the PRT targeting specific risks should be based on a proper

environmental impact and risk evaluation (see the MWEI BREF, European Commission 2018), usually carried out through an EIA for non-energy extractive activities[31].

- Only 2% of the PRT are indicated as based on the results of a proper EIA.

4% of the responses provided by stakeholders during the consultation highlight the lack of data on the PRT applicability and ask for additional information on applicability considerations and restrictions.

The study reflects the information extracted from the collected literature references, where most of the PRT are indicated as "generally applicable". No specific information in the description of the PRT was found within these references, or better specified by stakeholder during the consultation, to enable a more specific description, i.e. the level of details in the literature does not allow to further delineate the applicability conditions (see also Section 4.3).

Stakeholders also highlighted the importance of applying a risk-specific approach in the evaluation of site/operation specific applicability as well as overall optimisation of environmental management and resource-efficiency of the operation, following the example of the MWEI BREF.

The information reported in the collected references do not generally refer to the application of a risk-specific approach. However, the importance of applying this approach has been emphasised as an essential condition since the introductory sections of this study (see Section 2 and Section 3.1).

In order to maximise the usability of the collected data, as pointed out by stakeholders, further information is needed with particular reference to the PRT applicability and the application of a risk-specific approach..

Level of implementation
As pointed out in Section 4.3, based on the information reported in the collected literature references, among the 149 PRT, 36% were assessed by the Wood mining experts as being applied when 10-50% of extractive industries are concerned by the specific environmental risk addressed, and 58% as being applied when more than 50% of extractive industries are concerned by the specific environmental risk addressed. According to the collected information and the expert judgement, the proposed PRT appear well implemented in the non-energy extractive activities.

Sites where the PRT are applied
Based on the information reported in the collected literature references, 41% of the proposed PRT, excluding cross-references include information on sites where the techniques are applied (15% from EU Member States, 21% from non-EU countries, 5% from both). The main sites are located in FI, IE, EE and SE for EU Member States, and Australia, USA and Canada for non-EU countries.
Sites where the PRT are applied still need further assessment, with particular reference to EU sites.

Reference literature
A very broad consultation allowed the collection of 430 unique references. 40% was provided by Member States (of which 86% by ES, EL, DE, PT, SE and FI), 16% by industry (of which 72% by the construction mineral associations).

As pointed out in Section 4.3, based on the information provided in the collected literature references, most PRT are indicated as deriving from multiple sources of information. The majority proceeds from EU Member States and non-EU countries (A+B, 38%) and from all categories (A+B+C, 37%). Only 5% derive solely from EU Member States.

Out of the 193 references finally used in the PRT, 58% were classified as sources from EU Member States (particularly applied in especially apply in ES, SE, the whole EU, PT, FI, EE, DE, CY and IE), 39% from non-EU countries (especially applied in Australia, USA, Canada, Russia and Asia as well as worldwide) and 3% from other similar relevant activities from EU Member States.

41% consist of guidance documents, 18% consist of technical reports and 13% consist of webpages.

(31) Hamor et al. (2021). Study on the environmental impact assessment of non-energy minerals extraction projects with regard to European Union Community requirements. *WP6 "Implementation of framework conditions for primary raw materials (non-energy minerals)", Task 6.2*

Few technical documents present factual technical and economic information, reflecting the outcome of an information exchange, to be considered similar to BREF documents. Very few documents describe, in particular, applied techniques, present emission and consumption levels, techniques considered for the determination of best available techniques as well as BAT conclusions and any emerging techniques. None of them apply to all considered mineral resources and extractive activities in EU.

Additional input on the collected literature references from industry would have been beneficial to the study, in order to understand the level of dissemination of these references among the main EU actors in the non-energy extractive activities.

Considering the low amount of literature references provided by industry, and mainly by the construction mineral associations, it seems that some industry sectors have little information available on PRT. Member States provided relevant input and information on techniques, which seems to be well disseminated amongst authorities across the EU. However, during the consultation a mining industry association explained that they have a comprehensible and broad knowledge about the PRT, which is, inter alia, taken into consideration in the permitting procedures for mining operations. This knowledge seems usually being used for identifying individual site specific practices rather than for providing guidance to the sector by the drawing-up of an internal reference document.

Finally, stakeholders pointed out that the PRT overview is not exhaustive and the presented PRT should be considered as a non-exhaustive list of techniques to prevent or reduce environmental impacts of the NEEI. In particular, 8% of the responses provided by stakeholders during the consultation highlights that some extractive sub-sectors were not very active during the data collection in providing information on advanced techniques and recent breakthroughs in mine automation, process optimisation and digitalisation. Therefore, a new section has been introduced to highlight these techniques to be better analysed in future studies (see Section 5.3). Furthermore, another 8% of the responses suggested some new literature references, which have not been included in the analysis but listed in Table 19 in Annex 5 for future consideration.

5.2 PRT and the European Green Deal commitments

In this study the KEI were grouped following the same structure as in the MWEI BREF, i.e. safety, emissions to soil, water and air, etc. On the one hand, this is a practical approach, considering that any possible future reference documents for extractive activities and the BREF for the management of extractive waste could be used together. They need thus to show similar structures and glossaries. On the other hand, the European Green Deal was launched in the meantime and its priorities, such as the climate change measures, are to be highlighted as much as possible.

Nevertheless, the current study has already taken on board several European Green Deal commitments. More in detail, and in line with the proposed European climate law, the European Industrial Strategy and European Biodiversity Strategy for 2030, the following climate impact aspects have been considered:

— Mitigation to climate change. This is covered under the following KEI:

  - Emissions to air - GHG and other combustion emissions. Examples of proposed PRT are decarbonisation (including electrification or fuel switching, including renewables) (PRT093) and increased equipment efficiency (PRT094).
  - Energy consumption and related contribution to climate change. Examples of proposed PRT are generic energy consumption reduction techniques (PRT128), operational energy consumption reduction techniques, optimisation of crushing and grinding processes (PRT130), optimisation of material flow (PRT131) and mine automation (including fully electrified mine) (PRT133).

— Adaptation to climate change. This is covered under structural stability, where more climate-resilient extractive activities, considering the risks of extreme floods, heavy rainstorms, landslides, during both the operational and the closure and after closure phases have been considered. Examples of proposed PRT are selection of extraction methods (PRT011), water management (PRT013), drainage systems (PRT014), geotechnical analysis (PRT015) and geotechnical monitoring (PRT016).

— Achieving climate change mitigation benefits by helping to influence the carbon sink. This is analysed under impacts on biodiversity and land. Examples of proposed PRT are soil conservation measures (PRT116), rehabilitation techniques (PRT118) or landscaping and geomorphic reclamation (PRT119).

Moreover, in line with the commitments of the European Green Deal and the new Circular Economy Action Plan, together with the indicative targets of the Action Plan on Critical Raw Materials, resource efficiency and circular economy aspects are considered in this study.

The current MWEI BREF has numerous relevant BAT on the above aspects. This document analysed extractive waste generation prevention and extractive waste reduction techniques, considering both waste and non-waste (by-products) materials in the following BAT:

— Prevention of solid extractive waste generation (BAT6): a) pre-sorting and selective handling of extractive by-products; b) placing extractive by-products back into excavation voids (note: placing extractive waste back into excavation voids is proposed as BAT29.c, a technique that helps ensure the physical stability of extractive waste); c) using extractive by-products for internal or external purposes.

— Reduction of non-inert extractive waste and hazardous extractive waste generation (BAT7): b) sorting and selective handling of extractive waste.

— Recovery of extraction waste (BAT10).

Furthermore, during the consultation stakeholders underlined the need of elaborating further on PRT for Critical Raw Materials extraction. They also pointed out the importance of providing additional support to the new Circular Economy Action Plan and the Action Plan on Critical Raw Materials by fostering the circular use of resources, including understanding the potential for recovery critical and other raw materials from re-mining extractive waste[32]. This may be analysed further in future potential guidance or reference documents.

(32) Blengini et al. (2019). Recovery of critical and other raw materials from mining waste and landfills: State of play on existing practices; doi:10.2760/600775
Gislev, M., Grohol, M., Mathieux, F., Ardente, F., Bobba, S., Nuss, P., Blengini, G., Alves Dias, P., Blagoeva, D., Torres De Matos, C., Wittmer, D., Pavel, C., Hamor, T., Saveyn, H., Gawlik, B., Orveillon, G., Huygens, D., Garbarino, E., Tzimas, E., Bouraoui, F. and Solar, S., 2018, Report on Critical raw materials and the circular economy — European Commission, 76 p., ISBN 978-92-79-94627-1, doi:10.2873/331561

Finally, resources efficiency and circularity were specifically tackled in the current study under the following KEI:

- Physical stability. An example of proposed PRT is backfilling (PRT019).
- Emissions to soil and groundwater. Examples of proposed PRT are soil management (PRT031) or progressive rehabilitation (PRT043).
- Emissions to surface water – EIW generation. Examples of proposed PRT are water management (PRT059, cross reference) or reuse or recycle the excess water (PRT60).
- Water consumption. Examples of proposed PRT are water management (PRT136, cross reference), water consumption reduction measures (PRT137) or water recovery techniques (PRT138).

5.3 Advanced technologies and recent breakthroughs in improving environmental performance in the extractive sector

Despite the extensive data collected, stakeholders highlighted during the consultation that a very minor amount of literature references had been provided on the novel, advanced techniques related to mine automation, process optimisation and digitalisation. This new Section 5.3 has been thus included for introducing information on these techniques, which need to be better analysed in future studies.

The extractive sector is in transition towards automation and digitalisation. Technologies to improve safety and productivity of the operations are under continuous development. For example, certain stakeholders suggested that the Nordic equipment providers are world leaders in advanced mine automation technology. Application of autonomous operations such as robotic technology to mining vehicles and equipment is increasing rapidly. These aspects are also currently analysed under H2020 projects such as Robominers. As another example, the Aitik copper mine of Boliden in Sweden leaped to automation route by turning to using a remotely controlled fleet of pit vipers in order to increase productivity, efficiency and safety. Converting to remote and autonomous operations reduces non-drilling time, increases utilization, and gains productivity.

In general, automation solutions improve the productivity and safety by enhancing control and optimization of the extractive operations. Automation systems provide a safe and controlled environment to operate in underground and surface mining by removing people from the process. Currently, according to stakeholders, the challenge lies in blending the autonomous and manual processes and causes some limitations in operations.

Automation solutions involve recent breakthroughs both for underground and surface extractive activity applications. Automation also holds a key role in process optimisation and management of information on process parameters (see description of PRT133 in Table 14 in Annex 4). Continuous process monitoring and early mineral analysis are crucial in optimisation of the performance of extraction and treatment of minerals. Process knowledge and use of artificial intelligence analytics and data mining to optimise production are in fast development. They improve the safety, reduce wastage, and increase productivity. As a cost-effective tool, machine learning allows simulation of operations prior to modifying the production process.

Advanced process control systems and techniques are in continuous development. The performance of beneficiation, e.g. flotation, can be further increased by using model-based optimizing control systems. By advance control strategies both optimisation of comminution and beneficiation processes and recovery as well as energy and reagent consumption can be achieved. Often an optimisation programme comprising the entire mill operation is used.

Stakeholders thus suggested that additional information should be collected in future studies, particularly on the following techniques:

- Process knowledge, continuous monitoring and analytics.
- Artificial intelligence and simulation in process optimisation.
- Performance optimisation of beneficiation.
- Advanced process control systems and techniques.
- Process optimisation programme for the entire operation.

6 Conclusions

This study presents the results from the analysis and classification of 430 literature references, of which 59% were gathered from Member State authorities, industry associations, environmental NGOs and other relevant stakeholders via an extensive data and information collection exercise and 41% were collected by means of a complementary literature search, identifying 149 Prevention and Reduction Techniques (PRT).

The study provides an in-depth overview of the currently available techniques for the prevention or reduction of environmental impacts in NEEI. However, the compilation of PRT presented in this study is not exhaustive.

The reported techniques have been collected and assigned into categories, without an evaluation of their actual contribution to the prevention or reduction of negative impacts on the environment from non-energy extractive activities. As stakeholders suggested, this study and particularly the Annexes, can be used as an interactive screening toolkit of PRT that may apply depending on the site-specific conditions.

As pointed out in Section 5, in order to maximise the usability of collected data, further information is needed, particularly on PRT relevance for different mineral resources and extractive activities and applicability conditions. Quantitative information on environmental performance and operational data and sites where the PRT are applied, needs also to be collected from EU mining operators, ideally through a targeted information exchange.

Furthermore, during the stakeholder consultation, the importance of applying a risk-specific approach in the evaluation of site/operation specific applicability emerged, including sectoral, geographic and climatic variations or site-specific conditions such as the geological characteristics of the deposit.

Even if the extractive industry suggested to be familiar with the PRT identified in this study a standardised internal reference document does not seem to exist or being in use in the sector. This further supports the assumption that an exchange of information with Member States and NGOs aimed at elaborating a guidance or reference document may be beneficial for the extractive industry.

According to the outcome of this study and based on the received stakeholder feedback, it is recommended for future work to pay particular attention to identifying techniques to address the following: to prevent or reduce saline drainage; metal leaching; emissions to surface water (particularly nitrogen); odour emissions from peat and metal ores; chemical stability issues from solution mining; and consumption of chemicals or energy consumption. This work should include processes and systems for control, optimisation and automation. Furthermore, information on the reduction or substitution of specific auxiliary materials for treatment processes, such as flocculants, and on specific standards related to emission monitoring needs to be collected.

Potential other needs for further work in this area appear related to developing studies supporting the twin green and digital transition, with specific focus on the European Green Deal commitments, the Circular Economy Action Plan and the Action Plan on Critical Raw Materials, particularly on circular use of resources, including understanding the potential for recovery of critical and other raw materials from extractive wastes.

Finally, any future potential guidance or reference documents that would be developed for non-energy extractive activities would have to pay particular attention to climate impacts, resource efficiency and circularity and help putting in place the measures of the Zero Pollution Action Plan for water, air and soil.

References

ACME (2010). Best Management Practices. Plan for the Control of Fugitive Dust; https://www.cemi.ca/wp-content/uploads/2017/06/ACME.pdf

ACMER (2005). A Summary of Passive and Active Treatment Technologies for Acid and Metalliferous Drainage (AMD); https://www.earthsystems.com.au/wp-content/uploads/2012/02/AMD_Treatment_Technologies_06.pdf

Alberruche del Campo, M.A., et al. (2018). Guía para la rehabilitación de huecos mineros con residuos de construcción y demolición (RCD). Ministerio para la Transición Ecológica; https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/guia_rehabilitacion_huecos_mineros_web_tcm30-487268.pdf

Alberta Government (2011). Erosion and Sediment Control Manual. Government of Alberta, Department of Transportation. Alberta, Canada; http://www.transportation.alberta.ca/Content/docType372/Production/ErosionControlManual.pdf

Albright, W.H. (2010). Water balance covers for waste containment: Principles and practice. ASCE. Reston, Virginia

Alcañiz, J. M. (2008). Utilización de lodos de depuradora en restauración. Manual de aplicación en actividades extractivas y terrenos marginales. Agència Catalana de l'Aigua (ed.), Departament de Medi Ambient i Habitatge, Generalitat de Catalunya; http://mediambient.gencat.cat/web/.content/home/ambits_dactuacio/empresa_i_produccio_sostenible/restauracio_dactivitats_extractives/Productes-emprats-restauracio-ambiental/restauracio_dactivitats_extractives_amb_fangs_de_depuradora/documentos/protocol_fangs_cast.pdf

Aluminium Stewardship Initiative (2017). ASI performance standard; https://aluminium-stewardship.org/asi-standards/asi-performance-standard/

Alvarenga et al. (2019). Towards product-oriented sustainability in the (primary) metal supply sector; https://www.sciencedirect.com/science/article/pii/S0921344919300758

AME BC (2008). Handbook For Mineral and Coal Exploration in British Columbia; https://www2.gov.bc.ca/assets/gov/business/natural-resource-industries/mineral-exploration-and-mining/handbookformineralexploration0809.pdf

ANEFA (2006). Gestion medioambiental en canteras y graveras. Spain (received as pdf file)

ANEFA (2007). Los aridos y el desarrollo sostenible. Spain (received as pdf file)

ANEFA (nd). Aridos. Guia de buena apariencia en canteras y graveras. Spain (received as pdf file)

ANEFA (nd). Explotaciones de aridos y medio ambiente. Spain (received as pdf file)

ANEFA (nd). Gestion del agua en explotaciones de aridos. Spain (received as pdf file)

ANEFA (nd). Los aridos y el desarrollo sostenible. Premios nacionales ANEFA restauracion, buena imagen, desarrollo sostenible. Spain (received as pdf file)

ANEFA (nd). Manual de restauracion de explotaciones mineras a cielo abierto de Aragon. Spain (received as pdf file)

ANIET (2019). Guia para a melhoria do desempenho ambiental no setor da pedra. Guidance document for the improvement of environmental performance of the quarry industry; http://www.aniet.pt/fotos/editor2/2.2._guia_sectorial.pdf

APA (2013). Guia AIA para a atuação das Entidades Acreditadas - Documento produzido pela Agência Portuguesa do Ambiente (APA); http://apambiente.pt/_zdata/Divulgacao/Documentos%20Referencia/4.GUIA%20PCIP.pdf

APEC (2019). APEC Study on Innovation Mining Industry of Sustainable Growth. Asia-Pacific Economic Cooperation

Association of Southeast Asian Nations (2017). Sustainable Minerals Development: Best Practices in ASEAN

Australia (2002). Overview of Best Practice Environmental Management in Mining. Department of Industry, Science, Energy and Resources

Australia (2008). Cyanide management. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government; https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-cyanide-management-handbook-english.pdf

Australia (2009). Airborne contaminants, noise and vibration. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government, Department of Industry Tourism and Resources; https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-airborne-contaminants-noise-and-vibration-handbook-english.pdf

