4 volume

ROTATE HANDBOOK

Environmental leadership in the European extractive sector

Air emissions and noise

Estimation and abatement during quarry operation

R8TATE
CIRCULAR ECOLOGICAL ESSENTIAL & CRITICAL RAW MATERIALS

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R8TATE – CIRCULAR ECOLOGICAL ESSENTIAL & CRITICAL RAW MATERIALS

Horizon Europe research and innovation programme (Nº 101058651)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement Nº 101058651).

Executive summary

In the context of the tightening the WHO air quality limits and in line with the European Green Deal, and particularly the EU zero-pollution action plan, which aims to modernise and expand the European Union's pollution-combatting regulatory framework, the quarrying sector should improve its performance to remain competitive while complying with the EU legislation.

Extractive industries, including opencast quarries, generate various direct air pollutants and greenhouse gases (GHG), including dust, nitrogen oxides (NO_x), and carbon dioxide (CO_2). Most of the fine particulate matter ($PM_{2.5}$) emitted by this industry originates from quarrying and mining of minerals other than coal.

According to the latest information, the largest proportion of air emissions comes from on-site transportation and mineral processing activities (diffused and channelled dust, emissions from fuel combustion), followed by mineral extraction (drilling and blasting of hard rock, including diffused dust and CO_2 and NO_x emissions due to explosive use), materials handling activities and stockpiles (diffused dust). Noise in quarries is mainly caused by extraction activities (drilling, blasting and hammering), processing (crushing and screening) and various on-site machinery operations.

So, the purpose of this handbook chapter is to provide an overview of the latest EU legislation regarding air emissions and noise in opencast quarries, as well as the main sources of air pollution and noise emitted by quarry operations. It also outlines the methods available for estimating emissions and noise, along with methods for mitigating them. Finally, it highlights air emissions (dust, CO_2 and NO_x) and noise abatement solutions offered by the ROTATE project.

The latest EU legislation on air emission and noise relevant to the sector has been analysed. This includes updated EU Directives and Regulations regarding air emissions and noise, such as the Ambient Air Quality Directive 2024/2881, the Industrial Emissions Portal Regulation (EU) 2024/1244, the Corporate Sustainability Reporting Directive 2022/2464 and the Directive 2000/14/EC on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors, among others.

The existing methodologies and tools used to estimate air emissions were identified and analysed to determine their relevance for use in the EU. The approach combining the experience of the team and a desk study suggested using an improved method based on the French approach and tool to assess diffuse and channelled dust emissions, as well as fuel- and explosive-related air emissions, adapted for use at EU level.

Regarding noise, the main noise sources were identified in the quarry environment and the potential solutions to reduce it were presented. Estimation and measurement of noise sources are important steps to evaluate the distribution of sound to the nearby area.

The methods for evaluating noise according to standards are presented and the noise levels for common quarry equipment is shown.

The author's experience, supplemented by a desk study, revealed that a number of techniques for reducing air emissions could be applied on site to manage air emissions in general. These include designing the layout of the quarry, planning of activities to avoid some operations during periods of dry and windy conditions, and monitoring emissions. Other measures could be applied to equipment, such as adhering to the latest standards when choosing NRMM, increasing automation and control, and regularly maintaining dust control equipment. Some measures could be applied to user solutions. For example, training could be provided to site personnel on air emission mitigation, inspections and improved communication. These measures could reduce air emissions directly or indirectly. To tackle dust emissions, a dust management plan that sets out the targeted use of different dust abatement techniques may be required.

Many primary and secondary techniques to reduce air emissions applied to quarry operations were identified and described. These techniques were designed to reduce air emissions in general, or to tackle diffuse and channelled dust emissions, as well as emissions of PM, CO_2 and NO_x from fuel and explosive use, during drilling and blasting operations, material processing (including measures applied at crushing, screening and transfer points), internal transport and material handling operations (loading and unloading), and wind erosion from stockpiles as relevant.

Regarding noise abatement, the solutions presented address the mitigation of sound generation and the distribution of it. For common quarry machinery, this often means encapsulating particular sections or parts of the machine. After a thorough evaluation of noise, the carefully selected noise encapsulation can make a significant impact on the overall noise levels. As the noise levels decrease in the quarry area, so does the risk of hearing loss for individuals.

As part of the ROTATE project, Metso as an equipment manufacturer, developed technologies to decrease dust and CO_2 emissions and noise during crushing and screening processes using Metso's mobile, track-mounted machines. These machines were used as platforms for demonstrating and piloting the improved technologies.

Another technology developed in the ROTATE project with the potential to indirectly reduce CO_2 emissions through process improvement is the automated vision system (AVS), which was developed by CTM.

As part of the Environmental Management Platform of the ROTATE project, AKKODIS and Citepa have developped an Emission estimation module to support aggregate quarries in managing and reducing their dust, carbon dioxide (CO_2), and nitrogen oxides (NO_x) throughout the key quarrying operations. In addition, Citepa has developped an emissions strategy guide to provide an overview of the most effective measures to reduce air emissions from the main operations in open-pit M&Q facilities.

In conclusion, the handbook outlines existing and ROTATE-developed emission and noise reduction measures for quarrying activities. Operators could apply these measures to align their activities with the European Green Deal and other relevant air emissions and noise regulations. The enhanced estimation provided by the emission estimation module and emission strategy guide could further assist operators in developing robust long-term strategies to reduce emissions.

List of Abbreviations

Abbreviation	Description
AAQD	Ambient Air Quality Directive
ARM	Advanced Risc Machine
ANFO	Ammonium Nitrate Fuel Oil
ATILH	Association Technique de l'Industrie des Liants Hydrauliques (France)
AVS	Automated Vision System
BAT	Best Available Techniques
CEPMEIP	Coordinated European Particulate Matter Emission Inventory Program
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO_2	Carbon dioxide
CSRD	Corporate Sustainability Reporting Directive
dB(A)	A-weighed decibels
dBP	Decibel peak pressure
DMP	Dust Management Plan
EF	Emission Factor
EGD	European Green Deal
EMEP	European Monitoring and Evaluation Programme
EPA	United States Environmental Protection Agency
EU	European Union
GHG	Greenhouse Gases
HMI	Human Machine Interface
IED (IED 2.0)	Industrial Emissions Directive
IEPR	Industrial Emissions Portal Regulation

Abbreviation	Description
IoT	Internet of Things
ISO	International Organization for Standardization
NEC Directive	National Emission reduction Commitments Directive
NH3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen oxides
NRMM	Non-Road Mobile Machinery
PC	Personal Computer
PLC	Programmable Logic Controller
PM_{10}	Particulate matter with diameters that are generally 10 micrometers and smaller
$PM_{2.5}$	Particulate matter with diameters that are generally 2.5 micrometers and smaller
RED III	Renewable Energy Directive
RES	Renewable Energy Sources
SCR	Selective Catalytic Reduction
SO_2	Sulfur dioxide
TSP	Total Suspended Particles/dust
UNICEM	Union Nationale des Industries de Carrières et Matériaux de Construction (France)
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

01 Introduction

This handbook chapter aims to shed light on the sources of air pollution and noise emitted by opencast quarries. It aims to provide a comprehensive overview of the up-to date EU control of emission and noise sources within the quarry and available methods for estimating emissions and noise, along with the measures for mitigating them. Finally, the handbook chapter outlines the ROTATE project's improvements in emission and noise abatement.

02 Air emission and noise sources in quarries

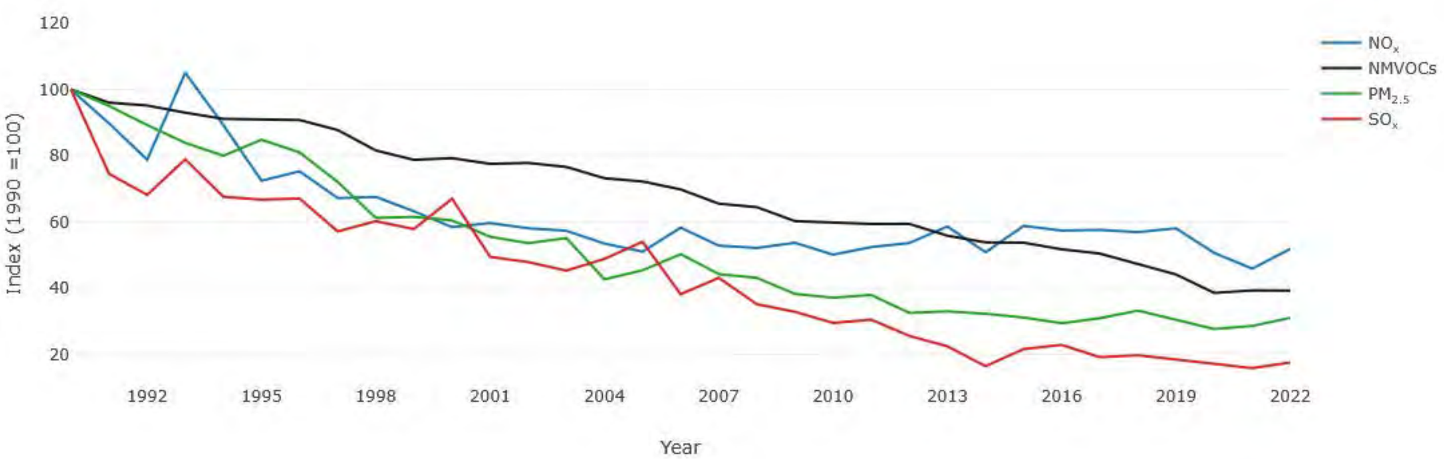
Air emissions in quarries

Air pollution affects our health, environment, and economy. The latest World Health Organization (WHO) assessment estimates that more than 99% of the population live in areas where the air pollution is above WHO air quality guidelines, and 4.2 million deaths are attributed to ambient air pollution each year. Overall air pollution is responsible for 6.7 million premature deaths every year (World Health Organization, 2023).