Australia (2010). A GUIDE TO LEADING PRACTICE SUSTAINABLE DEVELOPMENT IN MINING. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government;

https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-a-guide-to-leading-practice-sustainable-development-in-mining-handbook-english.pdf
Australia (2016). Biodiversity management. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government; https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-biodiversity-management-handbook-english.pdf
Australia (2016). Energy management in mining. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government; https://www.industry.gov.au/data-and-publications/leading-practice-handbook-energy-management-in-mining
Australia (2016). Evaluating performance: monitoring and auditing. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government; https://www.industry.gov.au/sites/default/files/July%202018/document/pdf/evaluating-performance-monitoring-and-auditing.pdf?acsf_files_redirect
Australia (2016). Hazardous materials management. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government; https://www.industry.gov.au/data-and-publications/leading-practice-handbook-hazardous-materials-management
Australia (2016). Mine closure Leading Practice Sustainable Development Program for the Mining Industry, Australian Government; https://www.industry.gov.au/sites/default/files/2019-05/lpsdp-mine-closure-handbook-english.pdf
Australia (2016). Mine rehabilitation. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government; https://www.industry.gov.au/sites/default/files/2019-05/lpsdp-mine-closure-handbook-english.pdf
Australia (2016). Preventing acid and metalliferous drainage. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government, Department of Industry Tourism and Resources; https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-preventing-acid-and-metalliferous-drainage-handbook-english.pdf
Australia (2016). Preventing acid and metalliferous drainage. Leading Practice Sustainable Development Program for the Mining Industry, Australian Government; https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-preventing-acid-and-metalliferous-drainage-handbook-english.pdf
Australia (2016). Water stewardship. Australian Government, Department of Industry, Science, Energy and Resources; https://www.industry.gov.au/data-and-publications/leading-practice-handbook-water-stewardship
Australian Centre for Mining Environmental Research (2002). Managing the impacts of the Australian minerals industry on biodiversity; https://pubs.iied.org/pdfs/G00569.pdf
AzoM (2002). BioHeap - A Bioleaching Process for Nickel Extraction; https://www.azom.com/article.aspx?ArticleID=1601
BC (2015). Developing a Mining Erosion And Sediment Control Plan; https://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/mining-smelt-energy/erosion_sediment_control_plan_guide.pdf
BC (2016). The Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators; https://mines.nrs.gov.bc.ca/water-quality
BC (2017). Bioremediation and Discharge of Hydrocarbon Impacted Soil at Producing Mine Sites; https://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/mining-smelt-energy/guidance-documents/guidance_for_hc_impacted_soils_at_mines.pdf
BC (2018). Guidance on Preparing Nitrogen Management Plans for Mines using Ammonium Nitrate Fuel Oil Products for Blasting; https://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/mining-smelt-energy/guidance-documents/guidance_for_developing_nitrogen_management_plans.pdf
BCMWRPRC (1991). Mined Rock and Overburden Piles Investigation and Design Manual Interim Guidelines. North Vancouver, British Columbia; http://mssi.nrs.gov.bc.ca/Geotechnical/minedrockoverburdenpile_investigationdesignmanual.pdf
Bezirkregierung Arnsberg. Umwelt- und Störfallüberwachungsplan/-programm 2018/2019 für Bergbau und Energie in Nordrhein-Westfalen
BGR Germany (2017). Sustainability Schemes for Mineral Resources: A Comparative Overview
BIO-IS (2010). Impacts of Gold Extraction In the EU; https://ec.europa.eu/environment/pdf/waste/mining/IH_2010-001.pdf
Bodenschutz in Hessen (2017). Rekultivierung von Tagebau- und sonstigen Abgrabungsflachen [Bodenschutz in Hessen (2017). Recultivation of open pit and other excavation areas]
Böhmer J. and Rahmann H. (1997), Faunistische Aspekte zum Naturschutz in Steinbrüchen. In: Böcker und Kohler (Hrsg): Abbau von Bodenschätzen und Wiederherstellung der Landschaft. Hohenemser Umwelttagung 29, Ostfildern [Böhmer J. and Rahmann H. (1997), Faunistic aspects of nature conservation in quarries. In: Böcker

and Kohler (ed.): Mining of mineral resources and restoration of the landscape. Hohenems environmental conference 29, Ostfildern]; Google Scholar
British Columbia Canada (2018). Developing a Fugitive Dust Management Plan for Industrial Projects; https://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/mining-smelt-energy/guidance-documents/dust_management_plan_guidance.pdf
Burger, J.A. & Zipper, C.E. (2011). How to Restore Forest on Surface-Mined Land. Powell River Project. Virginia Cooperative Extension Publication 460-123. Blacksburg, Virginia; https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/460/460-123/CSES-211.pdf
Cambridge, M. (2018). The Hydraulic Transport and Storage of Extractive Waste
Canada (2009). Environmental Code of Practice for metal mines; https://www.canada.ca/content/dam/eccc/migration/main/lcpe-cepa/documents/codes/mm/mm-eng.pdf
Canada (2012). Summary Review of Performance of Metal Mines; http://publications.gc.ca/collections/collection_2014/ec/En49-15-22-eng.pdf
Cardu et al. (2014). Evidences of the influence of the detonation sequence in rock fragmentation by blasting – Part I; http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0370-44672015000300337
Carlà et al. (2019). Perspectives on the prediction of catastrophic slope failures from satellite InSAR. Nature research. Scientific reports 9.1, 1-9; https://www.nature.com/articles/s41598-019-50792-y.pdf
CBI Mineral group, Mineral Products Association. UK minerals strategy; https://mineralproducts.org/documents/UK_Minerals_Strategy.pdf
CDC (2010). Best Practices for Dust Control in Coal Mining; https://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/2010-110.pdf
CEMI (2010). The Preparation of a Best Management Practices Plan for the Control of Fugitive Dust for the Ontario Mining Sector; https://www.cemi.ca/wp-content/uploads/2017/06/Fugitive.pdf
Chalkiopoulou, F. and Hatzilazaridou, K. (2011). How to achieve aggregates resource efficiency in local communities, Manual. SARMa (Sustainable Aggregates Resource Management) Project (SEE/A/151/2.4/X); http://www.southeast-europe.net/document.cmt?id=279
China (2010). Guidelines on Available Pollution Prevention and Control Techniques for the mining and mineral processing of the iron and steel industry
Columbia Center on Sustainable Innovation (2018). The renewable power of the mine. Accelerating renewable energy integration
Countess Environmental (2006). WRAP Fugitive Dust Handbook; https://www.wrapair.org/forums/dejf/fdh/content/FDHandbook_Rev_06.pdf
Csavina (2012). A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3418464/
CSBI_ICMM (2015). Good Practices for the Collection of Biodiversity Baseline Data; https://www.icmm.com/en-gb/guidance/environmental-stewardship/biodiversity-baseline-data
Cyprus. BATs for copper and gold that are being used
Cyprus. Parts from EWMPs of copper and gold
Cyprus. The Extractive waste permit N 2017.001
Cyprus. The IED permit N /2018
da Cunha Rodovalho (2017). Reducing environmental impacts via improved tyre wear management; https://www.sciencedirect.com/science/article/pii/S0959652616315505
Decision for the Approval of Environmental Terms for the exploitation of ferronickel ore (laterite), at "Kaki Rachi", Aspropyrgos Municipality, Attiki Prefecture, by "INTERBETON CONSTRUCTION MATERIALS SA"; https://diavgeia.gov.gr/luminapi/api/decisions/9%CE%A0554653%CE%A08-%CE%9E2%CE%9F/document.pdf
Decision for the Approval of Environmental Terms regarding the Activity: "Aggregate quarry of the company LESVOS Quarries S.A., in the quarry area of Geraneio, Local Community of Avalon, Mytilene, Lesvos Prefecture"; https://diavgeia.gov.gr/luminapi/api/decisions/%CE%A8%CE%931%CE%9A%CE%9F%CE%A11%CE%99-%CE%A7%CE%A6%CE%A5/document.pdf
Decision for the Approval of Environmental Terms regarding the exploitation of slate quarry in Ztokos Sistrouni, Municipality of Dodoni, Ioannina Prefecture. Activity owner: Athanasios Tsolis; https://diavgeia.gov.gr/luminapi/api/decisions/%CE%A8%CE%96%CE%97%CE%A9%CE%9F%CE%A11%CE%93-%CE%A0%CE%A5%CE%9B/document.pdf
Decision for the Approval of Environmental Terms regarding the Surface Exploitation of Chromite Mines and for Exploration Boreholes within the Mining Concessions OP30 and OP25 of North Vourino at the Rizo site in Grevena and Kozani regions of the company "Grevena Kozani Mines SA";

https://diavgeia.gov.gr/luminapi/api/decisions/66%CE%91%CE%9E4653%CE%A08-%CE%A82%CE%A4/document.pdf
Decision for the Approval of Environmental Terms regarding the underground exploitation of bauxite ore in Makrylakkoma, Gravia, Municipality of Delphi, Regional Division of Fokida; https://diavgeia.gov.gr/luminapi/api/decisions/%CE%A9%CE%947%CE%934653%CE%A08-%CE%A5%CE%9B%CE%A6/document.pdf
DGEG (2019). Plano de Intervencao nas pedreiras em situacao critica. Action Plan for Quarries in Critical Condition for the Environment, Human Health and Built Infrastructure; http://www.dgeg.gov.pt/default.aspx?cn=733384818488AAAAAAAAAAAA
DGEG. Guião de Pedreiras. Guidance for Licensing and Best Practice in the Quarry Industry; http://www.dgeg.gov.pt/default.aspx?cn=733384818488AAAAAAAAAAAA
DGEG. Roadmap for licensing quarries; http://www.dgeg.gov.pt?cr=16619
DHI (2010). Environmental effects of the use of large vessels for raw material extraction on the seabed
"Dundee Precious Metals (2016). NI 43-101 Technical Report Mineral Reserve Update Chelopech Project, Chelopech, Bulgaria (Gold); https://www.sedar.com/search/search_en.htm
EBRD (2014). Sub-sectoral Environmental and Social Guidelines: Stone, Sand and Gravel. European Bank for Reconstruction and Development; https://www.ebrd.com/downloads/policies/environmental/mining/stone-sand.pdf
EBRD. Mining - Operations Policy. European Bank for Reconstruction and Development; https://www.ebrd.com/downloads/policies/sector/mining-operations-policy.pdf
ECAFIR (2013). REALITZACIÓ DE TREBALLS DE CAMP I RECULL DE DADESSOBRE ELS COSTOS REALS DE RESTAURACIÓ DEDIFERENTS TIPOLOGIES D'ACTIVITATS EXTRACTIVES; http://mediambient.gencat.cat/web/.content/home/ambits_dactuacio/empresa_i_produccio_sostenible/restauracio_dactivitats_extractives/Documents_tecnics-glossari-estadistiques-bibliografia/Documents_tecnics/Costos-restauracio-ECAFIR.pdf
EEERE Project (2014). An Overview of Energy Efficiency Opportunities in Mining and Metallurgy Engineering. Energy Efficiency Education Resources for Engineering
EIT Raw Materials (2018). SO4Control project - Scale-up of Solution for Mining Water Sulphate Control with Side-product Recovery; https://eitrawmaterials.eu/project/so4control/
ELAW (2010). Guidebook for evaluating mining project EIAs. Environmental Law Alliance Worldwide
ERMITE (2002). Guidelines - Mining Impacts on the Fresh Water Env - Catchments; http://www.mwen.info/ERMITE/ERMITE_D6.pdf
ES-LOM (2015). GUÍA SOBRE CONTROL GEOTÉCNICO EN MINERÍA A CIELO ABIERTO; https://energia.gob.es/mineria/Seguridad/Guias/Guías/Guia-control-geotecnico-en-mineria-a-cielo-abierto.pdf
ES-LOM (2015). GUÍA SOBRE CONTROL GEOTÉCNICO EN MINERÍA SUBTERRÁNEA; https://energia.gob.es/mineria/Seguridad/Guias/Guías/Guia-control-geotecnico-mineria-subterranea.pdf
ES-MITECO (2011). Guia Metodológica: Mineria de sulfuros polimetálicos, sales sódicas y potásicas; https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/responsabilidad-mediambiental/memoriayanejos_gm_mineria_web_tcm30-194065.pdf
Estonia (2010). Conclusions based on the description of BAT for Estonian shale oil production. Ministry of the Environment; https://www.envir.ee/sites/default/files/eesti_p6levkivi6li_tootmise_pvt_jareldused.pdf
Estonia (2017). Handbook for reclamation of aggregates quarries. Ministry of the Environment; https://www.envir.ee/sites/default/files/korrastamise_rmt_2017.pdf
Estonia (2017). Validation of BAT conclusions. The best use of Estonian oil shale for energy purposes based on a description of the available technique; https://www.envir.ee/sites/default/files/eesti_p6levkivi_energeetilise_kasutamise_pvt_jareldused.pdf
EUPG. Life in quarries (Life project); https://www.youtube.com/watch?v=Mqdgv-jTBR0; http://www.lifeinquarries.eu/
EUROGYPSUM (2010). Biodiversity Stewardship in Gypsum Quarrying: our Best Practices; https://www.business-and-biodiversity.de/fileadmin/user_upload/documents/The_Good_Companies/Knauf/EUROGYPSUMBIODIVERSITY_EN.pdf
EUROGYPSUM (2013). Performance indicators framework for biodiversity management in gypsum quarries throughout Europe; https://www.eurogypsum.org/wp-content/uploads/2015/04/EUROGYPSUMPERFORMANCEINDICATORSBD.pdf
EUROGYPSUM. Saint-Gobain case studies
Euromines (2005). Ultimate SME Implementation Guides to ISO9001 & ISO14001; http://www.euromines.org/what-we-do/environment/environmental-certification

EUROMINES (2006). Euromines Guidelines for Sustainable Development; http://www.euromines.org/files/what-we-do/sustainable-development-issues/euromines-sustainable-development-guidelines-jan2012.pdf
Euromines (2011). Natura 2000: A Guide to the Guide; http://www.euromines.org/files/publications/natura-2000-guide-guide.pdf
EUROMINES (2012). HEAP LEACHING TECHNIQUE in MINING; http://www.euromines.org/files/mining-europe/mining-techniques/batforheapleaching-feb2013-c.zanbak-euromines.pdf
European Aggregates Association (2019). Sustainable development awards. Promoting good practice; http://www.uepg.eu/uploads/Modules/Publications/uepg-sda2019_awards_brochure-v08-(08112019)_pbp-final.pdf
European Aggregates Association. Online case studies; http://www.uepg.eu/key-uepg-topics/case-studies/biodiversity
European Commission (2000). Good environmental practice in the EU extractive industry in the EU extractive industry; https://ec.europa.eu/growth/content/good-environmental-practice-european-extractive-industry-reference-guide_en
European Commission (2001). FMP BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/fmp_bref_1201.pdf
European Commission (2006). ECM BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/ecm_bref_0706.pdf
European Commission (2006). EFS BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/esb_bref_0706.pdf
European Commission (2006). Emissions from Storage. EFS BREF. European IPPC Bureau, JRC; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/esb_bref_0706.pdf
European Commission (2009). ENE BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/ENE_Adopted_02-2009.pdf
European Commission (2012). Establishment of guidelines in the inspection of mining waste facilities, inventory and rehabilitation of abandoned facilities and review; https://ec.europa.eu/environment/pdf/waste/mining/Inspection-Rehabilitation_BREF_report.pdf
European Commission (2013). CLM BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/CLM_Published_def_0.pdf
European Commission (2013). IS BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/IS_Adopted_03_2012.pdf
European Commission (2016). CWW BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/CWW_Bref_2016_published.pdf
European Commission (2017). Environmental Impact Assessment of Projects. Guidance on the preparation of the Environmental Impact Assessment Report; https://ec.europa.eu/environment/eia/pdf/EIA_guidance_EIA_report_final.pdf
European Commission (2017). NFM BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC107041_NFM_bref2017.pdf
European Commission (2018). Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries. JRC. MWEI BREF; https://publications.jrc.ec.europa.eu/repository/handle/JRC109657
European Commission (2018). ROM REF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-12/ROM_2018_08_20.pdf
European Commission (2018). WT BREF. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC113018_WT_Bref.pdf
European Commission (2019). Best Available Techniques Guidance Document on upstream hydrocarbon exploration and production; https://op.europa.eu/en/publication-detail/-/publication/f9265d2b-574d-11e9-a8ed-01aa75ed71a1/language-en/format-PDF/source-93598867
European Commission (2019). Development of a guidance document on best practices in the Extractive Waste Management Plans; https://op.europa.eu/en/publication-detail/-/publication/f18472f8-36aa-11e9-8d04-01aa75ed71a1/language-en/format-PDF/source-87989698
European Commission (2019). FMP BREF_D1. EIPPCB; https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/FMP_D1_web.pdf
European Commission (2019). Non-energy mineral extraction in relation to Natura 2000. Case studies; http://www.termeszetvedelem.hu/index.php?pg=menu_1713
European Commission (2019). Non-energy mineral extraction in relation to Natura 2000. Case studies; https://ec.europa.eu/environment/nature/natura2000/management/docs/NEEI%20case%20studies%20-%20Final%20booklet.pdf

European Commission (2011). Non-energy mineral extraction and Natura 2000; https://ec.europa.eu/environment/nature/natura2000/management/docs/neei_n2000_guidance.pdf
FAO Webpage. Topographical surveys; http://www.fao.org/tempref/FI/CDrom/FAO_Training/FAO_Training/General/x6707e/x6707e07.htm
Federacion de Aridos (2009). Los aridos y el desarrollo sostenible. Spain (received as pdf file)
Federacion de Aridos (2012). Los aridos y el desarrollo sostenible. Premios FdA. Spain (received as pdf file)
Federacion de Aridos (2015). Los aridos y el desarrollo sostenible. Premios FdA. Spain (received as pdf file)
Federacion de Aridos (2018). Los aridos y el desarrollo sostenible. Premios FdA. Spain (received as pdf file)
Finland (2015). Guide: Environmental Impact Assessment Procedure for Mining Projects in Finland; http://en.gtk.fi/export/sites/en/mineral_resources/EIA_guidelines_for_mining_projects_in_Finland_2015.pdf
Finland Government (2010). Finland's mineral strategy; http://projects.gtk.fi/minerals_strategy/index.html
Finnish Environment Institute (2013). Best Environmental Practices in Metal Ore Mining; https://helda.helsinki.fi/bitstream/handle/10138/40006/FE_29en_2011.pdf?sequence=4&isAllowed=y
First Quantum (2015). NI 43-101 Technical Report Mineral Reserve Update Cobre Las Cruces Operation Andalucía, Spain (Copper); https://www.sedar.com/search/search_en.htm; https://www.miningdataonline.com/reports/Cobre%20Las%20Cruces_06302015_Technical%20report.pdf
First Quantum (2015). NI 43-101 Technical Report Mineral Reserve Update Kevitsa Nickel Copper Mine, Lapland, Finland (Nickel); https://www.sedar.com/search/search_en.htm; http://tupa.gtk.fi/karttasovellus/mdae/references/12_Kevitsa/12_Kevitsa_Ni43-101_TechnicalReport_20160330.pdf
Forum Mineralische Rohstoffe. Austria; http://www.forumrohstoffe.at/umwelt/#nachhaltigkeit
France (2017). Bonnes pratiques de l'activité minière. Ministère de l'Économie et des Finances, BRGM, INERIS, Réseau d'Excellence Mine & Société [Ministry of the economy and finance, BRGM, INERIS, Réseau d'Excellence Mine & Société (2017). Good practices in mining activities]; http://www.mineralinfo.fr/sites/default/files/upload/tome_12_tableau_bonnes-pratiques_final24032017.pdf
France (2017). La mine en France : l'état de l'art. Ministère de l'Économie et des Finances, BRGM, INERIS, Réseau d'Excellence Mine & Société [Ministry of economy and finance, BRGM, INERIS, Réseau d'Excellence Mine & Société (2017). Mining in France: state of the art]; http://www.mineralinfo.fr/page/mine-en-france-letat-lart
France (2017). Sondages miniers. Ministère de l'Économie et des Finances, BRGM, INERIS, Réseau d'Excellence Mine & Société [Ministry of the economy and finance, BRGM, INERIS, Réseau d'Excellence Mine & Société (2017). Mining surveys]; http://www.mineralinfo.fr/sites/default/files/upload/tome_11_sondages_miniers_final24032017.pdf
G. Gaidajis, K., et al. (2012). Ambient air quality at the wider area of an industrial mining facility at Stratoni, Chalkidiki, Greece", Journal of Environmental Science and Health, 2012 (47), 1869-1877; https://www.tandfonline.com/doi/full/10.1080/10934529.2012689581
Gammons C.H., Harris L.N., Castro J.M., Cott P.A., Hanna B.W. (2009). Creating lakes from open pit mines: processes and considerations, with emphasis on northern environments, Canadian Technical Report of Fisheries and Aquatic Sciences 2826; https://pdfs.semanticscholar.org/de6c/d39654348f897019db8a7b6822bc2bf44a8a.pdf
GAP ARIDOS (nd). Buenas practicas medioambientales. Spain (received as pdf file)
GAP ARIDOS (nd). Concienciacion medioambiental a los trabajadores y empresarios (received as pdf file)
GAP ARIDOS (nd). Criterios para la mejora continua de la gestion medioambiental en el sector de los aridos (received as pdf file)
GAP ARIDOS (nd). Dia de los arboles y los aridos (received as pdf file)
GAP ARIDOS (nd). Diagnosis ambiental del sector de los aridos. Avance de resultados (received as pdf file)
GAP ARIDOS (nd). Diagnostico medioambiental de las pyme del sector de los aridos (received as pdf file)
GAP ARIDOS (nd). Estudio buenas practicas medioambientales en el sector de los aridos (received as pdf file)
GAP ARIDOS (nd). Guia par las relaciones con el entorno social (received as pdf file)
GAP ARIDOS (nd). Herramienta para la mejora de la gestion ambiental de canteras y graveras (received as pdf file)
GAP ARIDOS (nd). Lineas de futuro para la gestion ambiental de canteras y graveras: 2010-2020 (received as pdf file)
GAP ARIDOS (nd). Sensibilizacion medioambiental en el sector de los aridos (received as pdf file)
GAP ARIDOS (nd). Una oportunidad para el desarrollo sostenible del sector de los áridos (received as pdf file)
Generalitat de Catalunya - Ecoquarry project (2007). Manual per a la restauració depedreres de roca calcàriaen clima mediterrani; http://mediambient.gencat.cat/ca/05_ambits_dactuacio/empresa_i_produccio_sostenible/restauracio_dactivitats_extractives/introduccio/limpuls-del-projecte-ecoquarry-programa-life-2004-07/

Generalitat de Catalunya (1987). Recomanacions tecniques per a la restauració I condicionament dels espais afectats per acitivitats extractives; http://www.gencat.cat/mediamb/publicacions/monografies/recomanacions_tecniques_restauracio_espais_afectats_activitats_extractives.pdf
Generalitat de Catalunya (1997). La restauració ambiental de les activitats extractives a Catalunya; http://www.gencat.cat/mediamb/publicacions/monografies/QMA6_restauracio_activitats_extractives.pdf
Geological Survey of Finland. Mine closure web pages; https://mineclosure.gtk.fi/
Germany (2017). Sustainability Schemes for Mineral Resources. BGE Germany [Federal institute for Geosciences and Natural Resources]; https://www.bgr.bund.de/EN/Themen/Min_rohstoffe/Downloads/Sustainability_Schemes_for_Mineral_Resources.pdf?__blob=publicationFile&v=6
Gilcher, S., und D. Bruns (1999). Renauturierung von Abbaustellen. Umer, Stuttgart; Google Scholar
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Agua (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Biodiversidad (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Eficiencia energetica (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Impacto visual (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Patrimonio (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Polvo (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Residuos (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Ruido (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Trafico (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Vegetacion (received as pdf file)
Gobierno de Aragon (nd). Buenas practicas medioambientales en canteras y graveras. Vibraciones (received as pdf file)
"Gobierno de Extremadura (2014). Guía para la tramitación ambiental mineras en la de las actividades Comunidad Autónoma de Extremadura
[Government of Extremadura (2014). Guide for mining environmental processing in the activities of the Autonomous Community of Extremadura]; http://extremambiente.juntaex.es/files/biblioteca_digital/Guia%20Tramitacion%20Ambiental%20Actividades%20Mineras_peq.pdf"
Gobierno de la Rioja (2010). Mejora de la gestion energetica en canteras y graveras de la Rioja. Spain
Golder Associates (2010). Literature Review of Current Fugitive Dust Control Practices within the Mining Industry; https://www.cemi.ca/wp-content/uploads/2017/06/Literature.pdf
Golomeova, M., & Zendelska, A. (2016). Application of some natural porous raw materials for removal of lead and zinc from aqueous solutions (pp. 21-49). InTech; https://www.intechopen.com/books/microporous-and-mesoporous-materials/application-of-some-natural-porous-raw-materials-for-removal-of-lead-and-zinc-from-aqueous-solutions
Golomeova, M., Stojanovska, M., Krstev, B., Golomeov, B., Zendelska, A., & Krstev, A. (2013). The treatment possibility of mining drainage from horizon 830 in the Sasa Mine, Macedonia; http://eprints.ugd.edu.mk/6752/
Gorman et al. (2018). A review of sustainable mining and resource management: Transitioning from the life cycle of the mine to the life cycle of the mineral; https://www.sciencedirect.com/science/article/pii/S0921344918302076
GOV-UK (2014). Guidance on the planning for mineral extraction in plan making and the application process; https://www.gov.uk/guidance/minerals
Great Lakes Indian Fish and Wildlife Commission (2016). Metallic Mineral Mining: The Process & the Price; https://www.glifwc.org/publications/pdf/2016Process.pdf
Greece (2011). Approval of environmental terms and conditions for the project: a) MINING - METALLURGICAL FACILITIES AT KASSANDRA MINES, and b) REMOVAL, CLEANING AND REHABILITATION OF OLYMPIAS OLD MINING TAILINGS AREA belonging to the company HELLAS GOLD S.A. in the Prefecture of Halkidiki

Greece (2011). National Reporting to the Eighteenth and Nineteenth Sessions of the Commission on Sustainable Development of the United Nations (UN-CSD 18/19), II Mining. Hellenic Ministry of Environment, Energy and Climate Change; https://sustainabledevelopment.un.org/content/documents/dsd/dsd_aofw_ni/ni_pdfs/NationalReports/greece/Greece-CSD18-19_Chapter_II-Mining.pdf
Greek Mining Enterprises Association: Annual reports 2005-2018; https://www.sme.gr/syndesmos/%ce%b5%cf%84%ce%ae%cf%83%ce%b9%ce%b5%cf%82-%ce%b5%ce%ba%ce%b8%ce%ad%cf%83%ce%b5%ce%b9%cf%82/
Holmberg et al. (2017). Global energy consumption due to friction and wear in the mining industry; https://www.sciencedirect.com/science/article/pii/S0301679X17302359
IAEA (2004). The long term stabilization of uranium mill tailings. IAEA-TECDOC-1403; https://www-pub.iaea.org/MTCD/Publications/PDF/te_1403_web.pdf
IAI (2018). Sustainable Bauxite Mining Guidelines. International Aluminium Institute
ICMM (2003). Mining and protected areas position statement. International Council on Mining and Metals; https://www.icmm.com/en-gb/members/member-commitments/position-statements/mining-and-protected-areas-position-statement
ICMM (2009). Mercury risk management position statement. International Council on Mining and Metals; https://www.icmm.com/en-gb/members/member-commitments/position-statements/mercury-risk-management-position-statement
ICMM (2012). Water management in mining: a selection of case studies; http://icmm.uat.bvng.uk.net/website/publications/pdfs/water/water-management-in-mining_case-studies
ICMM (2014). Water stewardship framework; https://www.icmm.com/water-stewardship-framework
ICMM (2015). A cross-sector guide for implementing the Mitigation Hierarchy. International Council on Mining and Metals; https://www.icmm.com/en-gb/publications/biodiversity/a-cross-sector-guide-for-implementing-the-mitigation-hierarchy
ICMM (2017). Position Statement Water Stewardship. International Council on Mining and Metals; https://www.icmm.com/water-ps
ICMM (2018). Performance expectations. International Council on Mining and Metals; https://www.icmm.com/website/publications/pdfs/commitments/181126_performance-expectations.pdf
ICMM (2019). Good practice guide for mining and biodiversity. International Council on Mining and Metals; https://guidance.miningwithprinciples.com/good-practice-guide-mining-biodiversity/
ICMM (2019). Mine closure good practice guide. International Council on Mining and Metals; https://guidance.miningwithprinciples.com/integrated-mine-closure-good-practice-guide/
ICMM (2019). Practical guide catchment based water management. International Council on Mining and Metals; https://guidance.miningwithprinciples.com/catchment-based-water-management/
IFC (2007). Environmental, Health and Safety Guidelines for Mining. Environmental, Health, and Safety Guidelines, International Finance Corporation, World Bank Group; https://www.ifc.org/wps/wcm/connect/595149ed-8bef-4241-8d7c-50e91d8e459d/Final%2B-%2BMining.pdf?MOD=AJPERES&CVID=jqezAit&id=1323153264157
IFC (2007). Environmental, Health and Safety Guidelines for onshore oil and gas development. Environmental, Health, and Safety Guidelines, International Finance Corporation, World Bank Group; http://documents.worldbank.org/curated/en/858751486372860509/pdf/112103-ENGLISH-Onshore-Oil-and-Gas-Development-PUBLIC.pdf
IFC (2007). Environmental, Health, and Safety Guidelines for Construction Materials Extraction. Environmental, Health, and Safety Guidelines, International Finance Corporation, World Bank Group; https://www.ifc.org/wps/wcm/connect/dad17995-66be-4280-86da-b438cf9fbefc/Final%2B-%2BConstruction%2BMaterials%2BExtraction.pdf?MOD=AJPERES&CVID=jkC-EN&id=1323162191491
IFC (2012). Performance standards on environmental and social sustainability. International Finance Corporation, World Bank Group; https://www.ifc.org/wps/wcm/connect/24e6bfc3-5de3-444d-be9b-226188c95454/PS_English_2012_Full-Document.pdf?MOD=AJPERES&CVID=jkV-X6h
IGME (1989). Manual de restauración de terrenos y evaluación de impactos ambientales en minería. Serie Guías y Manuales, nº 2. Instituto Geológico y Minero de España. Ministerio de Industria y Energía. Madrid; http://info.igme.es/SidPDF%5C065000%5C106%5C65106_0001.pdf
Ignacy (2019). Relative elevations of the surface of artificially drained mine subsidence areas as significant aspects in formulating environmental policy; https://www.sciencedirect.com/science/article/pii/S0022169419305360
IGREMAP (2015). GUIA METODOLÒGICA PER A LA REDACCIÓ DE PLANS DE GESTIÓ DE RESIDUS EN LES ACTIVITATS EXTRACTIVES; http://mediambient.gencat.cat/web/.content/home/ambits_dactuacio/empresa_i_produccio_sostenible/restaur

acio_dactivitats_extractives/Documents_tecnics-glossari-estadistiques-bibliografia/Documents_tecnics/Proposta-metodologica-Residus-Extractives.pdf
Ilieva et al. (2019). Mining Deformation Life Cycle in the Light of InSAR and Deformation Models. Remote Sensing 11.7, 745; https://doi.org/10.3390/rs11070745
IMA Europe (). EU 2030 Strategy and its relation to industrial minerals
IMA Europe (2018). Industrial minerals sector contribution to circular economy; https://www.ima-europe.eu/sites/ima-europe.eu/files/publications/IMA-Europe_Circular%20Economy%20Report_2018.pdf
IMERYS (2010). Land reclamation and biodiversity management on Milos island S&B mines; http://www.imerys-additivesformetallurgy.com/sustainability-case-studies/land-reclamation-and-biodiversity-management-on-milos-island-sb-mines/
INAP (2014). Global Acid Rock Drainage Guide (GARD). The International Network for Acid Prevention; http://www.gardguide.com/images/5/5f/TheGlobalAcidRockDrainageGuide.pdf
INAP (2014). The International Network for Acid Prevention Global Acid Rock Drainage Guide; http://www.gardguide.com/index.php?title=Main_Page
Indian Ministry of Environment and Forests (2007). Comprehensive Industry Document on iron ore mining
Indian Ministry of Environment and Forests (2010). Minimum National Standards for iron ore mining; https://www.cpcb.nic.in/displaypdf.php?id=SW5kdXN0cnktU3BlY2lmaWMtU3RhbmRhcmRzL0VmZmx1ZW50L0lyb25fb3JlbWluaW5nX29yZXByb2Nlc3NpbmcucGRm
International Cyanide Management Code (2019). International cyanide management code; https://www.cyanidecode.org/about-cyanide-code/cyanide-code
Ireland (2006). Environmental Management In The Extractive Industry. Environmental Protection Agency; http://www.epa.ie/pubs/advice/general/EPA_management_extractive_industry.pdf
Ireland (2007). Environmental Management in the Extractive Industry (Non-Scheduled Minerals). Environmental Protection Agency; http://www.epa.ie/pubs/reports/research/waste/ERTDI%20Report%2033.pdf
Ireland (2012). Guidance on the Waste Management (Management of Waste from the Extractive Industries) Regulations 2012. Environmental Protection Agency; http://www.epa.ie/pubs/advice/waste/extractive/guidanceonthewastemanagementextractivewasteregs2012.html
Ireland (2014). Guidance on Assessing and Costing Environmental Liabilities. Environmental Protection Agency; http://www.epa.ie/pubs/reports/enforcement/EPA_QEE%20Guidance%20and%20Assessing%20WEB.pdf
Ireland (2015). Guidance on Financial Provision for Environmental Liabilities. Ireland Protection Agency; https://www.epa.ie/pubs/advice/licensee/guidanceonfinancialprovision.html
Ireland (2018). Industrial Emissions Licence Register No. P0516-04 and accompanying inspector's report for Boliden Tara Mines Designated Activity Company. Environmental Protection Agency
IRMA (2018). IRMA Standard for Responsible Mining. IRMA-STD-001. Initiative for Responsible Mining Assurance; https://responsiblemining.net/wp-content/uploads/2018/07/IRMA_STANDARD_v.1.0_FINAL_2018.pdf
ITERAMS. Reinventing the role of water and waste in mining. European H2020 project; http://www.iterams.eu/
ITRC (2010). Mining Waste Treatment Technology Selection; https://www.itrcweb.org/miningwaste-guidance/
ITRC (2010). Mining Waste Treatment Technology Selection; https://www.itrcweb.org/miningwaste-guidance/to_membrane_sep.htm
IUCN (2009). Guía de gestión ambiental para minería no metálica. International Union for Conservation of Nature [International Union for Conservation of Nature (2009). Environmental management guide for non-metallic mining]; https://portals.iucn.org/library/node/45819
IUCN (2014). Biodiversity management in the cement and aggregates sector Integrated Biodiversity Management System (IBMS). International Union for Conservation of Nature; https://portals.iucn.org/library/node/44626
Jain et al. (2015). Environmental Impact of MINING AND MINERAL PROCESSING Management, Monitoring, and Auditing Strategies; https://www.sciencedirect.com/book/9780128040409/environmental-impact-of-mining-and-mineral-processing
Jakupi, S. (2016). Removal of nickel, cobalt and chromium ions from aqueous solutions using natural zeolite (Doctoral dissertation, Goce Delcev University, Stip); http://eprints.ugd.edu.mk/17296/
JRC (2018). Non-energy, non-agriculture raw materials production: Data to monitor the sector's water use and emissions to water; https://ec.europa.eu/jrc/en/publication/non-energy-non-agriculture-raw-materials-production-data-monitor-sector-s-water-use-and-emissions
Junta de Andalucía (2002). Guía para el diseño y construcción de escombreras. Consejería de Empleo y Desarrollo Tecnológico de la Junta de Andalucía. Sevilla; http://www.asociacionversos.org/files/documentos/_192/Junta-de-Andalucia-2015-Guia-dise%C3%B1o-y-construccion-de-escombreras.pdf

Kaivosvastuu (2017). Finnish Towards Sustainable Mining (TSM) Standard; https://www.kaivosvastuu.fi/app/uploads/2017/03/Kaivosvastuujarjestelma_EN_13-03-17.pdf
Kempton, H., et al. (2010). Policy guidance for identifying and effectively managing perpetual environmental impacts from new hardrock mines. Environmental Science & Policy, 13(6), 558-566; https://www.sciencedirect.com/science/article/pii/S146290111000064X
Landcom (2004). Managing urban stormwater: soils and construction; https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Water/Water-quality/managing-urban-stormwater-soils-construction-volume-1-fourth-edition.pdf
Landesamt für Bergbau, Energie und Geologie. Verfügbare Techniken zur Vermeidung oder Verminderung (PRT) von Umweltauswirkungen im nichtenergetischen Bergbau, ausgenommen Rohstoffabfälle [State Office for Mining, Energy and Geology. Available techniques for avoiding or reducing (PRT) environmental impacts in non-energy mining, excluding raw material waste]
Landesbund für Vogelschutz in Bayern eV (2014). Kiesgewinnung und Artenvielfalt, Handlungsleitfaden für Schwaben; https://www.natur-auf-zeit.de/media/pdf/schwabenleitfaden.pdf
LBGR (2018). Richtlinie vom für die Handhabung des Betriebsplanverfahrens hier: Gliederung Hauptbetriebsplan für Steine- und Erdenbergbaue; PDF file
LNEG (1999). Regras de Boa Prática no Desmonte a Céu Aberto; http://www.lneg.pt/CienciaParaTodos/edicoes_online/diversos/boa_pratica
LNEG (2000). As Boas Práticas Ambientais na Indústria Extractiva: Um Guia de Referência; https://www.lneg.pt/CienciaParaTodos/edicoes_online/diversos/praticas_ambientais
LNEG (2000). Guia de Acesso à Actividade Mineira; http://www.lneg.pt/CienciaParaTodos/edicoes_online/diversos/guia_acesso
LNEG (2008). Geochemistry and Mineralogy of Mill Tailings Impoundments from the Panasqueira Mine (Portugal): Implications for the Surrounding Environment; https://link.springer.com/article/10.1007/s10230-008-0046-4
LNEG (2010). Assessment of soil contamination by potentially toxic elements in the aljustrel mining area in order to implement soil reclamation strategies; https://onlinelibrary.wiley.com/doi/full/10.1002/ldr.1035
LNEG (2010). The use of multivariate statistical analysis of geochemical data for assessing the spatial distribution of soil contamination by potentially toxic elements in the Aljustrel mining area (Iberian Pyrite Belt, Portugal); https://link.springer.com/article/10.1007/s12665-010-0631-2
LNEG (2011). Mine tailings integrated investigations: The case of Rio tailings (Panasqueira Mine, Central Portugal); https://www.sciencedirect.com/science/article/pii/S0013795211002420
LNEG (2011). Quantitative–spatial assessment of soil contamination in S. Francisco de Assis due to mining activity of the Panasqueira mine (Portugal); https://link.springer.com/article/10.1007%2Fs11356-013-1495-2
LNEG (2014). Acid mine drainage from the Panasqueira mine and its influence on Zêzere river (Central Portugal); https://www.sciencedirect.com/science/article/pii/S1464343X13001921
LNEG (2014). Contributo para o Plano de Gestao Ambiental do Nucleo de Pedreiras das Pedras Finas; http://repositorio.ipvc.pt/bitstream/20.500.11960/1562/1/Goncalves_Sofia_2053.pdf
LNEG (2014). Heavy metal pollution in mine–soil–plant system in S. Francisco de Assis – Panasqueira mine (Portugal); https://www.sciencedirect.com/science/article/pii/S0883292713001819
LNEG (2014). Identifying Sources and Assessing Potential Risk of Exposure to Heavy Metals and Hazardous Materials in Mining Areas: The Case Study of Panasqueira Mine (Central Portugal) as an Example; https://www.researchgate.net/publication/266237778_Identifying_Sources_and_Assessing_Potential_Risk_of_Exposure_to_Heavy_Metals_and_Hazardous_Materials_in_Mining_Areas_The_Case_Study_of_Panasqueira_Mine_Central_Portugal_as_an_Example
LNEG (2014). Sustentabilidade dos Georrecursos: Proposta de Definição de Índice de Sustentabilidade para Pedreiras Produtoras de Agregados; https://recipp.ipp.pt/bitstream/1040022/6254/1/DM_PauloPita_2014_MEGG.pdf
LNEG (2015). Integrated approach to assess the environmental impact of mining activities: estimation of the spatial distribution of soil contamination (Panasqueira mining area, Central Portugal); https://link.springer.com/article/10.1007/s10661-015-4343-7
LNEG (2015). Plano ambiental e de recuperação paisagística de um campo de exploração de uma concessão mineira de caulino; https://repositorio-aberto.up.pt/handle/10216/79634
LNEG (2015). Water–Rock Interaction and Geochemical Processes in Surface Waters Influenced by Tailings Impoundments: Impact and Threats to the Ecosystems and Human Health in Rural Communities (Panasqueira Mine, Central Portugal); https://link.springer.com/article/10.1007/s11270-014-2255-8