Extractive industries, including open cast quarries, generate various direct air pollutant emissions and greenhouse gases (GHG). Dust, NO_x, and CO_2 are among them. According to recent data, between 2010 and 2022, air pollution caused by resource extraction fell in the EU for all major pollutants, including nitrogen oxides, non-methane volatile organic compounds, particulate matter and sulphur dioxides (Figure 1). The increasing demand for materials at the EU and global levels, alongside EU initiatives that intend to boost domestic extraction through the implementation of the Critical Raw Materials Act (European Union, 2024c), are expected to impact this trend (European Environment Agency, 2025).

Notes: The figure includes releases from the following nomenclature for reporting (NFR) sectors: NFR 1B1a (fugitive emissions of coal mining and handling), 1B1c (other fugitive emissions from solid fuels), 1B2ai (fugitive emissions from oil exploration, production and transport), 1B2b (fugitive emissions from natural gas exploration), 1B2C (oil and gas venting and flaring) and 2A5a (quarrying and mining of minerals other than coal). Ammonia (NH_3) emissions are not included because of low values.

Figure 1: Emissions of major air pollutants from extractive industries between 1990-2022 in the EU-27, indexed to 1990 (European Environment Agency, 2025).



According to the European Environment Agency (2025), fine particulate matter ($PM_{2.5}$) in extractive industry mostly originates from the quarrying and mining minerals other than coal.

Dust emissions in quarries, including $PM_{2.5}$, originate from multiple emissions sources that are distributed over a wide area and vary over time and in accordance with the quarry's operations. These emissions consist of coarse mineral particles (Total suspended particles, TSP), particularly the PM_{10} fraction, and to a lesser extent the $PM_{2.5}$ fraction (European Environment Agency, 2023). According to the Institute of Air Quality Management, (2016), adverse dust impacts from sand and gravel sites are uncommon beyond 250 m and from hard rock quarries beyond 400 m, measured from the nearest dust-generating activities.

The following seven types of dust-generating activities on mineral extraction sites are likely to have the greatest potential for dust emissions (Institute of Air Quality Management, 2016).

- Site preparation/restoration (including soil and overburden handling).
- Mineral extraction (including blasting).
- Materials handling (e.g. loading onto haul trucks or conveyors).
- On-site transportation (haul roads).
- Mineral processing (e.g. crushing and screening).
- Stockpiling/exposed surfaces; and
- Off-site transportation (e.g. leading to track out onto external road network).

According to the Institute of Air Quality Management (2016), classification of residual source emissions[1] shows that share of emissions is ***large*** from on-site transportation and mineral processing activities, ***medium*** from mineral extraction, materials handling activities, stockpiles and exposed surfaces, and ***small*** from site preparation and restoration and off-site transportation activities. This is why emission estimation from quarries should focus primarily on large or medium residual sources of emissions.

The nature of the deposit is also important in terms of dust emissions. Different types of deposit, such as crushed rock, sand and gravel, and recycled aggregates may result in different emissions. In crushed rock quarries, the deposit consists of solid, compact rock that requires blasting and drilling for extraction. In contrast, the deposits of sand and gravel quarries are soft, allowing the material to be extracted directly with excavation. Additionally, the process of transforming the deposit into aggregates varies depending on the nature of the deposit. Crushed rock quarries require significant crushing steps, whereas some sand and gravel quarries only require the material extracted directly from the deposit to be collected and sorted by size add full-stop aggregates are mostly produced from construction and demolition residues, therefore blasting and drilling are not required and usually transport within the quarry is usually minimal because the processing equipment is often mobile and can be placed close to the material's source (European Environment Agency, 2023). Hereafter, the Table 1 summarizes the main emission sources depending on the nature of the deposit in the aggregates industry.

[1] Residual source emissions could be defined as the potential dust emissions after designed-in mitigation measures have been taken into account.

Table 1: Simplified table of air emission sources in quarries depending on the nature of the deposit.

		Crushed rock	Sand and Gravel	Recycled aggregates
1	Drilling and Blasting	x	-	-
2	Treatment operations	x	x	x
3	Internal transport in the quarry	x	x	-
4	Storage management	x	x	x
5	Erosion of stocks	x	x	x

The operations that have large and medium dust impact risk encountered for two types of quarries, namely crushed rock quarries and sand and gravel.

Air emissions such as dust, NO_x and CO_2 and others within the quarries could also be due to the combustion of fuel in non-road mobile machinery (NRMM) and the use of explosives.

The following explains the typical emission sources for each processing step:

Drilling and blasting are usually involving two steps: first, a hole is drilled; then explosives are placed in the hole and detonated to collapse the wall. This source includes the particulate emissions (TSP, PM_{10}, $PM_{2.5}$) released during drilling and blasting, as well as CO_2, NO_x and other emissions due to the use of explosives. After drilling and blasting, large rocks can be broken down by hammering to a size suitable for feeding into the crusher. Particulate matter emissions (TSP, PM_{10}, $PM_{2.5}$) are generated during this process, as the rocks are broken up. In addition, there are emissions from the diesel-powered hammers.

Three stages of **material processing** emit particles (TSP, PM_{10}, $PM_{2.5}$): screeners, crushers and transfer points, which are fall points on/ or from conveyor belts used to transfer material towards equipment and towards storage. If material processing takes place using mobile machinery, air emissions due to the use of diesel fuel in this machinery may occur (PM, NO_x, CO_2 and others).

Internal transport refers to emissions related to the transportation of materials within the quarry. The transport of material emits particles (TSP, PM_{10}, $PM_{2.5}$) due to contact between the tires of the non-road mobile machinery (NRMM) and the road, as well as the dispersion of the transported material. Resuspension of soil dust by dumper traffic also contributes significantly to overall dust emissions in quarries. Published literature suggests that, under the same meteorological conditions, resuspension on quarry sites is usually several times higher than 'normal' traffic-induced resuspension. Dust resuspension may also depend on whether the road is paved or unpaved, given the significant difference in particulate emissions between the two surfaces. In addition, fuel combustion is a source of air emissions from internal transport within the quarries (PM, NO_x, CO_2 and the others).

Material handling involves the emission of particulates (TSP, PM_{10}, $PM_{2.5}$) from dumpers unloading material directly into stockpiles, and to loaders loading material from the stockpiles into dumpers or trucks.

Wind erosion from stockpiles is the source of particles (TSP, PM_{10}, $PM_{2.5}$) emitted when the wind blows over uncovered stockpiles. Therefore, this depends on meteorological conditions.

Dust emissions in the quarries are also dependent on the size of the quarry.

Noise sources

In addition to dust emission, noise is also considered a nuisance in the quarrying environment. Noise type can either be steady or impulse, which can affect the level of disturbance experienced and the reference values for the human ear exposure limits. This underlines the importance of conducting noise measurements at work sites and developing proper noise reduction solutions (Hakala & Laurila, 2010). For continuous sound, a level of 85 dB(A) (A-weighed decibels) is considered acceptable during a normal workday (8 hours of exposure), as it poses a lower risk of hearing damage (Metso, 2022). Sounds below 70 dB(A) are generally always considered safe (Acoustical Society of America, 2023). Conversely, impulse sounds exceeding 120 dB(P) (dB peak pressure) are unsafe at any period of time and can cause damage for hearing (American Speech-Language-Hearing Association, 2023). Extended exposure to high noise levels can lead to permanent hearing loss or other health issues, including cardiovascular diseases, psychological issues and sleep disturbance.

In the context of quarrying, there are multiple noise sources, including:

- Drilling
- Blasting
- Hammering
- Crushing
- Screening
- Various machinery operating on site (wheel loaders, excavators, trucks, etc.).

Drilling, blasting and hammering: These are the first steps in quarry operations for removing the material from the pit. The majority of the noise in drilling originates from the drilling rigs as they drill holes in preparation for blasting. Other equipment used in the drilling processes, such as generators and air compressors, also produces a moderate noise level (Health and Safety Executive, 1993), (GeoDrilling International, 2019).

Unlike drilling operations, blasting causes momentary noise excessive noise vibrations in the surrounding area. For this reason, blasting events are monitored using instruments that record vibrations and sound. According to Hakala & Laurila (2010), the disturbance and the level of noise caused by blasting is affected by:

- Rock quality (hardness, composition of the bedrock)
- Number of blasts (once/day – once/week)
- Blasting mass
- Amount of charges

After blasting, larger rocks need to be broken down into smaller pieces before the suitable-sized material can be fed into the crusher. As for hammering, the noise produced is typically brief and occurs in a single location. Hammering is usually done at the edge of the worksite to reduce disturbances to the surrounding area. However, the noise levels can be harmful to the machine operator (Hakala & Laurila, 2010).

Crushing, screening and working machines: The noise generated in a **crushing plant** comes from multiple sources. The most significant of these are the primary crushers and screens. There are significant differences in sound frequency distribution between different crusher types. Secondary and tertiary crushers produce a steady sound consisting of high-frequency components, whereas the primary jaw crushers also generate varying low-frequency sound. Low- frequency sound is often considered the most problematic as it can travel long distances from the original source (Hakala & Laurila, 2010). Regarding **screening**, noise is created by the action of extracting or rejecting material, and this depends mainly on the size of the material being processed (Health and Safety Executive, 1993). Also, the noise level produced by the screen media depends on the hardness of the material. The impact is louder on harder rock material, producing more noise.

Considering the working machines, which consist mainly of wheel loaders, dumpers, excavators, and trucks, the majority of sound originates from operational noises. For example, there are alarm sounds when the machine reverses. Excavators and wheel loaders produce excessive noise when their buckets collide with other machine parts or drag on the ground while picking up or unloading material (Hakala & Laurila, 2010).

03 EU control

The European Green Deal (EGD), and particularly the zero-pollution action plan have modernised and expanded the European Union (EU)'s pollution-combatting regulatory framework.

The EU's 2030 clean air targets in the zero-pollution action plan related to clean air are:

- Improving air quality to reduce the number of premature deaths caused by air pollution by 55%.
- Reducing by 25% the EU ecosystems where air pollution threatens biodiversity.

An analysis of the zero pollution targets reveals a mixed picture showing:

- Target 1, aimed at reducing health impacts from air pollution, is on track, highlighting successful regulatory improvements and emissions reductions that have led to significant decreases in premature deaths.
- Target 2, which aims to reduce the impact of air pollution on ecosystems by 25%, seems unlikely to be met. Ongoing pollution, particularly from ammonia and nitrogen oxides, continues to threaten EU ecosystems (European Environment Agency - Joint Research Centre, 2025).

The EU is currently on track to meet the zero-pollution target to reduce the health impacts under the baseline scenario. The analysis of the Fourth Clean Air Outlook estimates a 62% reduction in the number of premature deaths between 2005 and 2030. However, it is not on track to meet the ecosystem target on time, with only a 19% reduction expected in areas at risk between 2005 and 2030 (European Commission, 2025).

Full implementation and enforcement of environmental legislation is crucial to achieve the 2030 zero pollution targets. Notable among these are the revisions to the legislation covering air pollutant sources, such as the Industrial Emissions Directive (IED) and the introduction of the new Industrial Emissions Portal Regulation (IEPR) and the Ambient Air Quality Directive (AAQD). Additionally, legislation under the Fit for 55 package is to play a key role in helping pollution reduction efforts alongside achieving climate goals (European Environment Agency - Joint Research Centre, 2025).

UNECE member States among which is the European Union have been working successfully to reduce air pollution in the region through the Convention on Long-range Transboundary Air Pollution (CLRTAP). Eight protocols identify specific measures to be taken by Parties to cut their emissions. The Convention provides access to emission, measurement and modelling data and information on the effects of air pollution on ecosystems, health, crops and materials (United Nations Economic Commission for Europe [UNECE], n.d.).

One of the Convention protocols, EMEP Protocol (EMEP Protocol, 1984) tackles monitoring and evaluation of the long-range transmission of air pollutants in Europe. It provides technical guidance to prepare national emission inventories covering quarrying and mining of minerals, other than coal sector, to assess direct dust (TSP, PM_{10}, $PM_{2.5}$) emissions from quarrying activities (European Environment Agency, 2023), to assess fuel burning exhaust (CO_2, NO_x, PM and others) emissions of NRMM and PM (TSP, PM_{10} and $PM_{2.5}$) emissions due to vehicles tyre and brake wear (Ntziachristos & Boulter, 2023). However, it should be noted that up to now the EMEP guidance doesn't include emissions of NO_x and CO_2 resulting from explosive usage.

The EU's approach to improve air quality involves taking action in three main areas (or 'pillars'), namely:

- The ambient air quality standards set out in the revised **Ambient Air Quality Directive (AQD)**, the Directive (EU) 2024/2881 to be transposed to the Member States national legislation by December 11, 2026 (European Union, 2024a).
- National emission reduction obligations under the National Emission reduction Commitments Directive (**NEC Directive**) for the main transboundary air pollutants; including SO_2, NO_x, NH_3, NMVOC and fine particulate matter $PM_{2.5}$ (European Union, 2016a).
- **Emission standards at EU level**, laid down in legislation, for key sources of pollution including among other vehicles, energy and industry (The Third Clean Air Outlook, 2022).

The EU has stepped up action under all three pillars to adapt to new policy and scientific developments. To implement the European Green Deal and the EU's ambition to reach zero pollution for a toxic-free environment, the **Ambient Air Quality Directive** has been revised to bring in more ambitious 2030 ambient air quality standards that will put the EU on a path to achieve zero air pollution at the latest by 2050. The standards are aligned more closely with the World Health Organization (WHO) updated air quality guidelines for key air pollutants (World Health Organization, 2021). These more ambitious ambient air quality standards mean that Member States will have to reduce their air pollutant emissions even further.

Table 2 summarizes main pollutants covered by the new AQD (European Union, 2024a) and compare them with the previous AQD, the previous (2005) and current WHO guidelines (World Health Organization, 2021).

Table 2: New and previous AQD limit values and WHO 2005 and new air quality goals, µg/m³

Pollutant	Averaging time	WHO AQG level 2005	EU AQD (previous)	WHO AQG level 2021	EU AQD (Directive (EU) 2024/2881*)
$PM_{2,5}$	Annual	10	25	**5**	**10**
	Daily	25	-	**15**	**25**
PM_{10}	Annual	20	40	**15**	**20**
	Daily	50	50 (35 d/y)	**45**	**45 (18 d/y)**
O_3	Max daily 8 hours mean	100	120 (25 d/y)	**100**	**120 (25 d/y**
NO_2	Annual	40	40	**10**	**20**
	Daily	-	-	**25**	**50 (18 d/y)**
	Hourly	-	200 (18 d/y)	-	**200 (3 d/y)**
SO_2	Annual	-	-	-	**20**
	Daily	20	125 (3 d/y)	**40**	**50 (18 d/y)**
	Hourly	-	350(24 d/y)	-	**350 (3 d/y)**

** To be attained by 1 January 2030*

The Directive (EU) 2024/2881 (the new AQD) specifies reference measurement methods in Points A and C of Annex VI (European Union, 2024a). As outlined in Point B of this Annex, to assess the contributions of industrial sources to ambient air quality, at least one sampling point shall be installed downwind of the main source within the relevant predominant wind direction in the nearest residential area; where the background concentration is not known, an additional sampling point shall be situated upwind of the main source, relative to the relevant predominant wind direction; the sampling points may be sited such that the application of Best Available Techniques (BAT) can be monitored.

Under the second pillar, the **NEC Directive** (European Union, 2016a), since 2022 the EU has carried out yearly compliance checks against the national emission reduction commitments for 2020-2029 for the five most harmful transboundary air pollutants (SO_2, NO_x, NH_3, NMVOC and $PM_{2.5}$). The first compliance check in 2022 using 2020 emission data revealed that much more actions to reduce air emissions are needed.

The third pillar is to tackle emissions at source. To this end, several revisions of legislation have been finalised, including revision of the **Industrial Emissions Directive (IED.2.0)** (European Union, 2024b) among others (European Commission, 2025). The revised Industrial and Livestock Rearing Emissions Directive (IED 2.0) as amended by Directive 2024/1785 (European Union, 2024b), is the main EU instrument to reduce these emissions into air, water and land, and to prevent waste generation from large industrial installations and intensive livestock farms (pig and poultry). The overall aim of the IED 2.0 is to minimise the impact of pollution on people's health and the environment by reducing harmful industrial and intensive livestock emissions across the EU. The IED 2.0 to be transposed to the Member States national legislation by July 1, 2026.