LNEG (2016). Health risk assessment through consumption of vegetables rich in heavy metals: the case study of the surrounding villages from Panasqueira mine, Central Portugal; https://link.springer.com/article/10.1007%2Fs10653-016-9834-0
LNEG (2019). Casos de boas práticas Portugal; https://www.lneg.pt/download/14163/Lisboa_Minland%20Apresentacao.pdf
LNEG. Manuais de boas práticas disponíveis no LNEG; http://www.lneg.pt/CienciaParaTodos/dossiers/recursos
London Mining Network (2019). Risk Analysis of the Tailings Dams at the Riotinto Mine, Andalusia, Spain; https://londonminingnetwork.org/wp-content/uploads/2019/11/RioTinto_Report_190930.pdf
Luís, A. T., et al. (2011). Environmental impact of mining activities in the Lousal area (Portugal): chemical and diatom characterization of metal-contaminated stream sediments and surface water of Corona stream. Science of the Total Environment, 409(20), 4312-4325; https://www.sciencedirect.com/science/article/pii/S004896971100708X
LUNDIN MINING (2017). NI 43-101 Technical Report Mineral Reserve Update FOR THE ZINKGRUVAN MINE, SWEDEN; https://www.sedar.com/search/search_en.htm ; https://www.lundinmining.com/site/assets/files/3642/zm-techreport-113017-sedar.pdf
LUNDIN MINING (2017). NI 43-101 Technical Report Mineral Reserve Update NEVES-CORVO MINE, PORTUGAL; https://www.sedar.com/search/search_en.htm; https://www.lundinmining.com/site/assets/files/3643/neves-corvo-technical-report.pdf
Manhart et al. (2019). The environmental criticality of primary raw materials – A new methodology to assess global environmental hazard potentials of minerals and metals from mining; https://link.springer.com/article/10.1007/s13563-018-0160-0
Manstein, Christopher, und Hartmut Stiller (2000). Anwendung der Materialintensitätsanalyse nach dem MIPS-Konzept auf österreichische Verkehrsträgersysteme. Studie des Vereins Faktor 4+ im Auftrag des österr. Ministeriums für Wissenschaft und Verkehr, Klagenfurt; Google Scholar
Maria do Carmo, L. I. M. A., et al. (2014). Evaluation of biological absorption coefficient of trace elements in plants from the pitinga mine district, amazonian region. Revista do Instituto Geológico, São Paulo, 35(1), 19-29; https://www.researchgate.net/publication/272829923_EVALUATION_OF_BIOLOGICAL_ABSORPTION_COEFFICIENT_OF_TRACE_ELEMENTS_IN_PLANTS_FROM_THE_PITINGA_MINE_DISTRICT_AMAZONIAN_REGION
MEND (2004). Design, construction and performance monitoring of cover systems for waste rock and tailings. Canadian Mine Environment Neutral Drainage Program, Project 2.21.4, July; http://mend-nedem.org/wp-content/uploads/2.21.4a-Cover-Design-Manual.pdf
MEND (2009). Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials. Mine Environment Neutral Drainage; http://mend-nedem.org/mend-report/prediction-manual-for-drainage-chemistry-from-sulphidic-geologic-materials/
MEND (2013). Review of Mine Drainage Treatment and Sludge Management Operations. Mine Environment Neutral Drainage; http://mend-nedem.org/mend-report/review-of-mine-drainage-treatment-and-sludge-management-operations/
MEND (2014). Study to Identify BATEA for the Management and Control of Effluent Quality from Mines. MEND Report 3.50.1. Mine Environment Neutral Drainage; http://mend-nedem.org/wp-content/uploads/MEND3.50.1BATEAAppAD.pdf
Michelini et al. (2015). Advanced data processing of ground-based synthetic aperture radar for slope monitoring in open pit mines. Proceedings of the 2015 24th International Mining Congress of Turkey; https://www.researchgate.net/publication/282699042_Advanced_data_processing_of_ground-based_synthetic_aperture_radar_for_slope_monitoring_in_open_pit_mines
Milos Vineyard (2017). an innovative reclamation project of IMERYS; http://www.imerys-additivesformetallurgy.com/sustainability-case-studies/milos-vineyard-an-innovative-reclamation-project-of-imerys/
Minéraux Industriels France, UP Chaux (2019). L'économie circulaire au cœur des minéraux pour l'industrie; http://www.unicem.fr/wp-content/uploads/mif-economie-circulaire-au-coeur-des-mineraux-pour-industrie-2019.pdf
Mining Association of Canada (2008). TSM - Mine Closure Framework; https://mining.ca/towards-sustainable-mining/protocols-frameworks/mine-closure-framework /
Mining Association of Canada (2019). A Guide to the Management of Tailings Facilities; https://mining.ca/documents/guide-management-tailings-facilities-third-edition
Mining Association of Canada (2019). Towards sustainable mining - TSM guiding principles; https://mining.ca/towards-sustainable-mining/tsm-guiding-principles/
Mining Association of Canada (2019). TSM - Biodiversity conservation management protocol; https://mining.ca/documents/biodiversity-conservation-management-protocol/

Mining Association of Canada (2019). TSM - Energy and greenhouse gas emissions management protocol; https://mining.ca/documents/energy-and-greenhouse-gas-emissions-management-protocol/
Mining Association of Canada (2019). TSM - Safety and health framework; https://mining.ca/documents/safety-and-health-framework/
Mining Association of Canada (2019). TSM - Safety and health protocol; https://mining.ca/documents/safety-and-health-updated-june-3-2019/
Mining Association of Canada (2019). TSM - Water stewardship protocol; https://mining.ca/documents/water-stewardship-protocol-updated-june-3-2019/
Ministerio para la transición ecológica y el reto demográfico (2018). Guía de restauración ecológica [Ministry for the ecological transition and the demographic challenge (2018). Guide to ecological restoration]; https://www.miteco.gob.es/es/ceneam/recursos/pag-web/guia-restauracion-ecologica.aspx
Ministerio para la transición ecológica y el reto demográfico (2018). Guía para la restauración de huecos mineros con residuos de construcción y demolición [Ministry for the ecological transition and the demographic challenge (2018). Guide for the restoration of mining holes with construction and demolition waste]; https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/guia_rehabilitacion_huecos_mineros_web_tcm30-487268.pdf
MIRO (2011). Management, mitigation and monitoring of nuisance dust and PM10 emissions arising from the extractive industries: an overview; https://www.researchgate.net/publication/324994466_Management_mitigation_and_monitoring_of_nuisance_dust_and_PM10_emissions_arising_from_the_extractive_industries_an_overview_Final_Report_to_the_Mineral_Industry_Research_Organisation_MIRO
MiSE (2014). Guidelines for monitoring seismicity, ground deformation and pore pressure in subsurface industrial activities
Moffat, A. and Mc Neill, J. (1994). Reclaiming disturbed land for forestry. Bulletin 110. HMSO. London; https://www.forestresearch.gov.uk/research/archive-reclaiming-disturbed-land-for-forestry/
Monserrat et al. (2014). A review of ground-based SAR interferometry for deformation measurement. ISPRS Journal of Photogrammetry and Remote Sensing 93, 40-48; https://www.sciencedirect.com/science/article/pii/S0924271614000884
NEMO project. Near-zero-waste recycling of low-grade suplhidic mining waste; https://h2020-nemo.eu/
Nikolaou, L.E, Evangelinos, K.I. (2010). A SWOT analysis of environmental management practices in Greek Mining and Mineral Industry", Resources Policy 35 (2010), 226-234; https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&cad=rja&uact=8&ved=2ahUKEwi-xqTz3_vmAhXREVAKHUX8DA8QFjADegQIAxAB&url=https%3A%2F%2Fideas.repec.org%2Fa%2Feee%2Fjrpoli%2Fv35y2010i3p226-234.html&usg=AOvVaw3QQt02vQuB_UMec-6baM8K
NORDEN (2013). Best Environmental Practices in the Mining Sector in the Barents Region
NORDEN (2015). Mining in the Nordic Countries; https://norden.diva-portal.org/smash/get/diva2:842595/FULLTEXT01.pdf
Nordic Council of Ministers (2017). Water Conscious Mining; http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1108991&dswid=-4573
Norgate, T., & Haque, N. (2010). Energy and greenhouse gas impacts of mining and mineral processing operations. Journal of Cleaner Production, 18(3), 266-274; https://www.sciencedirect.com/science/article/pii/S0959652609003199
NORUT (2018). Remote sensing for the mining industry; https://www.oulu.fi/sites/default/files/36/RESEM_EOReview.pdf
OECD (2019). BEST AVAILABLE TECHNIQUES (BAT) FOR PREVENTING AND CONTROLLING INDUSTRIAL POLLUTION. Activity 2: Approaches to Establishing BAT Around the World; https://www.oecd.org/chemicalsafety/risk-management/approaches-to-establishing-best-available-techniques-around-the-world.pdf
OECD (2019). Mining and green growth in the EECCA region. Organisation for Economic Co-operation and Development; https://www.unece.org/fileadmin/DAM/env/documents/2019/TEIA/20190413_Mining_and_Green_Growth_Final.pdf
Oeko-Institut (2016). Voluntary initiatives in the mining sector and their principles and criteria on environmental sustainability; https://www.stradeproject.eu/fileadmin/user_upload/pdf/STRADE_PB_07_OEI_Nov.2016.pdf
Ontario (2017). Management approaches for industrial fugitive dust sources; https://files.ontario.ca/management-approaches-for-industrial-fugitive-dust-sources.pdf
ORBICON. Stiksugningsprojekt 2016
Papanikolaou, I., Iatrou, G. Panitsa, M., Papageorgiou, N., Katsiamboulas, A. (2013). Titan Patras Cement Plant: Biodiversity Study for Artimes Limestone Quarry;

http://www.sdimi.org/papers_2013/SDIMI_A2/2nd%20day/09.00-10.30/05_Titan%E2%94%AC%C3%A1Patras%E2%94%AC%C3%A1Cement%E2%94%AC%C3%A1Plant-Biodiversity%E2%94%AC%C3%A1Study%E2%94%AC%C3%A1for%E2%94%AC%C3%A1Artimes%E2%94%AC%C3%A1%20Limestone%E2%94%AC%C3%A1Quarry.pdf
PDEP (2012). Erosion and Sediment Pollution Control Program Manual; https://pawccd.org/uploads/3/4/8/2/34827270/363-2134-008.pdf
Pennsylvania Department of Environmental Protection (1999). Engineering Manual for Mining Operations; http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=7707&DocName=ENGINEERING%20MANUAL%20FOR%20MINING%20OPERATIONS.PDF%20%20%3Cspan%20style%3D%22color%3Agreen%3B%22%3E%3C%2Fspan%3E%20%3Cspan%20style%3D%22color%3Ablue%3B%22%3E%3C%2Fspan%3E
Pieraccini and Miccinesi (2019). Ground-based radar interferometry: A bibliographic review. Remote Sensing 11.9, 1029; https://www.mdpi.com/2072-4292/11/9/1029
Plachter, H. (1983). Die Lebensgemeinschaften aufgelassener Abbaustellen — Ökologie und Naturschutzaspekte von Trockenbaggerungen mit Feuchtbiotopen. Schriftenreihe Bayrisches Landesamt für Umweltschutz 56. Oldenbourg Verlag, München; Google Scholar
PM (2007). Sektorsko upatstvo za tretman na otpadni vodi i otpadni gasovi Zajaknuvawe na upravuvaweto so `ivotnata sredina Republika Makedonija [PM (2007). Sectors for the treatment of auto accident and gas accidents in Zajaknuva will be upgraded so that the Republic of Macedonia]; http://www.moepp.gov.mk/wp-content/uploads/2014/10/Sektorski%20upatstva-otpadni%20vodi%20i%20otpadni%20gasovi_%20mkd.pdf
Politis, A., Paspaliaris, I., Taxiarchou, M and Tserou, E. (2017). Report on innovation evaluation criteria and best case practices in waste management and mine closure, Deliverable 5.2. MIN-GUIDE (Minerals Policy Guidance for Europe) EU Horizon 2020 Project, Grant agreement No. 689527; https://www.min-guide.eu/sites/default/files/project_result/d5.2_report_on_innovation_evaluation_criteria_and_best_case_practices_in.pdf
Polster, D. F. (2003). Soil bioengineering for slope stabilization and site restoration. Mining and the Environment III, 25-28; https://botanicgardens.uw.edu/wp-content/uploads/sites/7/2013/12/SoilBioengineeringForSlopeStabilizationAndSiteRestoration.pdf
Poschlod, P. et al. (1997). Steinbrüche und Naturschutz-Sukzession in Renaturierung. ecomed, Landsberg; Google Scholar
Projects in the Czech Republic; https://portal.cenia.cz/eiasea/view/eia100_cr
Przyłucka et al. (2015). Combination of Conventional and Advanced DInSAR to Monitor Very Fast Mining Subsidence with TerraSAR-X Data: Bytom City (Poland). Remote Sensing 7.5, 5300-5328; https://www.mdpi.com/2072-4292/7/5/5300
Punkkinen H. et al. (2016). Guideline for mine water management; https://www.vtt.fi/inf/pdf/technology/2016/T266.pdf
Rauche, H. (2015). Die Kaliindustrie im 21. Jahrhundert; https://www.springer.com/de/book/9783662468333
Regulation of Mining and Quarrying activities (Ministerial Decision 12050/2223, Gazette B' 1227/14-06-2011); http://www.ypeka.gr/LinkClick.aspx?fileticket=8jP1EcjPHIk%3D&tabid=296&language=el-GR
Resavski, A. (2016). Искористување на комуналниот отпад за производство на топлинска енергија. Masters thesis, Goce Delcev University, Stip; http://eprints.ugd.edu.mk/16070/1/Teza.pdf
RESEM (nd). REmote SEnsing supporting surveillance and operation of Mines; https://www.oulu.fi/water/resem
Responsible Mining Foundation (2019). RMI Framework 2020; https://www.responsibleminingfoundation.org/rmi-framework-2020/
Responsible Steel (2019). Responsible steel standard 1.0; https://www.responsiblesteel.org/wp-content/uploads/2019/11/ResponsibleSteel_Standard_v1-0.pdf
Ritthof, Michael, Holger Rohn undChrista Liedtke (2002). MIPS berèchnen. Ressourcenproduktivität von Produktion und Dienstleistungen, Wuppertal Spezial 27; Wuppertal Institut für Klima, Umwelt, Energie; Google Scholar
Runge, H., und B. Mestermann (2002). Verbesserung der Renaturierungsmöglichkeiten bei Abbauvorhaben. Reihe Angewandte Landschaftsökologie Heft 48, Hrsg. BfN, Bonn-Bad Godesberg; Google Scholar
Russia (2016). BREF Mining industry, general processes and methods; http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=801&etkstructure_id=1872
Russia (2017). BREF Coal mining and processing; http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1130&etkstructure_id=1872
Russia (2017). BREF mining and processing of ferrous metal ores; http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1106&etkstructure_id=1872
Russia (2017). BREF mining and processing of non ferrous metal ores; http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1102&etkstructure_id=1872

Russia (2017). BREF precious metals mining; http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1155&etkstructure_id=1872
Samini Namin et al. (2011). Environmental impact assessment of mining activities. A new approach for mining methods selection; http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BPZ1-0068-0018
Schmidt-Bleek, F. (1994). Wie viel Umwelt braucht der Mensch? MIPS. Das Maß für ökologisches Wirtschaften. Birknäuser Verlag, Berlin/Basel/Boston; Google Scholar
Schmidt-Bleek, F. (1998). Das MIPS-Konzept. Weniger Naturverbrauch — mehr Lebensqualität durch Faktor 10. Droemer Verlag, München; Google Scholar
Schmidt-Bleek, F. (2004). Der ökologische Rucksack. Wirtschaft für eine Zukunft mit Zukunft. Hirzel Verlag, Stuttgart/Leipzig; Google Scholar
Schmidt-Bleek, F., et al. (1998). MAIA, Einführung in die Material-Intensitäts-Analyse nach dem MIPS-Konzep. Wuppertal Texte, Birkhäuser Verlag, Berlin/Basel/Boston; Google Scholar
SEDAR DATABASE. NI 43-101 Technical Report Mineral Reserve Update; https://www.sedar.com/search/search_en.htm
SERENE project (2018). IoT Monitoring for mines; https://eitrawmaterials.eu/project/serene-2/
Simevska, Golomeova, Zendelska (2017). Water quality control in WWTP - Berovo; http://js.ugd.edu.mk/index.php/NRT/article/view/1999/1778
Skobelev (2017). BAT Application in various industries
Skousen, J., & Ziemkiewicz, P. (2005). Performance of 116 passive treatment systems for acid mine drainage. Proceedings, American Society of Mining and Reclamation, Breckenridge, CO, 1100-1133; https://www.asmr.us/Portals/0/Documents/Conference-Proceedings/2005/1100-Skousen.pdf
SME - Nelson (2011). Site environmental considerations. P. Darling (Ed.), SME Mining Engineering Handbook (3rd ed); https://smemi.personifycloud.com/PersonifyEbusiness/Store/Product-Details/productId/2824786
SME (2008). Basics of metal mining influenced water. Society for Mining, Metallurgy and Exploration; https://smemi.personifycloud.com/PersonifyEbusiness/Store/Product-Details/productId/116888
SME (2009). Mine Pit Lakes - Characteristics, Predictive Modeling, and Sustainability. Society for Mining, Metallurgy and Exploration; https://smemi.personifycloud.com/PersonifyEbusiness/Store/Product-Details/productId/116919
SME (2009). Mitigation of Metal Mining Influenced Water. Society for Mining, Metallurgy and Exploration; https://smemi.personifycloud.com/PersonifyEbusiness/Store/Product-Details/productId/3242386
SME (2011). Mining Engineering Handbook, 3rd edition. Society for Mining, Metallurgy and Exploration; https://smemi.personifycloud.com/PersonifyEbusiness/Store/Product-Details/productId/2824786
SME (2014). Sampling and Monitoring for the Mine Life Cycle. Society for Mining, Metallurgy and Exploration; https://smemi.personifycloud.com/PersonifyEbusiness/Store/Product-Details/productId/3209412
SME (2014). Techniques for Predicting Metal Mining Influenced Water.Society for Mining, Metallurgy and Exploration; https://smemi.personifycloud.com/PersonifyEbusiness/Store/Product-Details/productId/3198118
SME (2017). Geochemical Modeling for Mine Site Characterization and Remediation. Society for Mining, Metallurgy and Exploration; https://smemi.personifycloud.com/PersonifyEbusiness/Store/Product-Details/productId/1988468
Society of Greek Mining Enterprises (2011). Decision for the Approval of environmental terms and conditions for the projects: a) Mining - Metallurgical facilities at Kassandra mines, and b) Removal , cleaning and rehabilitation of Olympias old mining tailings area belonging to the company Hellas Gold S.A. in the Prefecture of Halkidiki; http://files.hellas-gold.com/kya/20110726_kya.pdf
Society of Greek Mining Enterprises (2017). Actions of TITAN S.A for sustainable development: Biodiversity studies in TITAN aggregate quarries in Patra, Rethymno, (Crete), Milos and Pella; https://www.titan.gr/uploads/special_publications/viopoikilotita-fusiki-isoropia.pdf
Society of Greek Mining Enterprises (2017). Hellas Gold Sustainability Report; https://www.hellas-gold.com/koinwnia/etairiki-eythini-2017/
Society of Greek Mining Enterprises (2019). Decision for the Approval of Environmental Terms for the exploitation of marble quarry covering an area of 92.014,62 Sqm, located in Papoutsi area, Municipality of Kato Nevrokopi, Regional Unit of Drama by the company MARMI Ltd; https://diavgeia.gov.gr/luminapi/api/decisions/%CE%A8%CE%99%CE%94%CE%A7%CE%9F%CE%A11%CE%A5-7%CE%97%CE%9C/document.pdf
Society of Greek Mining Enterprises (2019). Decision for the Approval of Environmental Terms regarding the exploitation of 98.084,00 Sqm of Industrial Minerals (zeolithos) in the area of "Skaloma", Municipality of Ariana, Regional Unit of Rodopi, by the company AVGI Ltd. (in Greek); https://diavgeia.gov.gr/luminapi/api/decisions/%CE%A8%CE%97%CE%9F6%CE%9F%CE%A11%CE%A5-%CE%A5%CE%9C%CE%A1/document.pdf

Society of Greek Mining Enterprises. Greek Mining Enterprises Association: Best Practices of Greek mining companies; https://www.sme.gr/%ce%b2%ce%b9%cf%8e%cf%83%ce%b9%ce%bc%ce%b7-%ce%b1%ce%bd%ce%ac%cf%80%cf%84%cf%85%ce%be%ce%b7/%ce%ba%ce%b1%ce%bb%ce%b5%cf%83-%cf%80%cf%81%ce%b1%ce%ba%cf%84%ce%b9%ce%ba%ce%b5%cf%83/
South Africa (2008). Best Practice Guideline - A5: Water Management for Surface Mines; https://www.mineralscouncil.org.za/work/environment/environmental-resources/send/26-environmental-resources/344-a5-water-management-for-surface-mines
SP (2015). Biological treatment toolbox for Swedish mine drainage. SP Technical Research Institute of Sweden; http://ri.diva-portal.org/smash/get/diva2:962891/FULLTEXT01.pdf
Spain (2006). Guía para el proyecto y la ejecución de muros de escollera en obras de carretera. Ministerio de Fomento, Dirección General de carreteras. Serie Normativas. Madrid; https://www.fomento.es/recursos_mfom/0710100.pdf
Spain (2015). Guía de buenas prácticas en el diseño y ejecución de voladuras en banco. Ministerio de Energía, Turismo y Agenda Digital [Ministry of Energy, Tourism and Digital Agenda, Spain (2015). Good practices guide for design and execution of bank blasting]; https://energia.gob.es/mineria/Explosivos/Guias/Guia_buenas_practicas_diseno_ejecucion_voladuras_banco.pdf
Spitz, K., & Trudinger, J. (2008). Mining and the environment: from ore to metal
Srour, G. H. (2011). Mine Waste Failure: An Analysis of Empirical and Graphical Runout Predition Methods; https://open.library.ubc.ca/cIRcle/collections/undergraduateresearch/52966/items/1.0053599
Starchl, M. Berg Huettenmaenn Monatsh (2006). Nachhaltigkeit im Steinbruch Hohenems-Unterklien [Sustainable work with stone quarries]; https://doi.org/10.1007/BF03165352
Stefanakis, M. (2018). S&B* Mining Stewardship in Milos Island. Bulletin of the Geological Society of Greece, 53(1), 50-63. doi:http://dx.doi.org/10.12681/bgsg.18661; http://dx.doi.org/10.12681/bgsg.18661
"Stojanovska M. (2013). Контрола и третман на рудничките дренажи во рудник Саса ДОО, М. Каменица. Masters thesis, Goce Delcev University, Stip
Stojanovska M. (2013). Control and treatment of mine drainage in the Sasa mine. ; http://eprints.ugd.edu.mk/10361/"
Strategic Dialogue on Sustainable Raw Materials for Europe (2016). Outlining Environmental Challenges in the Non-fuel mining sector; http://stradeproject.eu/fileadmin/user_upload/pdf/PolicyBrief_04-2016_Sep2016_FINAL.pdf
SVEMIN (2015). SveMin's instruction for vehicles, machinery and technical equipment; https://www.svemin.se/?file_download&file=2481
Sweden (2018). Resultat av Energiutredning U8 Aitikgruvan [Results of Energy Investigation at the Aitik mine], Boliden; https://www.boliden.com/operations/mines/boliden-aitik
Sweden. Alternativ. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Alternativ-/
Sweden. Artskydd i specifik miljöbedömning. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/Biologisk-mangfald/Artskydd/
Sweden. Avgränsning och avgränsningssamråd. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Avgransning-/
Sweden. Befolkning och hälsa i miljöbedömningen. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/Befolkning-och-halsa/
Sweden. Biologisk mångfald i miljöbedömning. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/Biologisk-mangfald/
Sweden. Ekologisk kompensation i specifik miljöbedömning. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Underlag-kompensation/
Sweden. Ekosystemtjänster i miljöbedömningar. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/Biologisk-mangfald/Ekosystemtjanster-i-miljobedomningar1/
Sweden. Integrera klimataspekten i specifik miljöbedömning. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/Klimat/Integrera-klimataspekten/