The IED 2.0 highlighted that the Union's extractive industry is key to achieving the objectives of the European Green Deal and the industrial strategy of the Union. Extraction including on-site treatment operations, such as comminution, size control, beneficiation and upgrading, of the bauxite, chromium, cobalt, copper, gold, iron, lead, lithium, manganese, nickel, palladium, platinum, tin, tungsten and zinc are covered by the new edition of the IED 2.0, however construction industry is out of the scope. The Industrial Emissions Directive will support industry in the EU in developing projects and facilitate sustainable and consensual growth of the mining activities in the Union in line with the 2030 benchmarks of the Critical Raw Materials Act (European Union, 2024c) and will help in meeting the targets for the streamlined permit granting process.

Industrial Emissions Portal Regulation (EU) 2024/1244 (IEPR) (European Union, 2024c) replaces the E-PRTR Regulation (EC) (European Union, 2006) and implements the Kyiv Protocol on Pollutant Release and Transfer Registers to the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters of the United Nations Economic Commission for Europe. It provides public access to key environmental data from industrial facilities in EU Member States, Iceland, Liechtenstein, Norway, Switzerland, Serbia and the UK through the Industrial Emissions Portal. Data published in the Portal allows for the identification and monitoring of sources of industrial pollution, in order to contribute to its prevention and reduction. Consequently, it builds awareness of environmental matters, enables a free exchange of views and effective participation by the public in environmental decision-making, and contributes to a better environment.

The Industrial Emissions Portal Regulation (IEPR) and the IED 2.0 are closely linked in terms of their scope. Reporting requirements for pollutant releases and transfers are aligned with the permit conditions set out under the IED 2.0. This enables the IEPR to provide reliable and comparable data on pollutant emissions and resource use by the EU industry and also supports the Portal's efforts in monitoring and reducing the environmental impact of these data (European Union, 2024c).

Activities covered by Annex I of the IEPR shall report their air emissions, water releases and waste. However, there was no changes for the opencast mining and quarrying. The IEPR is applied to opencast mining and quarrying where the surface of the area effectively under extractive operation equals 25 hectares. "Surface of the area effectively under extractive operation" means the surface of the area of the site reduced by the surface of the rehabilitated area and reduced by the area of future excavation. Rehabilitation areas and areas of future excavation are therefore not concerned with the reporting (United Nations Institute for Training and Research, 2006). The list of air emissions applied for quarrying includes CH_4, CO, CO_2, NO_x, SO_2, HCl, PM_{10}, and several heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) (European Union, 2024c).

In addition, the following is a list of relevant EU legislation related to the regulation of air emissions from quarrying activities.

EU Regulation 2016/1628 covers non-road mobile machinery (NRMM), setting out emission limits for gaseous and particulate pollutants from the engines of such machinery (European Union, 2016b). The regulation sets out pollutant emission limits for different power ranges of NRMM engines. The NRMM category includes the following types of machinery and equipment:

- small gardening and handheld equipment (chainsaws, lawnmowers, etc.)
- construction machinery (loaders, excavators, bulldozers, etc.)
- agricultural and farming machinery (cultivators, harvesters, etc.)
- locomotives, railcars and inland waterway vessels.

Most machines used in quarrying operations fall into the second category of construction machinery. In order to obtain type-approval for their products, manufacturers of the engines need to follow a set of procedures including the ones in terms of air emissions. Type approval is a requirement to place the manufacturer's engine on the EU market. Once a type of approval has been issued, it is valid indefinitely (European Commission, 2023a).

EU Renewable Energy Directive 2023/2413 (RED III) is part of the EU's broader strategy to achieve climate neutrality by 2050 and to meet the intermediate target of at least 42.5% renewable energy in the EU's gross final energy consumption by 2030, with an aspirational target of 45% in line with the REPowerEU Plan (European Union, 2023). RED III also specifies sector-specific targets. For instance, for industry "to increase the share of renewable sources in the amount of energy sources used for final energy and non-energy purposes in the industry sector by an indicative increase of at least 1,6 % as an annual average calculated for the periods 2021 to 2025 and 2026 to 2030".

The amended Directive 98/70/EC of 13 October 1998 or **Fuel Quality Directive** sets quality standards for petrol, diesel fuels, and biofuels used in road vehicles as well as for gas oil used in non-road-mobile machinery. It regulates the sulphur content of fuels (so SO_2 emissions) and emissions of VOCs (European Union, 1998). EU Member States shall ensure that petrol may be placed on the market within their territory only if it complies with the environmental specifications set out in Annex I.

Corporate Sustainability Reporting Directive 2022/2464 (CSRD) extends the scope of reporting of non-financial information in financial disclosures concerning sustainability reporting standards that include among others information about air pollutants and greenhouse gas emissions (GHG) (European Union, 2022). It applies to both EU and non-EU companies operating in the European Union from the 2024 financial year. A set of large companies (exceeding an average of 500 employees during the financial year), as well as SMEs, are required to report on sustainability. The sustainability reporting standards should specify the information that undertakings are to disclose on all major environmental factors, including their impacts and dependencies on climate, air, land, water and biodiversity.

Noise control and vibrations

According to the European Commission's website, long-term exposure to environmental noise causes approximately 12 000 premature deaths in the EU each year (European Commission, 2023d). Requirements for noise produced by outdoor equipment must be harmonized in the EU internal market. The noise generated by the equipment mainly affects the health and well-being of local citizens in the area.

The Directive 2000/14/EC (European Commission, 2023b), of the EU Parliament and the Council of the European Union (updated 03/2021), addresses noise emissions produced by outdoor equipment. The directive applies to a wide range of outdoor equipment and machinery, requiring them to meet specific noise emission limits or be labeled with their sound power level to reduce environmental noise and protect public health. The machinery and equipment include e.g. construction, gardening, and municipal machines that emit noise into the environment during operation. As stated in the directive, the Fifth Environmental Action Program identified noise as one of the most pressing environmental problems in urban areas, highlighting the needs for actions relating to various noise sources (European Commission, 2023c). The EU aims to decrease environmental noise to protect human health. The policy target set out in the Zero Pollution Action Plan is to reduce the share of people chronically disturbed by transport noise by 30% by the year 2030. Up to now, limited progress has been made towards this target and current efforts appear inadequate, particularly in urban areas, and more proactive noise management strategies are needed at national or local levels (European Environment Agency - Joint Research Centre, 2025).

Article 13 of the Directive 2000/14/EC lists the equipment, which shall be marked with the maximum noise level. Manufacturers are responsible for ensuring that their equipment is fully compliant with the Directive and applicable EU legislation. The final sound power level of the equipment depends on the noise measurement method used. However, the following standards define the basic principles of noise measurement (International Organization for Standardization, 2023):

- ISO3741 to ISO 3747
- ISO 9614-1 to ISO 9614-3
- ISO/TS 7849-1 and ISO/TS 7849-2.

Annex III of the Directive (European Commission, 2023b) contains information on the measurement methods for airborne noise and the determination of sound power levels for outdoor equipment:

- a reference to basic noise emissions standards (listed in Part A of Annex III)
- the number of microphones and their positioning
- the test area
- the value of a constant K2A (environmental correction)
- the shape of the measurement surface.

Operating conditions are also laid down for each type of equipment. Table 3 lists the permissible sound power levels for different types of equipment, according to Article 12 (European Commission, 2023b).

Table 3: Permissible sound power levels, according to the Article 12. of Directive 2000/14/EC.

Type of equipment	Net installed power P (in kW) Electric power P_{el} (1) in kW Mass appliance m in kg Cutting width L in cm	Permissible sound power level in dB/I pW	
		Stage I as from 3 January 2022	Stage II as from 3 January 2006
Compaction machines (vibrating rollers, vibratory plates & rammers)	P ≤ 8	108	105 (2)
	8 < P ≤ 70	109	106 (2)
	P > 70	89 + 11 lg P	86 + 11 lg P (2)
Tracked dozers, tracked loaders, tracked excavator-loaders	P ≤ 55	106	103 (2)
	P > 55	87 + 11 lg P	84 + 11 lg P (2)
Wheeled dozers, wheeled loaders, wheeled excavator-loaders, dumpers, graders, loader-type landfill compactors, combustion-engine driven counter-balanced lift trucks, mobile cranes, compaction machines (non-vibrating rollers), paver-finishers, hydraulic power packs	P ≤ 55	104	101 (2) (3)
	P > 55	85 + 11 lg P	82 + 11 lg (2) (3)
Excavators, builders' hoists for the transport of goods, construction winches, motor hoes	P ≤ 15	96	93
	P > 15	83 + 11 lg P	80 + 11 lg P
Hand-held concrete-breakers and picks	m ≤ 15	107	105
	15 < m < 30	94 + 11 lg m	92 + 11 lg m (2)
	m ≥ 30	96 + 11 lg m	94 + 11 lg m
Tower cranes		98 + lg P	96 + lg P
Welding and power generators	P_{el} ≤ 2	97 + lg P_{el}	95 + lg P_{el}
	2 < P_{el} ≤ 10	98 + lg P_{el}	96 + lg P_{el}
	P_{el} > 10	97 + lg P_{el}	95 + lg P_{el}
Compressors	P ≤ 15	99	97
	P > 15	97 + 2 lg P	95 + 2 lg P
Lawnmowers, lawn trimmers/lawn-edge trimmers	L ≤ 50	96	94 (2)
	50 < L ≤ 70	100	98
	70 < L ≤ 120	100	98 (2)
	L > 120	105	103 (2)

Regarding **vibrations**, EU Directive 2002/44/EC (last updated March 2021) sets out the minimum health and safety requirements relating to risks arising from physical agents (vibrations) (European Commission, 2023e). The objective of the Directive is to ensure the minimum basis of protection for all Community workers against exposure to mechanical vibrations. The Directive defines two types of vibration:

- "Hand-arm vibration" – meaning the vibration transmitted to the hand-arm system, entailing risks relating particularly to vascular, bone, joint or muscular disorders.
- "Whole-body vibration" – referring to vibration, which is transmitted through the whole body, entailing safety risks regarding lower-back morbidity and trauma of the spine.

Exposure limits for the hand-arm vibration:

- The limit for daily exposure for the reference time period of eight-hours is 5 m/s^2.
- The daily exposure action value for the reference time period of eight-hours is 2.5 m/s^2.

Exposure limits for the whole-body vibration:

- The limit for daily exposure for the reference time period of eight-hours is 1.15 m/s^2 or, at the choice of the Member State concerned, a vibration dose value totalling to 21 $m/s^{1.75}$.
- The daily exposure action value for the reference time period of eight-hours is 0.5 m/s^2 or, at the choice of the Member State concerned, a vibration dose value totalling to 9.1 $m/s^{1.75}$.

If the limit values are exceeded, the employer must take immediate in order to reduce the exposure below the set limits. If the action values are exceeded, the employer must implement an action plan to prevent or minimize the exposure. This may include organisational and/or technical measures to reduce exposure to mechanical vibrations (European Union, 2002).

04 Emission and noise estimation from the main sources in quarries

Diffused and channelled dust emissions estimation from activities within the quarry

The open literature on the emission estimation methodologies related to quarry activities focus mainly on particles concentration rather than particulate emissions. Several approaches to calculate particulate emissions from quarries have been developed by different countries and by the European Union. All of these methods developed to estimate emissions of quarries are based on the AP-42 of the US EPA (U.S. Environmental Protection Agency, n.d.). This is the most acknowledged methodology to quantify particulate emissions from quarries. The AP-42 is a compilation of emission factors of air pollutants for various pollution source categories and provides emission factors or equations to calculate particulate emissions related to the various steps from a quarry to produce aggregates.

Several Excel-based tools already exist to assess air emissions from the quarries. These include:

- The Pits and quarries reporting guide for the National Pollutant Release Inventory in Canada, which includes associated Excel-based emission calculator tools to assess air emissions from crushed stone processing, road dust and wind erosion of stockpiles (Environment and Climate Change Canada, n.d.).
- Air emissions calculators to help small businesses in Minnesota, USA, determine whether they require an air permit and to track emissions, as stipulated by their current air permits, including those for blasting activities and aggregate, non-metallic mineral processing (Minnesota Pollution Control Agency, n.d.).
- EMEP guidelines to estimate air emissions for reporting under CLRTAP and NECD in the EU and CLRTAP regions (European Environment Agency, 2023) (Lambrecht, U., Ntziachristos, L., & Hausberger, S. 2023).
- The Annual air pollutant emissions reporting guide for quarries and primary treatment facility operators and the Carrières excel based tool (Citepa, 2021).

The EMEP methodology, which is adapted and used in the EU and UNECE regional context for national inventory compilation,and so is considered the most appropriate for assessing air emissions from mining and quarrying in the region. It is mainly based on the AP-42 methodology and the French experience of emission inventory development from quarrying activities with regard to diffuse dust (European Environment Agency, 2023). According to EMEP methodology dust (European Environment Agency, 2023), various approaches to estimate dust emissions from quarries exist. Tier 1, so called “worst case approach” (default approach) consists of multiplication of the production of the site by an emission factor.

$$Emission_{Total} = Production \times EF$$

Emission factors of the Tier 1 method assume old technology and little to no abatement implementation. The emission factors are average factors taken from the Coordinated European

Particulate Matter Emission Inventory Program (CEPMEIP) (Visschedijk, 2004) (Table 4).

Table 4: Tier 1 emission factors for source category 2.A.5.a Quarrying and mining of minerals other than coal (Visschedijk, 2004)

Pollutants	Medium to high emission level [g/t] (95% confidence interval)	Low to medium emission level [g/t] (95% confidence interval)
TSP	102 (50 – 200)	51 (25 – 100)
PM_{10}	50 (25 – 100)	25 (13 – 50)
$PM_{2.5}$	5 (2.5 – 10)	3.8 (1.9 – 7.6)

This methodology is extremely simple and can be applied easily by any site knowing the quantity of material produced in the quarry. However, it is quite approximate and does not consider the various parameters influencing the quantity of particulates emitted in a quarry. Therefore, technological progress or implementation of abatement technologies are not directly taken into account. In addition, the methodology is not flexible, and emission factors cannot be adapted depending on their real situation and the available data.

Tier 2 technology-specific approach aims to calculate emissions to produce aggregates (European Environment Agency, 2023). It takes into account the following emission sources in the quarry:

1. Drilling and blasting (hammering doesn't cover by the approach) (diffuse dust emission sources)
2. Material processing: crushing, screening and transfer points (diffuse and channelled dust emission sources)
3. Internal transport (diffused dust emission sources)
4. Material handling operations: loading and unloading (diffuse dust emission sources)
5. Wind erosion from stockpiles (the other dusty surfaces are not taken into account e.g. open fields, roads, open conveyor belts, etc.) (diffuse dust emission sources).

The "internal transport", "material handling operations" and "stockpiles erosion" have regionalized emission factors taking into account the regional variability of meteorological parameters (wind speed and precipitations). This regionalization is important because meteorological parameters have thresholds and non-linear impacts on the emissions.

According to the European Environment Agency (2023), the size of quarries does not affect the method used to calculate particulate emissions, but it affects the input parameters. In fact, large quarries tend to be more efficient in terms of transport, more likely to use dust abatement technologies to reduce emissions and often produce a wider range of aggregate grain sizes, requiring additional crushers and screens. These differences are taken into account in the parameters of the Tier 2 methodology to allow for the variability in operations between the size categories of quarries. These categories are based on production. However, when classifying quarries, production capacity should be used where possible rather than current annual production. Indeed, some quarries may have a low annual production because they produce aggregate for a short period of time and then sell the production for the rest of the year. However, the operations of this type of quarry are similar to those of larger quarries and should not be assimilated to smaller quarries with constant production throughout the year.

The quarry size distinction used is the one of the EMEP (European Environment Agency, 2023):

- Large quarries (Production ≥ 500 kt),
- Medium quarries (100 kt ≤ Production < 500 kt), and,
- Small quarries (Production < 100 kt).

In addition to stationary quarries, there are mobile solutions, such as track-mounted crushers and screens, which operate at the worksite for a limited period. The scale of these operations varies. Track-mounted material processing machinery has emission sources that are very similar to those of stationary plants. However, the process and crushed rock are often more exposed in mobile equipment, making dust control more difficult due to the lack of fixed enclosures.

The Tier 2 approach could be applied at both the national and a site levels. When applied at the site level, it could be considered as Tier 3 approach, as it uses facility-specific information and is considered site-specific. For example, based on EMEP methodology According to the European Environment Agency (2023). France has developed a method and tool to calculate dust and other pollutant and GHG emissions from the above-mentioned operations – emission sources for quarries, developed by Citepa in collaboration with UNICEM and ATILH for quarry operators and primary materials processing companies (Citepa, 2021). The French approach was also adapted based mainly on the US EPA's method and French national specifications. The results of the developed model were validated using the EMCAIR study (Cesbron & Air Breizh, 2018).

To further improve emission estimation, Tier 3 site-specific direct monitoring can be used. This method involves measuring emissions in real time or periodically at the source or in the environment. While it is suitable for stack emissions, it is challenging for diffuse sources, as it requires complex inverse modelling and access to background concentrations and meteorological data. Although resource-intensive, direct monitoring is recommended when high accuracy is needed or when emissions are highly variable due to local conditions or specific equipment.

PM, NO_x and CO_2 emission estimations in NRMM from fuels

Depending on the information available, Tier 1, Tier 2 and Tier 3 methods and respective emission factors for CO_2, NO_x, and PM emissions from NRMM fuel combustion of the relevant EMEP guide could be used to estimate emissions of NRMM from fuel combustion (Lambrecht, Ntziachristos, & Hausberger, 2023). Tier 1 approach could be used, when detailed information on the NRMM is not available. However, as more detailed information is available especially on the Stage of the NRMM, Tiers 2 and 3 methods could be used.