Sweden. Integrera miljöbedömning i utvecklingen av en verksamhet eller åtgärd. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Hallbar-utveckling-i-miljobalken/Integrera-miljobedomning/
Sweden. Klimat i miljöbedömningar. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/Klimat/
Sweden. Klimatanpassning. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/Klimat/Mer-information-om-klimatanpassning/
Sweden. Krav på sakkunskap. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Kompetenskrav/
Sweden. Kumulativa effekter. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/Kumulativa-effekter/
Sweden. Miljöbedömning vid Natura 2000-tillståndsprövning. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Natura2000-och-specifik-miljobedomning/
Sweden. Miljöeffekter. Environmental Protection Agenc; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljoaspekter-i-miljobedomning/
Sweden. Miljökonsekvensbeskrivningen. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Miljokonsekvensbeskrivningen-/
Sweden. Nuläge och framskrivet nuläge. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Nulage-och-framskrivet-nulage/
Sweden. Samrådsunderlag. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Samradsunderlag/
Sweden. Specifik miljöbedömning – miljöbedömning för verksamheter och åtgärder. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/
Sweden. Syftet med miljöbedömningar. Environmental Protection Agency; https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Miljobedomningar/Specifik-miljobedomning/Hallbar-utveckling-i-miljobalken/
SYKE (2010). Paras käyttökelpoinen tekniikka (BAT) Ympäristöasioiden hallinta kiviainestuotannossa; https://helda.helsinki.fi/bitstream/handle/10138/37976/SY25_2010.pdf?sequence=1&isAllowed=y
SYKE (2014). Parhaat ympäristökäytännöt (BEP) luonnonkivituotannossa; https://helda.helsinki.fi/handle/10138/152750
The National Academy of Sciences, Engineering, Medicine (2002). Evolutionary and Revolutionary Technologies for Mining. US
Thenepalli, T., et al. (2019). A Brief Note on the Heap Leaching Technologies for the Recovery of Valuable Metals. Sustainability, 11(12), 3347; https://www.mdpi.com/2071-1050/11/12/3347/pdf
Toy, T.J. and Foster, G.R. (1998). Guidelines for the use of the Revised Universal Soil Loss Erosion Equation (RUSLE), version 1.06 on Mined Lands, Construction Sites and Reclaimed Lands. USDI- Office of Surface Mining. Denver, Colorado; http://www.ott.wrcc.osmre.gov/library/hbmanual.htm
Tränkle, U. (1997). Naturschutzwert von Steinbrüchen und ein Verfahren zur standorts- und naturschutzgerechten Renautierung durch Einbringung von Mähgut. In: Böcker und Kohler (Hrsg): Abbau von Bodenschätzen und Wiederherstellung der Landschaft. Hohenheimer Umwelttag 29, Ostfildern; Google Scholar
TRUEL. Austria; https://www.treulkies.at/renaturierung.html
Tuokuu (2019). Identifying and clarifying environmental policy best practices for the mining industryeA systematic review; https://www.sciencedirect.com/science/article/pii/S0959652619308029
UBA (2017). Responsible mining? Challenges, perspectives and approaches; https://www.umweltbundesamt.de/en/publikationen/responsible-mining-challenges-perspectives
UK (2006). Planning and minerals: Practice guide. UK Government; https://www.gov.uk/government/publications/planning-and-minerals-practice-guide
UK (2011). How to comply with your environmental permit. Additional guidance for: mining waste operations. Environment Agency; https://www.gov.uk/government/publications/mining-waste-operations-epr-614-additional-guidance
UK (2016). Onshore Oil & Gas Sector Guidance. Environment Agency

UNDP (2018). Managing Mining for Sustainable Development. United Nations Development Programme; https://www.undp.org/content/undp/en/home/librarypage/poverty-reduction/Managing-Mining-for-SD.html
UNEP (2001). Mining and Environment in the Western Balkans; http://www.unep.at/documents_unep/Balkan_Feasibility_Studies/Mining_Western_Balkans_2001_01_11.pdf
UNEP (2007). Innovative Techniques and Technologies for Contaminated Mine Waters Assessment, Management and Remediation - Technical Workshop Report; http://www.envsec.org/publications/Innovative%20techniques%20and%20technologies%20for%20contaminated%20mine%20water%20assessment,%20management%20and%20remediation.%20Technical%20workshop%20report_June%202007.pdf
UNEP-ICMM (2005). Good Practice in Emergency Preparedness and Response. UNEP-International Council on Mining and Metals; https://www.icmm.com/en-gb/publications/health-and-safety/good-practice-in-emergency-preparedness-and-response
University of Belgrade. Dust and Noise Environmental Impact Assessment and Control in Serbian Mining Practice; https://www.mdpi.com/2075-163X/8/2/34/pdf
US EPA (2007). The use of soil amendments for remediation, revitalization and reuse; https://www.epa.gov/sites/production/files/2015-08/documents/soil_amendments_542-r-07-013.pdf
US Federal Remediation Technologies Roundtable. Remediation Technologies Screening Matrix and Reference Guide, Version 4.0; https://frtr.gov/matrix2/top_page.html
USA (2007). Mining Industry Energy Bandwidth. US Department of Energy; https://www.energy.gov/sites/prod/files/2013/11/f4/mining_bandwidth.pdf
USAID (2011). EIA Technical Review Guideline: Non-Metal and Metal Mining. United States Agency for International Development; https://www.epa.gov/sites/production/files/2014-04/documents/miningvol2.pdf
USBLM (1992). Solid Minerals Reclamation Handbook. BLM Manual Handbook H-3042-1. U.S. Government Printing Officce. Washington, D.C.; https://www.ntc.blm.gov/krc/uploads/239/Solid%20Minerals%20Reclamation%20Handbook%20H-3042-1.pdf
USDA-NRCS (1992). Chapter 18: Soil Bioengineering for Upland Slope Protection and Erosion Reduction. Engineering Field Handbook, Part 650 210-EFH. USDA-NRCS. Washington, D.C. ; https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17555.wba
USDI (1982). Surface Mining Water Diversion Design Manual. Office of Surface Mining OSM/TR-82/2. U.S. Government Printing Office. Washington, D.C. National Technical Reports; https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB90153164.xhtml
USDI (1987). A manual for training reclamation inspectors in the fundamentals of soils and revegetation. Prepared for the Office of Surface Mining and Enforcement by the Soil and Water Conservation Society. Ankeny, Iowa; https://www.arcc.osmre.gov/resources/impoundments/OSM-AManualforTrainingReclamationInspectorsintheFundamentalsofSoilsandRevegetation1987.pdf
US-EPA (1979). Mineral Mining and Processing Effluent Guidelines; https://www.epa.gov/eg/mineral-mining-and-processing-effluent-guidelines
US-EPA (1988). Ore Mining and Dressing Effluent Guidelines; https://www.epa.gov/eg/ore-mining-and-dressing-effluent-guidelines
US-EPA (1993). Handbook for constructed wetlands receiving acid mine drainage. Risk Reduction Engineering Laboratory Office of Research and Development, U.S. EPA. EPA/5401R-93/523. Cincinnati, Ohio; https://nepis.epa.gov/Exe/ZyPDF.cgi/P10048QQ.PDF?Dockey=P10048QQ.PDF
US-EPA (1998). Permeable reactive barriers technologies for contamination remediation. Office of Research and Development. EPA 600-R-98-125. Washington D.C.; https://clu-in.org/download/rtdf/prb/reactbar.pdf
US-EPA (2001). Ore Mining and Dressing Preliminary Study Report; https://www.epa.gov/sites/production/files/2016-05/documents/ore_mining_study_sept_2011.pdf
US-EPA (2006). Industrial Stormwater - Fact Sheet - Sector E: Glass, Clay, Cement, Concrete, and Gypsum Product Manufacturing Facilities; https://www.epa.gov/sites/production/files/2015-10/documents/sector_e_glass.pdf
US-EPA (2006). Industrial Stormwater - Fact Sheet - Sector F: Primary Metals Facilities; https://www.epa.gov/sites/production/files/2015-10/documents/sector_f_primarymetals.pdf
US-EPA (2006). Industrial Stormwater - Fact Sheet - Sector J: Mineral Mining and Processing Facilities; https://www.epa.gov/sites/production/files/2015-10/documents/sector_j_mineralmining.pdf
US-EPA (2006). Management and Treatment of Water from Hard Rock Mines; https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=158390
US-EPA (2011). Gold Mine Ore Processing and Production: National Emission Standards for Hazardous Air Pollutants for Area Sources; https://www.epa.gov/stationary-sources-air-pollution/gold-mine-ore-processing-and-production-national-emission-standards

US-EPA (2014). REFERENCE GUIDE to Treatment Technologies for Mining-Influenced Water; https://www.epa.gov/remedytech/reference-guide-treatment-technologies-mining-influenced-water
US-EPA (2019). Taconite Iron Ore Processing: National Emission Standards for Hazardous Air Pollutants (NESHAP); https://www.epa.gov/stationary-sources-air-pollution/taconite-iron-ore-processing-national-emission-standards-hazardous
USGS. Environmental Considerations Related to Mining of Nonfuel Minerals. United States Geological Survey; https://pubs.usgs.gov/pp/1802/b/pp1802b.pdf
Vayionas P., Papageorgiou P., Efstathiadis T., Kalfas A. I., Yiannoulakis H. and Zampetakis T. (2017). New desulfurization technology for SOx reduction with positive net environmental impact based on MgO reagents. Poster presented at 6th International Conference on Environmental Management, Engineering, Planning and Economics in Thessaloniki-Greece (June 25-30, CEMEPE 2017); http://www.betterlife-withmgo.eu/attachments/article/103/CEMEPE_2017_poster.pdf
VDI. VDI 3790 Guideline No. 3: Environmental meteorology - Emission of gases, odours and dusts from diffuse sources - Storage, transhipment and transportation of bulk materials; https://www.vdi.de/richtlinien/details/vdi-3790-blatt-3-umweltmeteorologie-emissionen-von-gasen-geruechen-und-staeuben-aus-diffusen-quellen-lagerung-umschlag-und-transport-von-schuettguetern-1
"VDZ. VDZ-Merkblatt Vt 15 – Umweltverträgliche Rohstoffgewinnung; https://www.vdz-online.de/publikationen/verfahrenstechnische-merkblaetter/
https://www.vdz-online.de/fileadmin/gruppen/vdz/Bilder/Publikationen/Vt-Merkblaetter/Vt_15_Inhalt.pdf"
Verein Deutscher Zementwerke e.V (2002). Naturschutz und Zementindustrie; https://www.vdz-online.de/publikationen/naturschutz-zementindustrie
VERO (2017). Maßnahmen zur Unterstützung der Abgrabungsamphibien in der Rohstoffgewinnung NRWs; https://www.vero-baustoffe.de/der-verband/publikationen?task=document.viewdoc&id=1105
VITO (2004). Best Available Techniques (BAT) for the extraction of sand, gravel, loam and clay; https://emis.vito.be/nl/bbt-studie-ontginning
VTT (2015). Nitrogen compounds at mines and quarries. VTT Technical Research Centre of Finland; https://www.vtt.fi/inf/pdf/technology/2015/T226.pdf
VTT (2015). Solutions for control of nitrogen discharges at mines and quarries Miniman project final report. VTT Technical Research Centre of Finland; https://www.vtt.fi/inf/pdf/technology/2015/T225.pdf
VTT (2016). Guidelines for mine water management. VTT Technical Research Centre of Finland; https://www.vtt.fi/inf/pdf/technology/2016/T266.pdf
WBCSD (2011). Guidelines on Quarry Rehabilitation. World Business Council for Sustainable Development; https://www.wbcsd.org/Sector-Projects/Cement-Sustainability-Initiative/Resources/Guidelines-on-Quarry-Rehabilitation
WBCSD (2014). Biodiversity Management Plan (BMP). World Business Council for Sustainable Development; https://www.wbcsd.org/Sector-Projects/Cement-Sustainability-Initiative/Resources/Biodiversity-Management-Plan-Guidance
WDEQ (1994). Guideline No. 1: Topsoil and Overburden. Wyoming Department of Environmental Quality. Land Quality Division; http://deq.wyoming.gov/media/attachments/Land%20Quality/Guidelines/Guideline_1_Topsoil_(8_1994)_reformat.pdf
World Bank (2015). The power of mine. A transformative opportunity for Sub-Saharian Africa; http://documents.worldbank.org/curated/en/429771468008719026/pdf/The-power-of-the-mine-a-transformative-opportunity-for-Sub-Saharan-Africa.pdf
World Economic Forum (2015). Mining and metals in a sustainable world; http://www3.weforum.org/docs/WEF_MM_Sustainable_World_2050_report_2015.pdf
WRC (2018). Development of a Web Enabled Mine Water Management Vulnerability Assessment Tool (MINEWATER) to facilitate Resource Protection; http://www.wrc.org.za/wp-content/uploads/mdocs/2451-1-18.pdf
Yfantis N., et al. (2018). Evaluation of a pilot plant for a secondary treatment of mining effluents" in Desalination and Water Treatment, 127(2018)184-196; https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwij05zk3fvmAhVHbVAKHTNZDs0QFjAAegQIARAB&url=https%3A%2F%2Fwww.deswater.com%2Fvol.php%3Fvol%3D127%26oth%3D127%257C0%257CSeptember%2520%2520%257C2018&usg=AOvVaw3oPtaHRjYZeNiPdqNLrizS
Zendelska A. (2010), Evaluation of the quality of water, soil and sediments in the vicinity of the tailing dam of Sasa mine and its impact on the environment. Masters thesis, University Goce Delcev Shtip; http://eprints.ugd.edu.mk/440/1/Afrodita_Zendelska.pdf

Zendelska A. (2015). Possibilities for use of natural raw materials in treatment of mine water contaminated with heavy metals. PhD thesis, Goce Delcev University, Stip; http://eprints.ugd.edu.mk/13952/

Zendelska, A., Golomeova, M., Blazev, K. R. S. T. O., Krstev, B., Golomeov, B., & Krstev, A. (2015). Adsorption of copper ions from aqueous solutions on natural zeolite. Environment Protection Engineering, 41(4); http://epe.pwr.wroc.pl/2015/4-2015/Zendelska_4-2015.pdf

Zendelska, A., Golomeova, M., Blažev, K., Boev, B., Krstev, B., Golomeov, B., & Krstev, A. (2015). Kinetic studies of manganese removal from aqueous solution by adsorption on natural zeolite. Macedonian Journal of Chemistry and Chemical Engineering, 34(1), 213-220; https://mjcce.org.mk/index.php/MJCCE/article/view/mjcce.2015.552/411

Zendelska, A., Golomeova, M., Golomeov, B., & Krstev, B. (2018). Effect of Competing Cations (Cu, Zn, Mn, Pb) Adsorbed by Zeolite Bearing Tuff from Macedonia. Nature Environment and Pollution Technology, 17(1), 21-24; http://www.neptjournal.com/upload-images/NL-63-5-(3)-D-673.pdf

Zendelska, A., Golomeova, M., Golomeov, B., & Krstev, B. (2018). Zeolite bearing tuff as an adsorbent for heavy metals removal from aqueous solutions and a acid mine drainage. EcoTerra-Journal of Environmental Research and Protection, 15(1), 35-43; http://www.ecoterra-online.ro/files/1526369947.pdf

Zendelska, A., Golomeova, M., Golomeov, B., & Krstev, B. (2019). Removal of Zinc Ions from Acid Aqueous Solutions and Acid Mine Drainage Using Zeolite-Bearing Tuff. Mine Water and the Environment, 38(1), 187-196; http://journals.pan.pl/dlibra/publication/118185/edition/102794/content

Zendelska, A., Golomeova, M., Golomeov, B., & Krstev, B. (2019). Removal of Zinc Ions from Acid Aqueous Solutions and Acid Mine Drainage Using Zeolite-Bearing Tuff. Mine Water and the Environment, 38(1), 187-196; https://link.springer.com/article/10.1007/s10230-018-0560-y

Zendelska, A., Golomeova, M., Jakupi, Š., Lisičkov, K., Kuvendžiev, S., & Marinkovski, M. (2018). Characterization and application of clinoptilolite for removal of heavy metal ions from water resources. Geologica Macedonica, 32(1), 21-32; http://js.ugd.edu.mk/index.php/GEOLMAC/article/view/2311

List of abbreviations and definitions

List of abbreviations

ALD	Anoxic Limestone Drain
AMD	Acid Mine Drainage
ARD	Acid Rock Drainage
BAT	Best Available Technique
BCR	Bio Chemical Reactor
Biodiv. & land use	Biodiversity and land use
BOD	Biological Oxygen Demand
Consum.	Consumption
BREF	Best Available Techniques Reference document
BTR	Best Truck Ratio
COD	Chemical Oxygen Demand
CRM	Critical Raw Materials
EFS BREF	Best available techniques Reference document for Emissions from Storage
EIA	Environmental Impact Assessment
Em.	Emissions
Em. soil & gr.	Emissions to soil and groundwater
Em. surface water	Emissions to surface water
Em. to air	Emissions to air
EMS	Environmental Management System
EIP	European Innovation Partnership
EIPPCB	European Integrated Pollution Prevention and Control Bureau
EIW	Extractive Influenced Water
ESP	ElectroStatic Precipitator
EWD	Extractive Waste Directive
EWIW	Extractive Waste Influenced Water
IED	Industrial Emissions Directive
IFC	International Finance Corporation
Gen.	Generic
Generally applic.	Generally applicable
GHG	Greenhouse Gases
GHG & other comb. em.	Greenhouse Gases and other combustion emissions
Haz. mat.	Hazardous materials
HC REF	BAT Guidance Document on upstream hydrocarbon exploration and production
JRC	Joint Research Centre of the European Commission
KEI	Key Environmental Issue
MEND	Mine Environmental Neutral Drainage program
MS	Member State

MWEI BREF	BREF for the Management of Waste from Extractive Industries
N/A	not available
NEEI	Non-Energy Extractive Industries
NF	Nanofiltration
NORMs	Naturally Occurring Radioactive Materials
OECD	Organisation for Economic Co-operation and Development
OLC	Open Limestone Channel
OLD	Oxic Limestone Drain
QA/QC	Quality Assurance and Quality Control
PRB	Permeable Reactive Barrier
PRT	Prevention or Reduction Technique
Reagents & other aux. mat.	Reagents and other auxiliary materials
RM	Raw Materials
RO	Reverse Osmosis
SAPS	Successive Alkalinity-Producing System
SWOT	Strengths, Weaknesses, Opportunities and Threats
TOC	Total Organic Carbon
TSS	Total Suspended Solids
VOC	Volatile Organic Compounds
UN/UNEP	United Nations /United Nations Environment Programme
Widely applic.	Widely applicable

Chemical elements

Symbol	Name	Symbol	Name
Ag	Silver	Mn	Manganese
Al	Aluminium	Mo	Molybdenum
As	Arsenic	N	Nitrogen
Au	Gold	Ni	Nickel
Ba	Barium	O	Oxygen
C	Carbon	Pb	Lead
Ca	Calcium	Pt	Platinum
Cd	Cadmium	Ra	Radium
Cl	Chlorine	S	Sulphur
Co	Cobalt	Se	Selenium
Cr	Chromium	Sn	Tin
Cu	Copper	U	Uranium
Fe	Iron	V	Vanadium
K	Potassium	W	Tungsten
Mg	Magnesium	Zn	Zinc

ISO Country codes

ISO code	Country
EU Member States (*)	
AT	Austria
BE	Belgium
BG	Bulgaria
CZ	Czech Republic
CY	Cyprus
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HU	Hungary
HR	Croatia
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom
Non-member countries	
CH	Switzerland
MK	Former Yugoslav Republic of Macedonia
NO	Norway
TR	Turkey
US	United States
(*) The protocol order of the Member States is based on the alphabetical order of their geographical names in the original language(s).	