However, other air emissions that may come from fuels are not covered in this handbook.

NO_x and CO_2 emission estimation from the use of explosives

Tier 1 of emission estimation method could be used to assess emissions from the explosive use, due to lack of more detailed methods (Tier 2 and Tier 3). The emission factors used to estimate CO_2 emissions of explosive are taken from French National Union of Public Works contractors specializing in the use of explosives (Dernoncourt, 2008). For NO_x emission factors for emulsion, AP-42 methodology of the U.S. Environmental Protection Agency (1980) could be used and for ammonium-nitrate fuel-oil (ANFO), the more recent methodology could be used.

Noise estimation

During aggregate processing, the need for noise estimation and declaration is evaluated on a regional basis (Hakala & Laurila, 2010). When creating the noise estimation mode, it's important to take into account the following points:

- Distance to the nearest noise-exposed location
- Estimation of area size
- Nature of the activity producing noise
- Other actors in the area
- Geological structure of the area

Regarding the noise estimation model to be valid, the initial information for the area operations and the cartographic data is essential to be as accurate and correct as possible. The estimation model used for noise declarations should be confirmed at the quarry site with measurements in compliance with the relevant standards (Hakala & Laurila, 2010).

The power levels of various noise sources can be summed up by first converting them separately from sound pressure (dB) to sound power level (W), then summing them and converting them back to sound pressure (dB). The formula for calculating the total sound level from multiple noise sources is presented below:

$$L_{TOTAL} = 10\log_{10}(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + I + 10^{\frac{L_n}{10}})\, dB$$

where L1 – Ln represents sound pressure levels for the various noise sources and LTOTAL is the final sum of these.

The sound power level of the equipment is highly affected by the layout of the quarry site and its surroundings, as well as by any potential noise mitigation solutions installed. These values are intended only as a reference for approximate calculations (Hakala & Laurila, 2010).

05 Emission abatement measures from the main sources in quarries

Based on our experience and literature review, including the Institute of Air Quality Management (2016), Cusano et al. (2017), BREF Management of Waste from Extractive Industries, in accordance with Directive 2006/21/EC (Pinasseau et al., 2018), the European Commission (2006), Cecala et al. (2019), the U.S. Environmental Protection Agency (2022) and others, a list of general measures applied to site, equipment, solutions and set of measures applied to main operations generating air emissions in the quarries was distinguished. It is recommended to use a combination of these techniques to **abate air emissions from the main sources of air pollution in quarries**.

5.1 General measures applied to all quarries

Applied to site:

The measures listed below could be used to manage ***air emissions in general*** at a quarry site.

Quarry layout: Design the layout of the quarry (equipment placement) for emissions minimization by utilizing the existing natural wind/noise barriers (e.g. quarry faces). This could prevent the emissions propagation to residential area.

Planning of activities: Some activities should ideally be planned only during favourable weather conditions. When possible, particularly dusty activities should be avoided during extended periods of dry and windy conditions. In addition, planning transport routes to minimize travel distances and reduce vehicle congestion, to avoid unnecessary travel, can reduce emissions. Unnecessary travel can also be reduced by acquiring fixed conveyors to transport the material.

Emission monitoring: Regular monitoring of air pollutants levels and compliance with applicable regulations are essential for evaluating the effectiveness of control measures and ensuring adherence to environmental standards. Implementation of an appropriate monitoring scheme can range from visual inspections, dust deposition/flux monitoring, to real-time PM_{10} continuous monitoring locations. If blasting operations are on the site, monitoring air quality after blasting can help identify areas with elevated CO_2 and NO_x levels. Installing emission monitoring systems on NRMM can help identify high-emitting equipment and optimize their operation. On-board diagnostics and real-time emission monitoring systems provide feedback to operators, facilitating emission control. Complying with local emission regulations and standards for equipment and operations in a quarry is also very important. Understanding and adhering to emission limits and reporting requirements help ensure proper emission control and management.

Windbreaks and barriers: Installing barriers, screens, or windbreaks around material processing areas can help reduce the spread of airborne dust and other emissions. Physical structures like berms or curtains around blast zones are especially effective when combined with dust suppression systems. Placing such barriers between major emission sources and sensitive areas like water bodies or residential communities can significantly reduce the impact of emissions on these environments.

Retaining native vegetation: Retaining as much vegetation as possible throughout the quarry's operation could also be important for emission reduction from the site. Root structures help maintain soil stability, while tall vegetation, especially trees, can act as a filter.

Applied to equipment:

The measures listed below could be used to manage air emissions in general associated with equipment.

Following up-to-date standards: By following the newest standards for NRMM, the compliance is ensured for reaching acceptable emission limits for various emission classes.

Increased automation and control: By increasing automation and digital control technology in quarry operations, the emissions originating from manual operations can be decreased.

Regular maintenance of dust control equipment: Maintaining dust control equipment, such as water trucks or dust suppression systems, ensures their effectiveness in minimizing emissions. Especially for the dust suppression systems based on water spraying, it is important to regularly check that the nozzles are not clogged and to ensure the purity of water used.

R&D investments: By investing in R&D, state-of-the-art equipment can be commissioned and utilized in the operations.

Applied to user solutions:

Providing training to the site personnel on air emission mitigation could improve awareness on the activities generating air emissions in a quarry. Well trained operators tend to change equipment wear parts and conduct proper maintenance more proactively, which in turn can reduce emissions. Training should also cover 'emergency preparedness plans' to react quickly in case of any failure of the planned dust mitigation.

Conduct inspections using visual emissions observations. For example, US EPA propose such methods when heavy trucks are using the roadway.

Communication: While not a direct emission reduction measure, maintaining open communication with surrounding communities helps build trust and reduce concerns related to air emissions. This can be achieved by establishing regular liaison meetings, sharing information transparently, and ensuring accessible channels for dialogue between the operator and local residents.

To manage fugitive dust emissions in the case, where there is potential for local receptors such as homes, schools, hospitals, car parks/showrooms, places of work and footpaths to be impacted by dust from a minerals development, a **Dust management plan (DMP)** may be required. DPM may contain:

- Fugitive dust emission sources
- Operation and maintenance procedures
- Facility layout
- Training
- Reporting
- Recordkeeping
- Updates and reviews.

Operations carried out within the quarry, such as drilling, blasting, material processing and handling, transport and erosion of stockpiles, are key contributors to air emissions primarily diffused dust (particulate matter), air pollutants associated with the use of explosives (e.g. NO_x, CO_2) and combustion-related pollutants (e.g. dust, NO_x, CO). This section describes effective measures to reduce air emissions, mainly dust (TSP, PM_{10}, $PM_{2.5}$), CO_2 and NO_x resulting from these operations.

5.2 Drilling and blasting

Reducing ***air*** emissions during drilling and blasting operations (dust, CO_2, NO_x and other) in open quarry mining is essential to minimize the environmental impact. While primary measures are essential, such as optimizing drilling techniques and using low-emission explosives, secondary measures can further abate air emissions.

Primary measures

The primary measures applied during drilling and blasting to reduce ***air emissions in general*** could be distinguished as follows:

Avoidance of blasting: Blasting may be avoided if appropriate alternatives can be employed, for example modern hydraulic excavators and breakers.

Blasting management: Implementing effective blasting management practices can contribute to air emission reduction. This includes proper blast monitoring, accurate timing, and adherence to blasting plans to ensure efficient use of explosives and minimize over-blasting, which can lead to unnecessary emissions.

Preconditioning and rock fracturing techniques: Implementing techniques like preconditioning, such as pre-splitting or smooth blasting, can help improve rock fragmentation efficiency. This reduces the amount of explosive required and subsequently lowers emissions.

Blast design optimization: Optimizing blast design can help minimize the amount of explosive material required, thereby reducing the associated emissions.

Detonation timing and sequencing: Optimizing the timing and sequencing of detonations can minimize the overall explosive energy required, resulting in lower emissions. Proper sequencing helps avoid unnecessary overlapping blasts and maximizes energy release efficiency.

Blast timing: Scheduling blasting activities during times when weather conditions are less likely to disperse emissions, such as during calm weather or when the wind is blowing away from sensitive areas could reduce air emissions.

Use of blasting mats or blankets: Employing blasting mats or blankets on the blast site can help confine the blast energy, reducing air blast and gas release. This can minimize the dispersion of gases and particulate matter, potentially reducing CO_2 and NO_x emissions.

Blasting equipment maintenance: Regular maintenance and calibration of blasting equipment, such as delay systems and electronic detonators, can optimize their performance and minimize variations that could lead to excessive explosive use and emissions.

The following primary measures are effective to reduce ***diffuse dust*** emissions during drilling and blasting:

Wet drilling: is considered an effective dust abatement technique, and it aligns with the principles of BAT for particulate emission control. Wet drilling suppresses dust at the point of generation by injecting water into the drill hole or onto the drilling surface, preventing dust from becoming airborne.

Stemming and decking: Proper stemming and decking techniques can be used during blasting to reduce flyrock and dust emissions. The proper drilling patterns and stemming materials can help contain the explosion's effects.

The following primary measures are effective to reduce **NO_x and CO_2** emissions during drilling and blasting associated with the **use of explosives**:

Selection of explosive type: Choosing appropriate explosive materials can contribute to emission reduction. Some explosives have lower carbon content and produce fewer emissions of GHG upon detonation. Exploring alternative explosives with lower environmental impact, such as low emission or oxygen-balanced explosives, can be considered.

Use of alternative oxidizing agents to avoid NO_x emissions: Even though the ammonium-nitrate (AN) technology has been established for applications in civilian explosives, there exist at least one non-nitrogen-based formulation replacing AN with hydrogen peroxide (H_2O_2), and used micro balloons, rather than chemical gassing, to avoid NO_x formation both in detonation and in emulsion sensitization. However, the technology requires further testing to verify its large-scale performance.

Secondary measures

The following secondary measures are effective to reduce ***diffuse dust*** emissions during drilling and blasting:

Dust suppression: Implementing dust suppression techniques to control dust generated during drilling and blasting can include using water trucks, dust suppressants, or misting systems to wet down the area and reduce airborne dust.

Local exhaust ventilation (LEV): Implementing local exhaust ventilation systems near drilling and blasting equipment could be used to capture and control dust emissions at the source. Best suited where water is not used for dust control.

Drilling rig drilling dust removal: Drilling construction adopts compressed air to discharge slag. The particle size of dust produced by drilling is small, and the dust concentration is very high. According to the characteristics of dust production in boreholes, the combination of orifice sealing and dry dust collector is adopted to treat the dust.

The following secondary measures are effective to reduce ***NO_x*** emissions during drilling and blasting, associated with the **use of explosives**:

Alkalimetric neutralization to abate NO_x emissions of ANFO explosives: tackling the formation of NO_x in blasting operation could be achieved by using neutralising additives, uniformly spread into the charge in small aliquots or added into sand stemming[2].

Application of stabilising and scavenging additives to abate NO_x emissions of ammonium nitrate fuel-oil (ANFO) explosives.

Reburning-like technique: Many practitioners applied reburning-like technology to reduce NO_x emission in blasting of AN explosives adding supplementary fuel (usually solid) of higher oxidation stability compared to fuel oil used in AN explosive.

[2] Stemming denotes the practice of placing soil, sand or rocks on the explosives in the blast hole

Chemical trapping: Spin traps can provide an effective reduction of the overall release of nitric oxide in sensitization (chemical gassing) of emulsion explosives.

Implementing a combination of primary and secondary measures can effectively reduce air emissions during drilling and blasting in open quarry mining, improving environmental stewardship and community relations. Additionally, regular monitoring and adjustment of these measures are crucial to maintaining compliance and minimizing the environmental impact.

5.3 Material processing: crushing, screening and transfer points

Reducing air emissions during material processing in open quarry mining, including crushing, screening, and transfer points, is crucial for minimizing the environmental impact.

This sub-chapter focuses exclusively on measures to reduce ***diffuse dust*** emissions generated during material processing (crushing, screening and transfer points) in quarries. It addresses both channelled emissions — captured at defined sources through systems such as local exhaust ventilation (LEV) — and diffuse emissions, which arise from a quarry processing installation consisting of one or more processing phases, which may be classified as primary, secondary or tertiary processing. These processes may include crushers, screens and transfer points.

Measures applied to air emissions due to fuel combustion in the quarry are described in the beginning of Chapter 5. General measures applied to all the quarries, in the part describing the measures applied to equipment and the sub-chapter 5.4 Internal transport.

Primary measures

Optimizing material transfer design of conveyor belts: To effectively control dust emissions at material transfer points, it is important to optimize transfer design by ensuring proper equipment alignment, minimizing the vertical fall distance, centring material on the receiving belt, containing the material during transfer, and keeping transfer distances as short as possible.

Preventing the creation of excess air velocity in conveyor belts: By implementing measures to avoid the material spread by shortening the drop or controlling the material flow, much of this added velocity can be avoided, reducing the ability of air to pick up dust.

Create a "stilling zone" in conveyor belts: It is an enlarged area beyond the transfer zone of a conveyor belt designed to slow the airflow and allow airborne dust to return to the ore. This enclosure is implemented to seal up the load zone, enlarge the air space, and allow for the implementation of measures to lengthen the amount of time provided for the material to settle out of the air.

Conveyor belt cleaning to control carryback in conveyor belts: To minimize dust emissions caused by material adhering to the return side of conveyor belts (known as carryback), it is recommended to clean the belt as it passes over or just beyond the head pulley, immediately after material discharge. This is typically achieved using mechanical scrapers, rotating brushes, or belt washing systems, which remove residual material and prevent buildup along the return path.

Local exhaust ventilation (LEV): These systems capture dust generated by various processes such as crushing, milling, screening, drying, bagging, and loading, and then transport this dust via ductwork to an air cleaning device. Capturing the dust at the source prevents it from becoming liberated into the processing. LEV systems use a negative pressure exhaust ventilation technique to capture the dust before it escapes from the processing operation. Effective systems typically incorporate a capture device (enclosure, hood, chute, etc.) designed to maximize the collection potential.

Prevention applications of wet control methods: Wet dust control systems can be very effective in material processing and are not usually costly to install and operate, but they may not be feasible due to characteristics of the mineral, subsequent processing steps, or customer specifications. Also, when operations are in cold climates, freeze protection is necessary, and ice buildup can create additional safety hazards for workers. Prevention is the application of water to prevent dust from becoming airborne. In general, prevention is more effective than suppression. Material is considered as wet when its moisture content is above 1.3%.

Enclosures and hoods: Enclosing crushing and screening equipment within specially designed enclosures or hoods to contain dust and prevent its release into the environment is another widely used emission abatement technique. However, effective ventilation is crucial to maintain air quality inside the enclosures.

Conveyor covers or conveyor hoods: Conveyor covers trap the fugitive dust, preventing it from spreading to the machine vicinity. Tarps or aluminium covers are typically used for this purpose. In addition, use of belt wipers is also recommended.

Conveyor belt sealing ((including skirting, belt-edge seals, and sometimes brushes or curtains): Implementing effective conveyor belt sealing mechanisms minimize dust generation during material transfer is another measure to abate emissions. Well-designed sealing systems help prevent dust emissions. However, regular maintenance is important.

Chutes and hoppers: Optimizing the design of chutes and hoppers can minimize material spillage and dust generation during transfer points.

Adjustment of the speed of open conveyor belts (< 3.5 m/s).

Maintenance practices applied to crushing, screening and transfer points equipment: Regularly maintaining and inspecting crushing, screening, and transfer points equipment to prevent leaks and dust emissions are important to reduce air emissions. Proper maintenance and regular change of wear parts ensures that the equipment operates efficiently.

Secondary measures

Although primary measures such as using control systems and enclosing equipment are essential for reducing dust, secondary measures can further help to abate air emissions.

Equipment selection: Choosing equipment and machinery designed to minimize dust emissions, such as crushers with built-in dust suppression systems could be useful to tackle emissions.

Suppression applications of wet control methods: Suppression is the use of water to wet dust particles that have already become airborne, increasing their mass and causing them to settle more rapidly. When the wetted material is subject to further size reduction, as in crushing operations, effective prevention requires application of additional water to the dry—and larger—surface area of the material exposed by the size-reduction process. This may create a complication because additional application of water to improve prevention may cause the material to become too wet, interfering with efficient handling, subsequent processing operations, or product sizing specifications. As a result, some trade-off between wet dust control and process efficiency is often unavoidable. Dust control for screening systems is similar to that for crushers, although wet systems are generally not used due to blanking of the screen openings by the wet material. In addition, screens are not normally subject to large surges of material flow as are crushers.

Chemical dust suppression: It involves the application of surfactants or binding agents at crushing and screening points to reduce airborne particulate emissions by enhancing moisture retention and agglomerating fine particles. Implementing dust suppression system with chemical dust suppressants at material processing points is useful to control the release of dust.

Dust control systems: Installing and maintaining up-to-date dust control systems at material processing points can include dust collectors, wet scrubbers, baghouses or cyclone separators, electrostatic precipitators near crushing and screening equipment can capture and filter out airborne dust and particulate matter.

Mist cannons: Employing mist cannons or fogging systems could be used to disperse fine water droplets into the air at transfer points. These droplets capture and weigh down dust particles, reducing their dispersion.