Glossary

Acid Mine Drainage (AMD)	Acidic drainage from mine wastes/materials resulting from the oxidation of sulphides such as pyrite
Backfilling	Refilling of an excavation or void
Basal layer	The soil or rock foundation layer at the base of an engineered structure
Baseline studies	Studies undertaken to describe the conditions that exist before an action is taken
Blasting	Fragmentation of rock by the use of explosives
Decommissioning	The process that begins near, or at, the cessation of mineral production and ends with removal of all unwanted infrastructure and services
Environmental Management System (EMS)	A tool for managing an organisation's impact on the environment. It provides a structured approach to planning and implementing environmental protection measures
Exploration	The search for mineral deposits up to discovery and includes the delineation of the deposit by means of drilling and sampling
Extractive industries	All establishments and undertakings engaged in surface or underground extraction of mineral resources for commercial purposes, including extraction by drilling boreholes, or treatment of the extracted material (Directive 2006/21/EC, Article 3(6))
Gangue	The part of an ore that is not economically desirable but cannot be avoided in mining
Heap leach	Using chemicals to dissolve minerals or metals out of an ore heap
Hydroseeding	Spraying a mixture of paper or straw mulch, containing seed, fertiliser and a binding agent, onto a slope which is too steep or inaccessible for conventional seeding techniques
Mineral resource or minerals	A naturally occurring deposit in the earth's crust of an organic or inorganic substance, such as energy fuels, metal ores, industrial minerals and construction minerals, but excluding water (Directive 2006/21/EC, Article 3(5))
Non-energy extractive industries (NEEI)	Extractive industries usually divided into three main sub-sectors, based on the different characteristics of the minerals, their use, and the downstream industries they supply: • construction minerals; • industrial minerals; • metallic minerals. (See https://ec.europa.eu/growth/sectors/raw-materials/industries/minerals_en)
Overburden	The material that extractive operations move during the process of accessing an ore or mineral body, including during the pre-production development stage: layer of natural soil or massive rock on top of an orebody.
Prevention or Reduction Technique (PRT)	Techniques for the prevention or reduction of environmental impacts in non-energy extractive industries (NEEI)
Rehabilitation	Treatment of the land affected by the extractive activity in such a way as to restore the land to a satisfactory state, with particular regard to soil quality, wildlife, natural habitats, freshwater systems, landscape and appropriate beneficial uses (modified from Directive 2006/21/EC, Article 3(20)) *[Note: for the purposes of this study, rehabilitation refers to the treatment of the land affected by the extractive activity]*
Riparian	Pertaining to, or situated on, the bank of a body of water, especially a watercourse such as a river
Treatment	The mechanical, physical , biological, thermal or chemical process or combination of processes carried out on mineral resources, including from the working of quarries, with a view to extracting the mineral, including size change, classification, separation and leaching, and the re-processing of previously discarded waste, but excluding smelting, thermal manufacturing processes (other than the burning of limestone) and metallurgical processes (Directive 2006/21/EC, Article 3(8)) *[Note: the re-processing of previously discarded waste is not included in the scope of this study]*
Upgrading	Removal of water, dewatering, sedimentation, drying.
Volatile Organic Compounds (VOC)	Volatile organic compounds are emitted as gases from certain solids or liquids. Some VOC have short-term and long-term health effects

Water balance	The sum of the water inputs (e.g. process water and rainfall runoff), and outputs (e.g. evaporation, return water, etc.). A water balance forecasts site water inflows, outflows and changes in water inventory and water management infrastructure over the life of the facility and including closure
Water cover	Layer of surface water (e.g. in a storage facility) or groundwater (e.g. in a backfilled pit) intended to limit the ingress of oxygen into AMD-generating materials

List of figures

List of tables

Annexes (See: https://publications.jrc.ec.europa.eu/repository/handle/JRC125247)

Annex 1. Overview of the KEI

The disaggregated table with the scores for each combination of (group of) mineral resource, extractive activity and environmental issue is provided in Table 3. The KEI scoring was preliminarily performed by a contracted consultant's (Wood) internal mining experts in a one-day workshop in November 2019. The panel included two senior experts on industrial emissions at the EU and global level, who were also involved in the development of the HC REF, a senior extractive industry expert with more than 25 years of expertise in mining and mining waste management, a senior engineering geologist expert in mining, research and innovation, and an environmental policy and economic expert. Four junior staff completed the Wood team. Furthermore, specific experts from different Wood departments have been consulted to refine the scoring (e.g. geochemist experts, geotechnical experts, etc.).

As introduced in Section 3.1, the KEI assessment criteria on the relevance of the environmental issues, and associated parameters, for the activity or process concerned and the fact that the process and its pollution and consumption is a significant part of the pollution and consumption in the EU extractive sub-sector guided the expert input to perform a scoring of the KEI for each combination of mineral resource and type of activity. As part of the scoring approach, the mining experts allocated each combination of extractive activity and (group of) mineral resource to one of the following categories:

- Grey: not covered, i.e. there is no aggregated impact in relation to the specific environmental issue and parameter. The combinations falling under the grey coloured category are combinations of activities and mineral resources that in reality do not occur and/or activities for which the specific aggregated environmental impact in the EU is considered as not significant.
- Green: low importance (1), i.e. the environmental issue is not relevant for the activity; although an aggregated impact could occur, this is considered as small or trivial for the activity in the EU extractive sub-sector.
- Amber: medium importance (2), i.e. the environmental issue is relevant for the activity, the aggregated impact is considered as medium for the activity in the EU extractive sub-sector; the associated risks have been assessed by Wood as usually considered and treated in order to reduce the potential environmental impacts.
- Red: high importance (3), i.e. the environmental issue is very relevant for the activity, the aggregated impact is considered as high for the activity in the EU extractive sub-sector; the associated risks have been assessed by Wood as typically considered and treated in order to reduce the potential environmental impacts.

Table 3. KEI disaggregated table

See the excel table PRT_FinalReport-Annexes.xlsx, sheet A1-Tab3 intro and sheet A1-Tab3

A summary of Table 3 is presented in the tables below for extraction (Table 4), treatment (Table 5), transport and handling (Table 6) and storage (Table 7). These summary KEI tables present the disaggregated scoring results in a more aggregated and comprehensible format.

Extraction

For surface extraction, the following can be concluded:

- For all minerals, stability impacts score high, apart from chemical stability that scores low for construction minerals.
- Emissions to soil and groundwater score high for all minerals.
- Emissions to surface water score high for metalliferous ores. In the case of industrial minerals, emissions to surface water score high for phosphate rock, moderate for limestone, gypsum and potash and low for

clay and kaolin, potash and peat. For construction minerals, emissions to surface water score low or not applicable apart from TSS emissions. More in detail, TSS scores high for all minerals.

- Dusting scores high for all minerals apart from construction and ornamental stones (medium/moderate). Dusting is followed by GHG and other combustion emissions impacts (scoring moderate for all minerals).
- Noise and vibrations score high for all minerals apart from aggregates (moderate). Odour emissions score high only for peat and moderate for metalliferous ores.
- Biodiversity and land use impacts are high (for habitats and visual, footprint and landscape impacts) or moderate (for material and natural assets impacts) for all minerals, apart from peat.
- Energy and water consumption impacts score high for all minerals, apart from construction and ornamental stones (moderate for water).
- Hazardous materials score moderate for all minerals apart from aggregates (low).

For subsurface extraction, the impacts can be summarised as follows:

- For all minerals, stability impacts score high, apart from chemical stability that scores low for construction minerals.
- Emissions to soil and groundwater score high for all minerals.
- Emissions to surface water (TSS, dissolved substances, metals and metalloids) score high for all minerals). Organic contaminants in surface water score low across all minerals. Emission of anion contaminants score high for metalliferous ores and industrial minerals, except for clay, kaolin and feldspar (low) and low for construction and ornamental stones.
- Emissions to air received the same score across all minerals, i.e. high for dust, medium/moderate for GHG and other combustion emissions and low for VOC and other pollutants.
- Vibrations score high for all minerals, whilst noise and odour emissions score low.
- The impacts on biodiversity and land are considered low for all minerals, except for the impacts on materials assets and cultural heritage (moderate score across all minerals).
- The consumption of energy and water is considered as a moderate impact for all minerals, whilst the use of reagents and auxiliary materials score low.
- Hazardous materials score moderate for all minerals.

For other extraction processes (i.e. borehole and solution mining), the following can be concluded:

- Stability impacts score high across all minerals in the case of borehole mining, except for chemical stability, scoring low for industrial and construction minerals. For solution mining, the stability impacts are considered as follows for both metalliferous ores and industrial minerals: high for chemical stability, moderate for structural stability and low for physical stability.
- Emissions to soil and groundwater score high for all minerals and processes, except for borehole mining of industrial and construction minerals (low).
- In the case of solution mining of metalliferous ores, emissions to surface water score high for TSS, acidity and dissolved substances, metals and metalloids; moderate for anion contaminants and low for organic contaminants. Borehole mining of industrial and construction minerals has a low impact on emissions to surface water. In the case of solution mining, the impacts for metalliferous ores score high for anion contaminants, acidity, suspended substances, metals and metalloids, and low for TSS and organic contaminants.
- Emissions to air, and related climate impacts, are considered as moderate for GHG and other combustion emissions and low for dust, VOC and other pollutants across all minerals and processes.
- The impacts on noise, vibrations and odour score low for all minerals and processes.
- Impacts on materials assets and cultural heritage are considered as moderate, and impacts on habitats, plants, wildlife, visual, footprint and landscape score low across all minerals and processes.

— The consumption of energy and water scores moderate for all minerals and processes. The consumption of reagents and auxiliary materials scores high in the case of solution mining and low in the case of borehole mining.

— In the case of solution mining, hazardous materials score high, whilst for borehole mining the impact is low for all minerals.

— No solution mining occurs for construction minerals.

Table 4. Summary of the KEI for extraction

Extractive activities	Extractive activity types	Sector	Safety			Em to soil &gr.	Emissions to surface water					Emissions to air			Other emissions			Biodiversity and land use			Consumption			Haz mat
			Structural stability	Physical stability	Chemical stability	Diffuse and channelled emissions	Anion contaminants	Acidity and dissolved substances	Suspended particles	Organic contaminants	Metals and metalloids	Dust	VOCs and other potential air pollutants	GHG and other comb. em	Noise	Vibrations-	Odour	Habitats, plants, wildlife	Visual, footprint and landscape impacts	Impacts on materials assets and cultural heritage	Energy consumption-	Water consumption-	Reagents and auxiliary materials	Lubricants, fuels, chemicals (incl. cyanide)
3-Extraction	3.1-Surface	Metallic minerals excluding P																					
3-Extraction	3.1-Surface	Industrial minerals					L & P C & F PE PH										PE			PE			
3-Extraction	3.1-Surface	Construction minerals										A COS			A COS						A COS		A COS
3-Extraction	3.2-Subsurface	Metallic minerals																					
3-Extraction	3.2-Subsurface	Industrial minerals excluding PE					C & F																
3-Extraction	3.2-Subsurface	Construction minerals only COS																					
3-Extraction	3.3-Other - borehole mining	Metallic minerals																					
3-Extraction	3.3-Other - borehole mining	Industrial minerals only PH & O																					
3-Extraction	3.3-Other - borehole mining	Construction minerals only A																					
3-Extraction	3.4-Other - solution mining	Metallic minerals only BM & PM																					
3-Extraction	3.4-Other - solution mining	Industrial minerals only O						P	P	P	P												
3-Extraction	3.4-Other - solution mining	Construction minerals																					

BM = base metals; PM = precious metals; L = limestone and gypsum; C = clay and kaolin; P = potash; F = feldspar; PH = phosphate rock; PE = peat; O = other industrial minerals; A = aggregates; COS = construction and ornamental stones

See Section 2 for the KEI definitions

Treatment

For treatment processes, the following can be concluded:

— Structural stability scores moderate for comminution (except for clay, kaolin and ornamental stones – low), considering the potential presence of a primary crusher underground. Furthermore, structural stability scores moderate for physical, chemical and biological separation; and low for size control and upgrading (see also the Glossary) for all minerals. Physical and chemical stability scores low for all treatment processes and minerals, apart from beneficiation of base and precious metals (moderate for chemical stability).

— Emissions to soil and groundwater score high for comminution for all minerals apart from ornamental stones (moderate). Similarly, a high score is allocated for size control for all minerals, apart from aggregates. In the case of physical separation, emissions to soil and groundwater score high for metalliferous ores and for industrial minerals (except for other industrial minerals – low); and moderate

for aggregates. In the case of the other treatment processes, emissions to soil and groundwater score low for all minerals, apart from the chemical separation of base and precious metals (moderate).

- In the case of comminution and size control, emissions to surface water of suspended particles (TSS) score high for all minerals, apart from ornamental stones (moderate for comminution) and aggregates (moderate for size control). Emissions of metals and metalloids to surface water for metalliferous ores score high for all treatment processes apart from size control and physical separation (moderate). In the case of physical separation, emissions of TSS score high for metalliferous ores and industrial minerals (apart from other industrial minerals - moderate), and moderate for aggregates. Furthermore, a moderate score is allocated to emissions of organic compounds for metalliferous ores. In the case of chemical separation of metalliferous ores, emissions of acidity and dissolved substances score high and emissions of TSS and organic compounds score moderate. In the case of biological separation of metalliferous ores, emissions of acidity, dissolved substances and of organic contaminants score high. In the case of upgrading metalliferous ores and industrial minerals, emissions of TSS score high and emissions of acidity and dissolved substances score moderate, apart from peat (low). All other impacts on emissions to surface water score low.
- Dust emissions to air score high for comminution, size control and physical separation for all minerals, apart from comminution of ornamental stones (low). Furthermore, upgrading of aggregates has a high score for dust emissions. All other emissions to air score low across all processes and minerals.
- Noise emissions score high for the size control and physical separation of aggregates and moderate for comminution, size control, physical separation and upgrading of all other minerals. Vibrations score high for comminution, size control, physical separation and upgrading of aggregates, because the aggregated environmental impacts for the EU per sub-sector as a whole have been considered, including cumulative effects (see Section 3.1). Odour scores high for the upgrading of peat and moderate for chemical separation (metalliferous ores and industrial minerals) and for biological separation (metalliferous ores).
- Visual, footprint and landscape impacts score moderate for comminution, size control and beneficiation of all minerals. The impacts on habitats, plants, wildlife score moderate for beneficiation of all minerals. All other biodiversity and land use impacts score low.
- Consumption of energy scores high for comminution and size control of metalliferous ores and moderate for comminution and size control Water consumption scores moderate for comminution, size control and physical separation of all minerals (apart from comminution of ornamental stones – low). The use of reagents and auxiliary materials scores high for the chemical separation of metalliferous ores and of phosphate rock as well as for the biological separation of metalliferous ores. The impacts from the use of reagents and auxiliary materials is moderate for the physical separation of metalliferous ores and industrial minerals (apart from other industrial minerals – low).
- Hazardous materials scores high for chemical and biological separation processes and low for all other treatment processes.
- Chemical separation does not occur for construction minerals and biological separation not for both construction and industrial minerals.

Table 5. Summary of the KEI for treatment

Extractive activities	Extractive activity types	Sector	Safety			Em to soil &gr.	Emissions to surface water					Emissions to air			Other emissions			Biodiversity and land use			Consumption			Haz mat
			Structural stability	Physical stability	Chemical stability	Diffuse and channelled emissions	Anion contaminants	Acidity and dissolved substances	Suspended particles	Organic contaminants	Metals and metalloids	Dust	VOCs and other potential air GHG and other comb. em.		Noise	Vibrations-	Odour	Habitats, plants, wildlife	Visual, footprint and landscape impacts	Impacts on materials assets and cultural	Energy consumption-	Water consumption-	Reagents and auxiliary materials	Lubricants, fuels, chemicals (incl. cyanide)
4-Treatment	4.1-Comminution (size reduction, e.g. crushing and grinding)	Metallic minerals																						
4-Treatment	4.1-Comminution (size reduction, e.g. crushing and grinding)	Industrial minerals excluding PE	C																					
4-Treatment	4.1-Comminution (size reduction, e.g. crushing and grinding)	Construction minerals	A COS			A COS			A COS			A COS									A COS	A		
4-Treatment	4.2-Size control (screening and classification)	Metallic minerals																						
4-Treatment	4.2-Size control (screening and classification)	Industrial minerals excluding PE																						
4-Treatment	4.2-Size control (screening and classification)	Construction minerals only A																						
4-Treatment	4.3-Beneficiation - physical separation	Metallic minerals																						
4-Treatment	4.3-Beneficiation - physical separation	Industrial minerals excluding PE				O			O														O	
4-Treatment	4.3-Beneficiation - physical separation	Construction minerals only A																						
4-Treatment	4.4-Beneficiation - chemical separation	Metallic minerals			BM, PM	BM, PM																		
4-Treatment	4.4-Beneficiation - chemical separation	Industrial minerals only PH & O																					PH O	
4-Treatment	4.4-Beneficiation - chemical separation	Construction minerals																						
4-Treatment	4.5-Beneficiation - biological separation	Metallic minerals																						
4-Treatment	4.5-Beneficiation - biological separation	Industrial minerals																						
4-Treatment	4.5-Beneficiation - biological separation	Construction minerals																						
4-Treatment	4.6-Upgrading (sedimentation, drying, dewatering)	Metallic minerals																						
4-Treatment	4.6-Upgrading (sedimentation, drying, dewatering)	Industrial minerals						PE	PE		PE						PE							
4-Treatment	4.6-Upgrading (sedimentation, drying, dewatering)	Construction minerals										A COS				A COS								

BM = base metals; PM = precious metals; C = clay and kaolin; PH = phosphate rock; PE = peat; O = other industrial minerals; A = aggregates; COS = construction and ornamental stones"

See Section 2 for the KEI definitions

Transport and handling

For transport and handling, the following can be concluded:

- Stability impacts score low for all activities and minerals.
- Similarly, emissions to soil and groundwater score low for all activities and minerals.
- Emissions to surface water of suspended particles (TSS) score moderate for loading, unloading and hauling of all minerals, apart from ornamental stones (low). All other emissions to surface water score low.
- Emissions to air (dust, VOC, GHG and other combustion emissions) score moderate for all activities and minerals, apart from combustion emissions from loading and unloading (low).
- Noise emissions score moderate for loading, unloading and hauling of all minerals. Vibrations score low for all activities and minerals. Odour emissions score high for loading, unloading and hauling of peat, but low for all other minerals.
- The impacts on biodiversity score low for all activities and minerals.
- Energy consumption score moderate for hauling across all minerals and low for loading and unloading. Consumption of water scores low for all activities and minerals. There are no impacts from the use of any reagents and auxiliary materials across all activities and minerals.
- Hazardous materials score moderate for loading, unloading and hauling of metalliferous ores (expect for bauxite (low). Hazardous materials score low for all other minerals.

Table 6. Summary of the KEI for transport and handling

Extractive activities	Extractive activity types	Sector	Safety			Em to groun dw	Emissions to surface water					Emissions to air			Other emissions			Biodiversity and land use			Consumption			Haz mat
			Structural stability	Physical stability	Chemical stability	Diffuse and channelled emissions	Anion contaminants	Acidity and dissolved substances	Suspended particles	Organic contaminants	Metals and metalloids	Dust	VOCs and other potential air pollutants	GHG and other comb. em.	Noise	Vibrations-	Odour	Habitats, plants, wildlife	Visual, footprint and landscape impacts	Impacts on materials assets and cultural	Energy consumption-	Water consumption-	Reagents and auxiliary materials	Lubricants, fuels, chemicals (incl. cyanide)
5-Transport and handling	5.1-Loading and unloading	Metallic minerals																						BA
5-Transport and handling	5.1-Loading and unloading	Industrial minerals															PE							
5-Transport and handling	5.1-Loading and unloading	Construction minerals							A COS															
5-Transport and handling	5.2-Hauling	Metallic minerals																						BA
5-Transport and handling	5.2-Hauling	Industrial minerals excluding PE															PE							
5-Transport and handling	5.2-Hauling	Construction minerals							A COS															

PE = peat; BA = Bauxite; A = aggregates; COS = construction and ornamental stones
See Section 2 for the KEI definitions

Storage

For storage, the following can be concluded:

- Structural stability scores moderate for all minerals, apart from limestone and gypsum, clay and kaolin, and bauxite. Physical stability score moderate for all minerals. Chemical stability scores moderate for metalliferous ores (apart from bauxite – low) and low for all other minerals.
- Emissions to soil and groundwater score moderate for all minerals, apart from peat and ornamental stones (low).
- Emissions to surface water score moderate for metalliferous ores and for industrial minerals (apart from peat and other industrial minerals – low) and low for construction minerals.
- Emissions of dust score moderate for all minerals, apart from peat and ornamental stones (low). Emissions of VOC and other pollutants score low for all minerals. GHG and other combustion emissions from storage do not occur.
- Odour scores high for peat, moderate for metalliferous ores and low for industrial minerals (except peat) and for construction minerals. Noise emissions score low for all minerals. Vibrations from storing are not significant.
- Habitats, plants, wildlife, visual, footprint and landscape impacts score moderate for all minerals. Impacts on materials assets and cultural heritage score low.
- Water consumption score low for all minerals. Energy consumption and the use of reagents and auxiliary materials is considered as insignificant.
- Hazardous materials score low for all minerals.

Table 7. Summary of the KEI for storage

Extractive activities	Extractive activity types	Sector	Safety			Em to groundw	Emissions to surface water					Emissions to air			Other emissions			Biodiversity and land use			Consumption			Haz mat
			Structural stability	Physical stability	Chemical stability	Diffuse and channelled emissions	Anion contaminants	Acidity and dissolved substances	Suspended particles	Organic contaminants	Metals and metalloids	Dust	VOCs and other potential air pollutants	GHG and other comb. em.	Noise	Vibrations-	Odour	Habitats, plants, wildlife	Visual, footprint and landscape impacts	Impacts on materials assets and cultural heritage	Energy consumption-	Water consumption-	Reagents and auxiliary materials	Lubricants, fuels, chemicals (incl. cyanide)
6-Storage	6.1-Storing (temporary storage)	Metallic minerals	BA		BA																			
6-Storage	6.1-Storing (temporary storage)	Industrial minerals	L,C			PE	PE,O	PE,O	PE,O	PE,O	PE,O	PE					PE							
6-Storage	6.1-Storing (temporary storage)	Construction minerals				A COS						A COS												

L = limestone and gypsum; C = clay and kaolin; BA = Bauxite; PE = peat; O = other industrial minerals; A = aggregates; COS = construction and ornamental stones
See Section 2 for the KEI definitions

Annex 2. Overview on the collection of PRT in the non-energy extractive industries

Description of the data collection process

Information and documents on PRT for the NEEI were gathered from Member State authorities, industry associations, environmental NGOs and other relevant stakeholders via a data and information collection exercise. This exercise was also supported by the JRC external contractor, Wood.

1. The PRT data collection timeline comprised the following steps:
    (a) Launch of the consultation on 30 October 2019 by the JRC and on 6 November 2019 by GROW. Simultaneous launch of a consultation by Wood.
    (b) Repeated extensions of the initial deadlines (18 and 29 November 2019, respectively for the JRC and GROW) to maximise the number of collected information.
    (c) Final deadline on 15 January 2020.
2. The data collection exercise was carried out through a very broad consultation of the following groups:
    (a) The Heads of European State Mining Authorities Group, composed of 26 members from AT, CZ, DE, EE, FI, IE, PL, RO, RS, SI, SK, UK, and consulted by GROW.
    (b) The Raw Materials Supply Group (RMSG), composed of 150 members from Member States, Industry and research organisations, and European Institutions and consulted by GROW.
    (c) The MWEI BREF Technical Working Group (TWG) and additional experts in the JRC network, consisting of 160 members (51% from Member States, 27% from Industry, 8% from NGOs and 14% from University, Research Institute, International Organisation, US EPA, Russian BAT Bureau, etc.), consulted by the JRC.
    (d) The Wood mining expert network, consisting of 68 experts (62% from Member States, 13% from Industry, 3% from NGOs, 22% from University, International Organisations, etc.).
3. Stakeholders were asked to provide the following data, in whatever language it was available:
    (a) Information that they considered relevant on PRT:
        i. Primarily being applied in the EU Member States (category A), whether at national or local level.
        ii. From non-EU countries or international organisations (including OECD, the World Bank/IFC, UN/UNEP, etc.) (category B).
        iii. From EU Member States on relevant activities with similar environmental issues (category C) as those encountered for extraction, treatment and storage of non-energy mineral resources (e.g. mining of energy mineral resources, upstream hydrocarbon exploration and production, management of waste from extractive industries, waste management, ferrous and non-ferrous metals industries, iron and steel production, cement, lime and magnesium oxide production, treatment of wastewaters from industrial activities, civil works and infrastructures or dredging). In this case, BREF information already published by the European Commission[33] was not analysed in detail, but clear links with these documents have been made, where useful.
    (b) Information in the form of (but not limited to) the following types of documents:
        i. Guidance documents issued by Competent Authorities at national or regional level, or industrial bodies.
        ii. Guidelines, technical publications, codes, standards.
        iii. Sections from Member States permits referring to available techniques, including management practices, use of certain technologies, as well as control and monitoring practices.

(33) https://eippcb.jrc.ec.europa.eu/reference/

iv. Technical or scientific papers and reports.

4. The PRT data collection was also complemented by the results from a techno-scientific literature search, carried out by the JRC, GROW and Wood. Furthermore, the MINLEX study was reviewed for relevant permitting data by the JRC in November 2019, but no specific information was identified that could be directly used in the study.

5. Several measures have been taken in order to ensure a very broad consultation. Apart from the already-mentioned repeated deadline extensions and the broad group consultations, stakeholders have been personally contacted and telephone discussions have been organised. Furthermore, in order to increase the number of non-English references collected, Wood organised follow up communication and made further contacts in native languages with experts in Bulgaria, Italy, Poland and Romania, in particular with a focus on EU Member States.

Analysis of the exchanged information

1. Description of collected literature references

   (a) In total 430 unique references (excluding 46 duplicates provided by stakeholders) have been collected (see Figure 7).

   (b) The input received from stakeholders and identified through the literature search is reflected in the excel Table 8.

Table 8. Overview of literature references

See the excel table PRT_FinalReport-Annexes.xlsx, sheet A2-Tab8 intro and sheet A2-Tab8

2. Analysis of collected literature references

   (a) Relevance

   Before extracting the information from the collected references, their relevance to the study was assessed, i.e. whether the references contain information on PRT under the scope of the study, as defined in Section 2 (see Table 8). References were as such considered as:

   i. 'Relevant' when contain useful information on techniques that might be used to derive PRT within the study.

   ii. 'Partly relevant' if, for example, do not contain details on techniques that might be used to derive PRT, but provided useful additional or contextual information on prevention and mitigation options or case studies, or refer to existing BREF.

   iii. 'Not relevant' when, for example, the information from these references did not contain any information on specific techniques, were published over 20 years ago, were not publicly available or addressed aspects out of scope of this project (e.g. mining waste, municipal waste, operational health and safety, sewage sludge, waste water treatment).

   In summary, 199 references were considered directly relevant (46%); 82 classified as 'partly relevant' (19%); and 149 references (35%) were not considered relevant for the scope of this study (see Figure 7 and Table 9).

   (b) Use of the references in the extracted techniques and in the PRT

   216 references (90% directly relevant and 10% partly relevant) out of 430 were considered. 2634 techniques were extracted from these. 1633 techniques out of 2634 were then aggregated in 149 PRT.

   193 references (89% directly relevant and 11% partly relevant, corresponding to 45% of the total number of references) were finally used in the PRT (see Figure 7 and Table 9).

Table 9. Relevance of all literature references

Literature reference (n.)	Relevance			Total
	No	Partly	Yes	
NOT USED in TECH (and in PRT)	**149**	**61**	**4**	**214**
USED in TECH		**21**	**195**	**216**
NOT USED in PRT			23	23
USED in PRT		21	172	193
Total	**149**	**82**	**199**	**430**

(c) Document source

The references were grouped in the document source categories already specified in the data collection: EU Member States (A), non-EU countries (B), similar activities in EU Member States (C) (see Table 8).

244 references out of 430 were classified as sources from EU Member States (A, 57%); 150 from non-EU countries (B, 35%); and 36 on other similar relevant activities from EU Member States (C, 8%) (see Table 10). Based on the results shown in Table 10 and Figure 28, among the 193 references used in the PRT:

i. 111 (58%) were classified as sources from EU Member States. They especially apply in ES, SE, the whole EU, PT, FI, EE, DE, IE and CY.

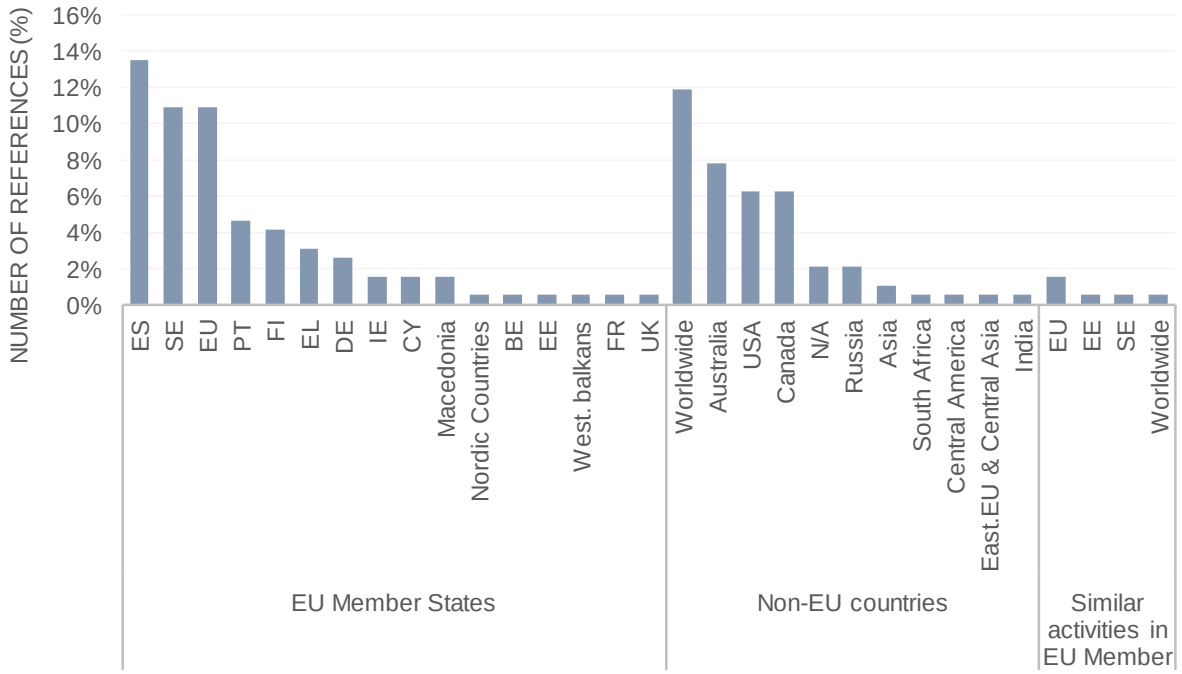
ii. 76 (39%) were classified as sources from non-EU countries. They particularly apply in Australia, USA, Canada, Russia and Asia as well as worldwide.

iii. 6 (3%) were classified as sources on other similar relevant activities from EU Member States.

Table 10. Document source of all literature references

Literature reference (n.)	Document source			Total
	EU Member States	Non-EU countries	Similar activities in EU Member States	
NOT USED in TECH (and in PRT)	**113**	**72**	**29**	**214**
USED in TECH	**131**	**78**	**7**	**216**
NOT USED in PRT	20	2	1	23
USED in PRT	111	76	6	193
Total	**244**	**150**	**36**	**430**

Figure 28. Document source and country of application for the literature references used in the PRT



(d) Document type

The different types of documents gathered through the data collection are listed in Table 11 (see also Table 8). Several documents (such as guidance documents, guidelines, handbooks, BREFs) provide guidance; other documents (such as Member States documents, permit sections, codes, standards) have a more "legal / regulatory" nature. Furthermore several technical documents (such as position papers, technical reports and webpages) and scientific documents (such as books, scientific papers, proceedings and theses) were also collected.

Considering the 394 references from EU Member States and non-EU countries, 31% consist of guidance documents, 24% consist of technical reports and 10% consist of scientific papers. Regarding the 36 references from similar activities in EU Member States, the main document provided consist of BREFs (see Figure 29).

Considering the 193 references used in the PRT, 41% consist of guidance documents, 18% consist of technical reports and 13% consist of webpages. The main document types are guidance documents and webpages in the case of EU Member States, guidance documents and technical reports in the case of non-EU countries and BREFs for similar activities in EU Member States (see Figure 30).

Table 11. Document type of all literature references

Literature reference (n.) / Document type	Use			Total
	NOT USED in TECH	USED in TECH		
		NOT USED in PRT	USED in PRT	
Guidance document	51	2	79	**132**
Guidelines	12		11	**23**
Handbook	14		2	**16**
BREF	14		8	**22**
Permit section	7		6	**13**
Member State document	8		3	**11**
Code	1		1	**2**
Standard	1		4	**5**
Position statement	3			**3**
Technical report	63	6	35	**104**
Webpage	6	1	25	**32**
Book	3		1	**4**
Scientific paper	28	8	9	**45**
Proceedings		3	5	**8**
Thesis	3	3	4	**10**
Total	**214**	**23**	**193**	**430**

Figure 29. Document type of all literature references not used for extracting techniques, used for extracting techniques but not used in the PRT and used in the PRT

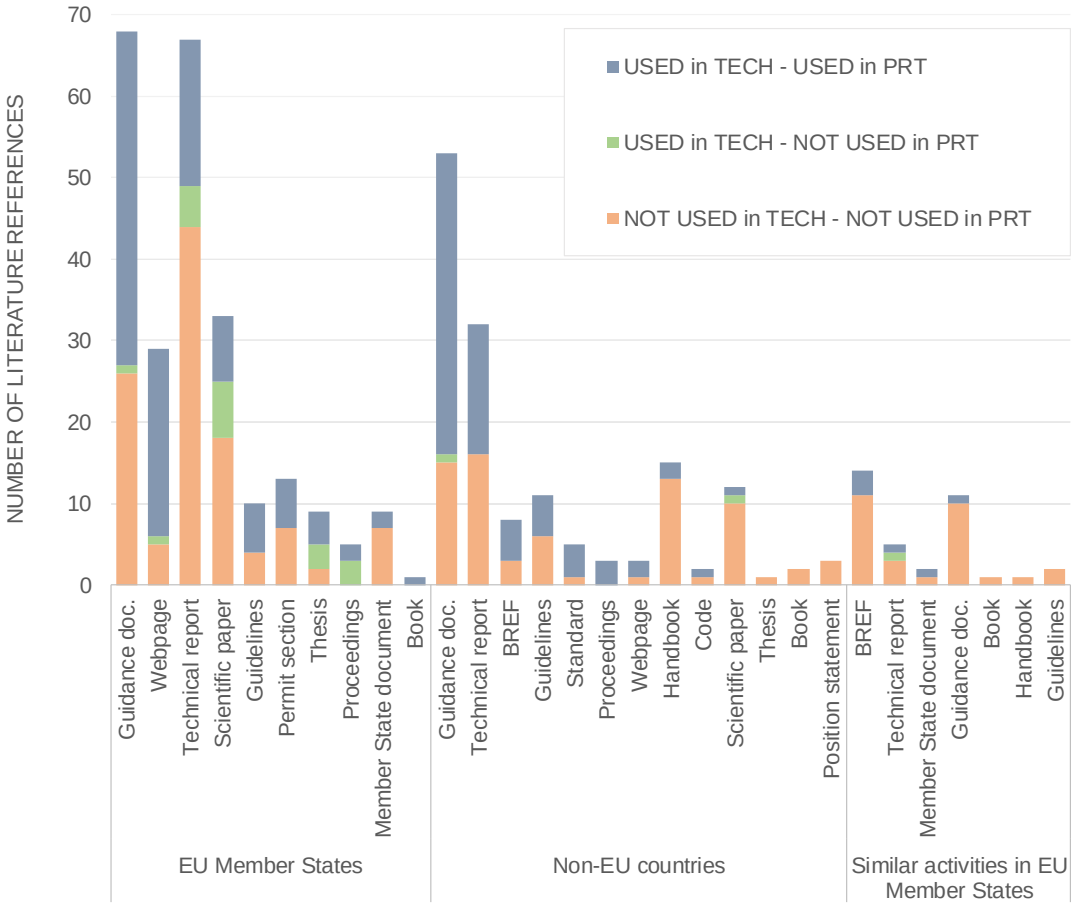
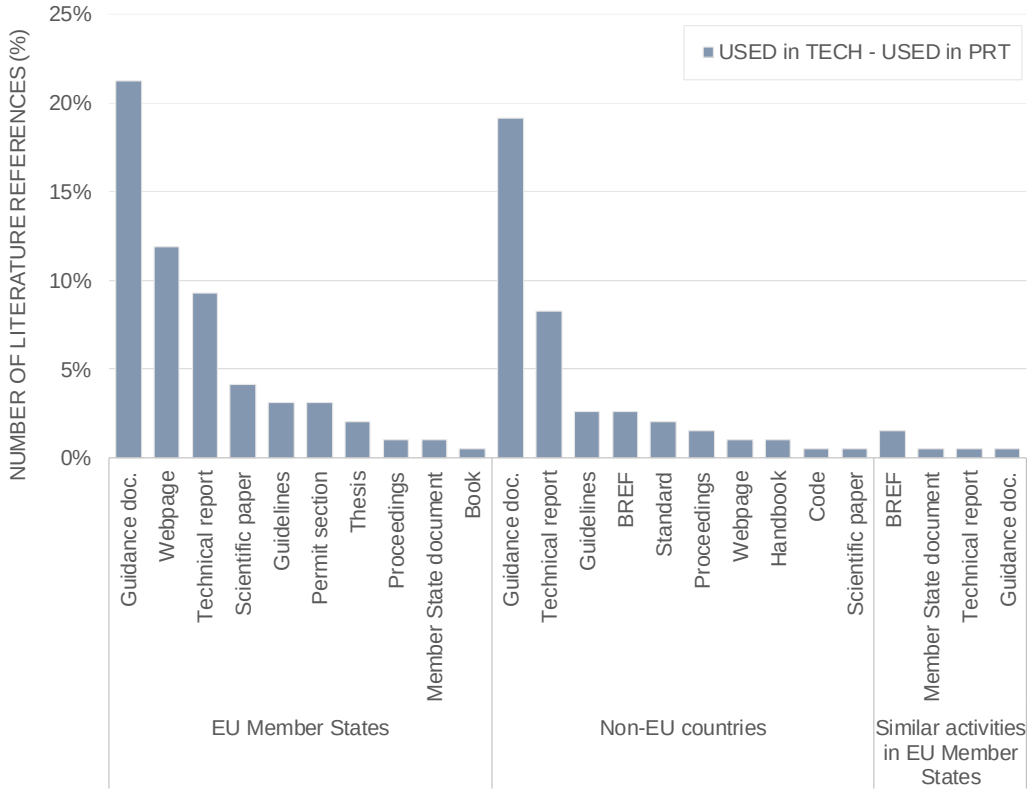


Figure 30. Document type of the literature references used in PRT



(e) **Language**

266 references out of 430 were in English (62%), **164** in non-English languages (38%), covering Czech, Danish, Dutch, Estonian, Finnish, French, German, Greek, Hungarian, Macedonian, Portuguese, Russian, Swedish and Spanish (see Table 8 and Table 12).

Table 12. Language of all literature references

Stakeholder	Reference (n.)	Share (%)
Member States (AT, BE, CY, CZ, DK, EE, FI, FR, DE, EL, HU, IE, PT, ES, SE)	**172**	**40**
English	82	48
Not English	90	52
Industry (Cembureau, Eurogypsum, Euromines, Euroroc, Federation de Aridos, Finnish association, UEPG)	**71**	**17**
English	15	21
Not English	56	79
Others (OECD/NGO/Cobalt Institute/European Copper Institute)	**14**	**3**
English	10	71
Not English	4	29
JRC	**106**	**25**
English	100	94
Not English	6	6
Wood	**67**	**16**
English	59	88
Not English	8	12
Total	**430**	**100**
English	266	62
Not English	164	38

(f) Year

25 references reviewed date from before the year 2000, all other references are more recent, with 163 from the last 5 years (2015-2019) (see Table 8).

3. Analysis of the dissemination level

(a) The contributions from the different stakeholders (Member States, Industry association, International organisation and NGOs, including the JRC and Wood) were assessed to identify the degree of dissemination of techniques within the extractive industry sub-sectors.

(b) Among the total 430 references gathered:

i. Member States (AT, BE, CY, CZ, DK, EE, FI, FR, DE, EL, HU, IE, PT, ES, SE) provided 172 references (40%). 86% of these latter was provided by ES (22%), EL (15%), DE (14%), PT (14%), SE (12%), FI (9%).

ii. Industry (Cembureau, Eurogypsum, Euromines, Euroroc, Federation de Aridos, Finnish association, UEPG) provided 71 references (16%), 72% of these latter was provided by the construction mineral associations (Euroroc, Federation de Aridos and UEPG), 20% by the industrial mineral associations (Cembureau and Eurogypsum) and the remaining 8% by Euromines and the Finnish association. This latter supported the relevant documents provided by the Finnish Ministry.

iii. Other institutions (OECD, NGOs, Cobalt Institute, European Copper Institute) provided 14 references (3%).

iv. 173 references (41%) were complemented by GROW, the JRC and Wood through literature search.

(c) The decision to extend the deadline for data collection has been successful, with especially 15 Member States providing useful input. Despite the extensions, industry and NGOs did not participate extensively in the exercise.

(d) Based on the information that was provided, the level of dissemination of techniques within the Member States appears good, particularly in the countries that have mostly participated in the data collection. There is a good variety of documents that Member States consider relevant. The provided guidance documents, webpages, technical documents, guidelines and permit sections have been of particular relevance for the identification of techniques and PRT titles (see Figure 31).

(e) Based on the information that was provided, the level of dissemination of techniques within the industry appears low, with the exception of the construction mineral sub-sector. Some guidance documents provided by industry have been used for identifying techniques and PRT titles (see Figure 32).

Figure 31. Document type of all literature references provided by the EU Member States

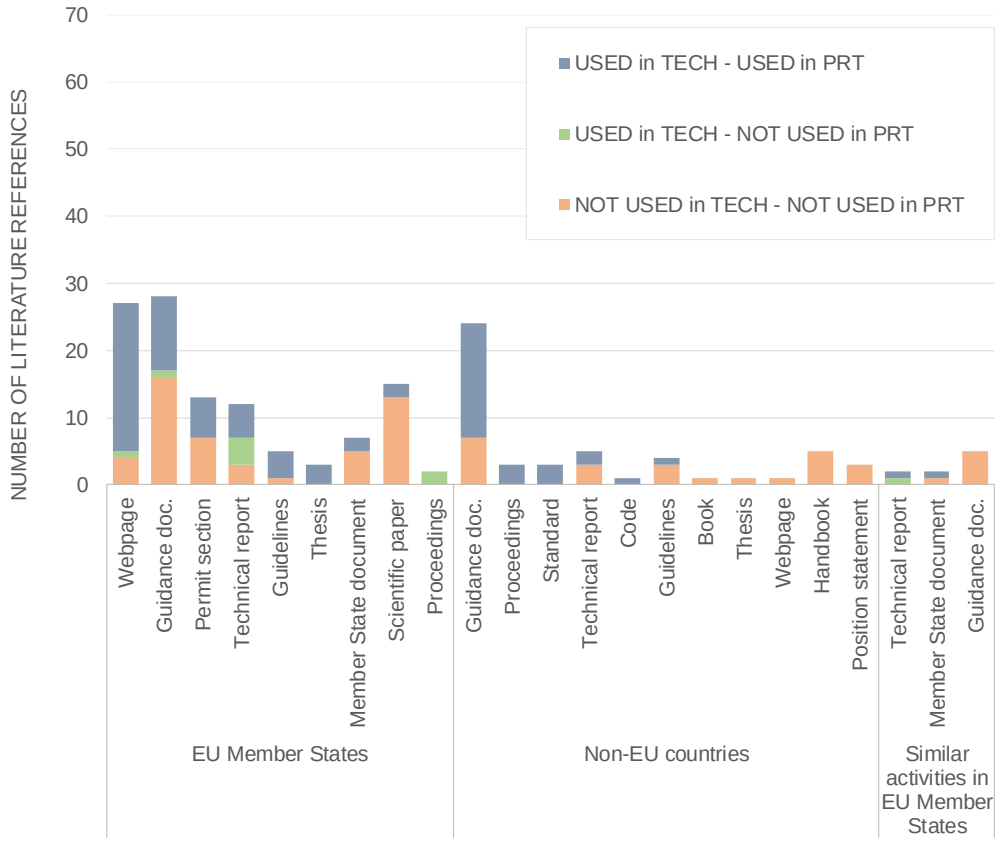
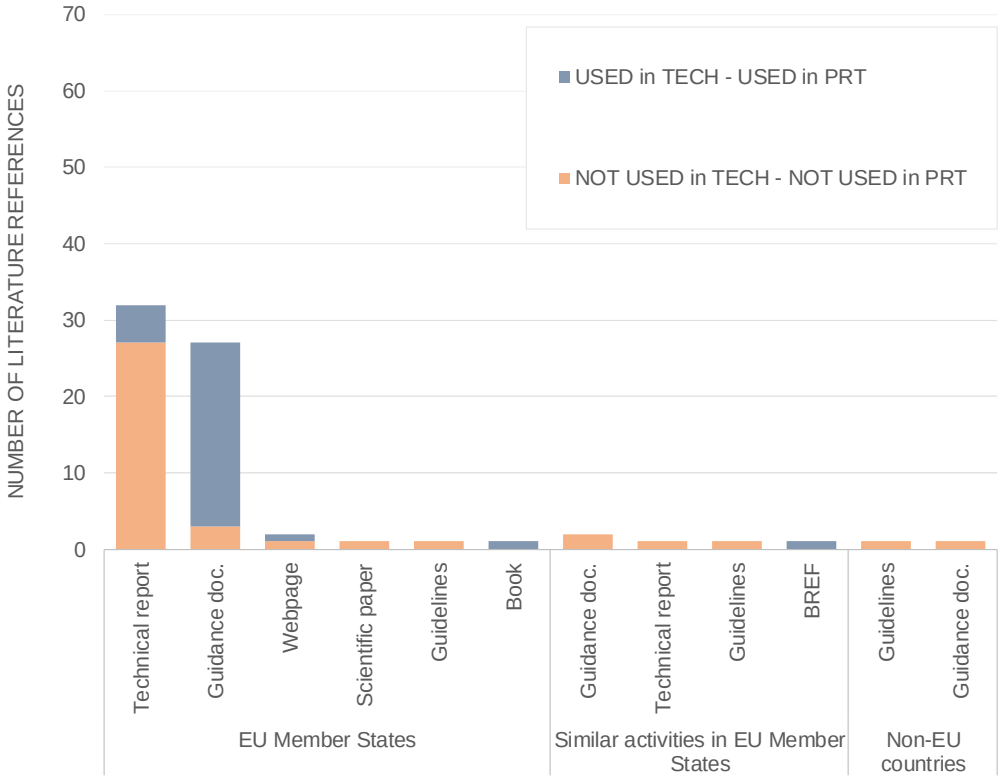


Figure 32. Document type of all literature references provided by industry



Annex 3. Overview of literature references, derived techniques and PRT

The list of literature references, derived techniques and PRT where each technique and related reference have been considered is reported in Table 13.

Table 13. Overview of literature references, derived techniques and PRT

See the excel table PRT_FinalReport-Annexes.xlsx, sheet A3-Tab13 intro and sheet A3-Tab13

Annex 4. Additional information on the PRT and links of the PRT with the key environmental issue(s) from disaggregated KEI table

The PRT titles are listed in Table 1.

Additional information on the proposed PRT, including a short description, generic information on quantitative indicators or criteria, applicability restrictions, level of implementations (as assessed by Wood mining expert judgement) and sites where the PRT is applied (A-B-C categories, see Annex 3) are reported in Table 14.

Table 14. Additional information collected on PRT

See the excel table PRT_FinalReport-Annexes.xlsx, sheet A4-Tab14 intro and sheet A4-Tab14

The links of the proposed PRT (considering both the main and secondary KEI targeted) with the key environmental issue(s) they are addressing and the extractive activities and mineral resources to which they are relevant (as specified in Table 13 in Annex 3) are reported in Table 15, i.e. specified in each cell of the disaggregated KEI table (see Table 3 in Annex 1). Generic PRT (PRT001-0007) apply to all combinations of KEI, extractive activity and mineral resource and therefore have not been reported.

Table 15. Links of PRT with the key environmental issue(s) from the disaggregated KEI table they are addressing

See the excel table PRT_FinalReport-Annexes.xlsx, sheet A4-Tab15 intro and sheet A4-Tab15

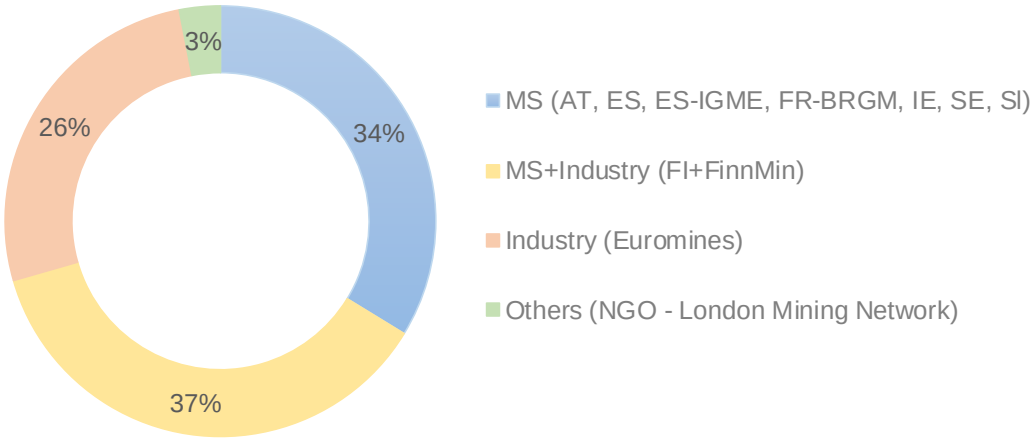
Annex 5. Stakeholder consultation

A written consultation was organised from 29 October 2020 to 7 January 2021 to collect feedback from stakeholders on the preliminary results reported in the background paper.
The same stakeholder groups already consulted in the data collection exercise (i.e. the Heads of European State Mining Authorities Group, the Raw Materials Supply Group (RMSG), the MWEI BREF Technical Working Group (TWG) and additional experts and the Wood mining expert network, see Annex 2) were asked for feedback. Additionally, the TAC/expert group on Extractive Waste was also consulted.

Furthermore, and in addition to the written consultation, an online workshop was organised on 3 December 2020 to present, discuss and exchange with stakeholders on the preliminary results presented in the background paper. 62 stakeholders participated in the workshop (26% from EU Institutions, 53% from EU Member States, 3% from NGO, 16% from Industry and 11% from other Institutions).

163 stakeholder responses on the background paper have been collected, out of which 34% were provided by EU Member States, 37% by Finland and the Finnish Mining Association (FinnMin), 26% by an industry association (Euromines) and 3% from an NGO (London Mining Network) (see Figure 33).

Figure 33. Responses provided by different stakeholders during the consultation



61% of responses refer to the main text of the background paper, out of which 44% are general or editorial and 56% technical/specific. Moreover, 33% of responses refer to Annexes, out of which 24% are general or editorial and 76% technical/specific. Finally 6% of responses refer to overlooked PRT and are technical (see Table 16).

Table 16. Number and type of responses provided by stakeholders during the consultation

Document	Number of responses (n.)	Type of response		
		General	Editorial	Technical/specific
Background paper	99	31%	13%	56%
Annexes - excel	54	24%	0%	76%
Overlooked PRT	10	0%	0%	100%
Total	**163**			

The main subjects of the responses and the way in which it has been used for finalising the current study are reported in Table 17, and summarised as follows:

- 4% of the responses refer to general considerations. They have been entirely or partly accepted;
- 6% of the responses point out that the KEI scoring is not applicable to a single extractive activity, where the site-specific conditions need to be properly evaluated by means of an EIA. Stakeholders suggested giving more emphasis to the need of applying a risk-specific approach and highlighting that the PRT collection can be used as an interactive screening toolkit of PRT that may apply depending on the site-

specific conditions. 90% of this responses have been partly accepted, as the risk-specific approach has been introduced as a general concept. Further specific details for the risk-specific approach could not be provided as these were not available from the collected literature references (see Section 3.1 and the Conclusions in Section 6).

— 9% of the responses highlight the lack of data on the PRT relevance and ask to introduce further classification based on the type of the extractive activity (e.g. extraction, treatment, transport and handling, storage), the type of the operation (e.g. subsurface/surface, underground/surface operations) and the rock type (e.g. soft, sedimentary, stratified rocks/hard rocks). 4% of the responses highlight the lack of data on the PRT applicability and ask for further information.

  85% of this responses have been partly accepted, by underlining the benefits of collecting additional information on the PRT relevance and applicability, in-depth discussing it with stakeholders and further assessing it in the development of a BREF or similar exercise. The importance of applying a risk-specific approach in the evaluation of site/operation specific applicability has been also underlined in the study. Some stakeholders ask for including specific information on PRT relevance, which was, however, not available in the collected literature references.

— 8% of the responses highlight that the collection lacks information on advanced technologies and recent breakthroughs in mine automation, process optimisation and digitalisation, as very little amount of literature was provided by stakeholders in the data collection. These comments have been, totally or partly, accepted by including a specific section on these topics (see Section 5.3).

— 2% of the responses point out overlooked PRT on water treatment. They have been partly accepted by including a better specification in the description of the related PRT. Furthermore, an overview of the BAT for treatment of EWIW included in the MWEI BREF, together with examples of abated pollutants/ targeted parameters, has been prepared in order to highlight where potential information on techniques for emissions to surface water management and treatment may be retrieved (see Table 18).

— 8% of the responses provide some new literature references, which have not been taken into consideration in the analysis, but listed for future consideration (see in Table 19).

— Finally, 19% of the responses refer to specific clarifications, which were provided in the majority of cases. Furthermore, 33% of the responses refer to specific issues. 81% of stakeholder proposals have been totally or partly accepted. Proposals not in line with the scope of the study (e.g. including rehabilitation as per-se extractive activities or techniques on extractive waste management) or asking to delete PRT already included in the MWEI BREF (remediation techniques for emissions to soil and groundwater or cyanide management techniques) have not been accepted.

Table 17. Main subjects of responses provided by stakeholders during the consultation and level of acceptance in the final report

Response main subject	Total (n.)	Total (%)	Accepted	Partly accepted	Rejected
General consideration	**6**	**4**	67%	33%	0%
Risk based approach	**10**	**6**	0%	90%	10%
Additional data / information required	**27**	**17**	0%	85%	15%
further data asked/needed	*7*	*26*			
lack of data on applicability	*6*	*22*			
lack of data on relevance	*14*	*52*			
Add section (automation - digitalisation)	**13**	**8**	54%	46%	0%
New PRT	**5**	**3**	0%	100%	0%
Overlooked PRT	**4**	**2**	0%	100%	0%
New reference	**13**	**8**	69%	23%	8%
Clarification	**31**	**19**	74%	26%	0%
Specific	**54**	**33**	48%	33%	19%
Total comments	**163**	**100**	42%	48%	10%

Table 18. Overview the BAT for prevention or minimisation of emissions to surface water in the MWEI BREF where useful information for the related PRT may be found

Main KEI - objective	BAT n.	BAT main title	Group of techniques		Techniques	Examples of abated pollutants/ targeted parameters	Information potentially useful for:
Prevention or minimisation of surface water status deterioration	BAT42	EWIW generation prevention		a	Re-use or recycle the excess water in the extraction, mineral processing and/or extractive waste management		PRT060
				b	Diversion of water run-off systems during operation		PRT062
				c	*Covering*		*PRT061*
				d	Landscaping and geomorphic reclamation		PRT119 *(PRT061)*
				e	To use reagents or chemicals with a low environmental impact		PRT142
	BAT43	Drainage of EWIW			Drained EWIW collection and handling		PRT062, PRT014
	BAT45	Removal of suspended solids or suspended liquid particles		a	Gravity separation in settling ponds	Suspended solids (TSS), suspended liquids such as oil and grease	PRT063
				b	Clarification in tanks	Suspended solids (TSS), suspended liquids such as oil and grease	
				c	Coagulation and flocculation	Suspended solids (TSS), suspended liquids such as oil and grease, colloids	
				d	Air flotation	Suspended solids (TSS), suspended liquids such as oil and grease, emulsions, COD	
				e	Media filtration	Suspended solids (TSS)	
				f	Membrane filtration for suspended particles	Suspended solids (TSS), suspended liquids such as oil and grease, colloids	
				g	*Hydro-cycloning*		
	BAT46	Removal of dissolved substances	Oxidation-based systems	a	Aeration and active chemical oxidation	Fe^{2+} for aeration, Fe^{2+}, Mn^{2+}, for chemical oxidation	PRT068 (*PRT064, PRT075)*
				b	Active aerobic biological oxidation	Oil/grease, nitrogen (ammonia, nitrates), cyanates, COD, BOD, metals	
				c	Aerobic wetlands	Dissolved solids (TDS), suspended solids (TSS), BOD, metals	
			Reduction-based	d	Anaerobic wetlands	Acidity, dissolved metals and metalloids, sulphates	PRT069 *(PRT065)*

			systems using bacterial activity	e	Anoxic BioChemical Reactors (BCRs)	Acidity, dissolved metals and metalloids, sulphates	
			Chemical precipitation	f	Hydroxide and carbonate precipitation	Dissolved metals	PRT070
				g	Sulphide precipitation	Dissolved metals and metalloids	
			Co-precipitation	h	Co-precipitation with chloride or sulphate metal salts	As, P, Se, ^{226}Ra	PRT071
			Adsorption	i	Adsorption	Dissolved metals, organic carbon, BTEX, oil and grease	PRT072 *(PRT076)*
			Ion exchange	j	Ion exchange	Ca, Mn, Ba, Sr, Ra, nitrates, fluorides, arsenates, chromates, uranium complexes, boron and heavy metals	PRT073 *(PRT066)*
			Filtration of dissolved substances	k	Nanofiltration	Multivalent ions	PRT074 *(PRT067)*
				l	Reverse osmosis	Dissolved metals, salts, macro-molecules	
	BAT47	Neutralisation of EWIW prior to discharge	Active treatment	a	Active neutralisation	pH, acidity, alkalinity	PRT077
			Passive treatment	b	Oxic Limestone Drains (OLDs)/Open Limestone Channels (OLCs)	Acidity, Mn, Al, Fe, Cu, Pb, Zn, Se	PRT078
				c	Anoxic Limestone Drains (ALDs)	Acidity	
				d	Successive Alkalinity-Producing Systems (SAPS)	Acidity, Al, Cu, Fe, Mn, Zn	
				e	*Anaerobic wetlands*		
	BAT48	Monitoring of emissions to surface water			Monitoring of emissions to surface water		PRT079

Table 19 provides the overview of the new literature references provided by stakeholders in the written consultation on the draft final report organised after completion of the data collection exercise, from October 2020 to January 2021.

Table 19. Overview of the new references provided by stakeholders during the consultation

See the excel table PRT_FinalReport-Annexes.xlsx, sheet A5-Tab19 intro and sheet A5-Tab19

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00800 6 7 8 9 10 11 (certain operators may charge for these calls),

- at the following standard number: +32 22999696, or

- by electronic mail via: https://europa.eu/european-union/contact_en

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from EU Bookshop at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

KJ-NA-30827-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub

ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office of the European Union

doi:10.2760/622092

ISBN 978-92-76-41493-3