5.4 Internal transport

Reducing air emissions during internal transport in open quarry mining is vital to minimizing environmental impact. Currently, internal transport on unpaved roads is the most significant source of dust emissions in quarries, representing between 50 and 83% of dust (TSP) emissions when dumpers are used. Primary and secondary measures are essential for effective air emission reduction.

Primary measures

The following primary measures are effective to reduce ***diffuse dust*** emissions during internal transport:

Minimizing material transfers between processes.

Properly constructed haul road: This is the most effective measure for controlling diffuse dust emissions. Well-designed roads reduce the need for frequent maintenance by minimizing equipment wear, extending tire life, and enhancing dust control efficiency. This is achieved by limiting the generation of fine particles and improving the effectiveness and longevity of applied dust suppressants.

Reduced speed limits: Implementing reduced speed limits on haul roads minimizing dust generation.

Pavement availability: Availability of pavement in haul roads could prevent dust resuspension from mobile sources within the quarry.

Cover open-bodied trucks: It is recommended to cover open-bodied trucks when the truck is carrying materials that can be released into the air.

Haul road maintenance: Maintaining haul roads and access roads minimizes dust emissions and reduces the need for frequent grading, which can lead to additional emissions.

The following primary measures are effective in reducing ***dust, NO_x, CO_2*** emissions, associated with fuel consumption during internal transport operations:

Fleet management systems: Implementing fleet management systems that track fuel consumption, and emission data can help identify opportunities for optimization and provide insights for emission reduction strategies.

Vehicle upgrades: Considering upgrading vehicles with cleaner and more fuel-efficient engines or retrofitting them with emission control devices could tackle emissions.

Electric and hybrid vehicles: Where feasible, considering the use of electric or hybrid NRMM can significantly reduce PM, CO_2 and NO_x emissions. Electric-powered equipment eliminates direct emissions at the point of use, while hybrid systems combine conventional engines with electric power to improve fuel efficiency and emissions.

Fuel quality: Usage of cleaner fuels, such as low-sulphur diesel or biodiesel, reduces emissions of sulfuric compounds and particulate matter.

Alternative fuels: Exploring the use of alternative fuels, such as natural gas or biodiesel can have lower emissions compared to conventional fuels.

Idle reduction: Implementing measures to minimize unnecessary engine idling, such as automatic engine shut-off systems, can reduce fuel consumption and associated emissions.

Reduced speed limits: Implementing reduced speed limits on haul roads reduces fuel consumption.

Vehicle load optimization: Ensuring that vehicles are properly loaded avoids overloading, which can lead to increased fuel consumption and emissions. Streamlining loading and unloading processes minimizes vehicle idling time and reduce emissions during these activities.

Proper vehicle maintenance: Maintaining internal transport vehicles ensuring they are in good working condition can help reduce emissions by preventing fuel and oil leaks. Regular maintenance, including cleaning and replacing air filters, fuel injection system optimization, and engine tuning, ensures optimal engine performance, leading to lower emissions.

Secondary measures

Secondary measures to reduce ***diffuse dust*** during internal transport operations are:

Dust suppression system: Implementing dust suppression systems that uses water or chemical dust suppressants (e.g. salts, petroleum emulsions, polymers, and adhesives) on haul roads controls dust emissions generated by vehicle traffic. Proper maintenance of haul roads is crucial in controlling fugitive dust emissions. Measures such as regular watering, grading, and applying dust suppressants on roads can minimize dust generation from vehicle traffic. Dust suppression agents (e.g. chemical binders or surfactants) help to bind the dust particles together, preventing them from becoming airborne.

Using planned campaigns for road sweeping.

Washing the wheels and chassis of vehicles used in internal transport helps prevent the spread of dust beyond active work areas and reduces re-entrainment of dust when vehicles move across the site.

Vehicle emissions controls are effective in reducing ***dust*** and ***NO_x*** emissions, associated with fuel consumption during internal transport operations: Installing emission control technologies on vehicles, such as diesel particulate filters and Selective Catalytic Reduction (SCR) systems, reduces emissions of particulate matter and NO_x.

5.5 Material handling operations: loading and unloading

Reducing air emissions during material handling operations, such as loading and unloading, in open quarry mining is crucial for environmental protection. Here are both primary and secondary measures to abate air emissions in these processes:

Primary measures

The following primary measures are effective to reduce ***diffuse dust*** emissions during material handling operations:

It is advisable to place transfer conveyors and pipelines in open, safe areas above ground, so that leaks can be detected quickly and damage from vehicles and other equipment can be prevented. **If buried pipelines** are used for non-hazardous materials, their location should be documented and marked, and safe excavation systems should be adopted.

Similar measures applied to transfer points are relevant for material handling operations. They include among others enclose conveyor discharges, optimization of hopper and chute design etc.

The following primary measures are effective to reduce ***NO_x*** and ***CO_2*** emissions during material handling operations associated with the **fuel use**:

Equipment selection: Choosing equipment designed for low emissions and high fuel efficiency is crucial. Modern, well-maintained machinery tends to produce fewer emissions.

Similar measures applied to internal transport can be applied to vehicles for loading and unloading operations (**use of electric and hybrid vehicles, improving fuel quality, using alternative fuels, idling reduction and other**).

Proper equipment maintenance of handling equipment: Implementing regular maintenance schedules ensures that equipment is in optimal condition, preventing fuel or oil leaks and excessive emissions.

Secondary measures

The following secondary measures are effective to reduce ***diffuse dust*** emissions during material handling operations:

Wash wheels and chassis of vehicles used to deliver or handle dusty materials. It reduces dust spread when vehicles handle or deliver dusty materials and prevents contamination of cleaner areas (e.g. near stockpiles, processing equipment, or exit points).

Dust suppression systems: Implementing dust suppression systems using water or chemical dust suppressants controls dust emissions generated during loading and unloading operations.

Dust collectors: Extraction of dust from delivery points, silo vents, pneumatic transfer systems and conveyor transfer points, and connection to a filtration system (for dust-forming materials). Installing dust collection systems equipped with efficient collectors, such as baghouses or cyclone separators, captures airborne dust and particulate matter.

Mist cannons: Employing mist cannons or fogging systems to disperse fine water droplets that can capture and weigh down dust particles at loading and unloading points.

5.6 Wind erosion from stockpiles

Reducing air emissions due to wind erosion from stockpiles in open quarry mining is essential for minimizing environmental impact. Here are both primary and secondary measures to abate ***diffuse dust*** air emissions from wind erosion:

Primary measures

Stockpile design and management: Properly designing stockpiles minimizes exposure to wind. The shape, size, and orientation of stockpiles can significantly affect wind erosion. Regularly assessing and maintaining stockpile conditions is also important. Store the material in one heap instead of several where feasible in the case of outdoor storage.

Stockpile shielding: Shielding the stockpile with encapsulation or mechanical structures may decrease the overall emissions. In order to prevent diffuse emissions from the storage of raw materials, enclosed buildings or silos/bins for storing dust-forming materials could be used.

Stockpile covering: Covering stockpiles with geotextiles, tarps, or other materials prevents wind from lifting and carrying away fine particles. Covers can be temporary or permanent, depending on the situation.

Physical stabilization: Physical stabilization of stockpiles and exposed areas involves coating the surface with less erodible material (such as gravel), altering the surface characteristic (roughness or compaction), or planting vegetation to prevent wind and water erosion.

Regular maintenance of stockpiles: Maintaining stockpile surfaces and any dust control equipment applied ensures their effectiveness in preventing wind erosion

Secondary measures

Moisture control: Applying water or chemical dust suppressants to stockpiles keeps the material damp. Moisture helps weigh down particles, preventing them from becoming airborne. Water cannons and spray nozzles mounted at fan discharge points are effective technologies for delivering water over large surface areas of stockpiles, helping to suppress dust emissions. An alternative to the use of plain water is to add chemicals (wetting agents) to the water in an effort to improve moisture distribution, moisture retention, or particle agglomeration. Other chemicals are designed to develop a wind-resistant crust on the surface of the stockpile in order to prevent wind erosion.

Dust collectors: Installing high-efficiency dust collection systems—such as baghouses or cyclone separators—at material handling points near stockpile areas can effectively capture and filter airborne dust and fine particles, especially in enclosed or semi-enclosed settings.

06 Noise abatement measures from the main sources in quarries

Regarding noise control in quarrying operations, the actions to reduce noise pollution can be divided into two main methods:

- Reducing the noise power directly from a source (primary measures)
- Preventing the propagation of sound (secondary measures)

Specific ways to minimize noise include ensuring the optimal operation of equipment and using internal and external polymers (e.g., wear materials and enclosures) in the machines. The type and thickness of the material used, and the sealing of the enclosure, are critical to ensuring minimal noise emissions. For example, in screening, using synthetic screening media (cloths or mats) instead of traditional woven wire or metal plate can be highly beneficial, especially when combined with chute linings, encapsulations, or enclosures (Health and Safety Executive, 1993).

The noise produced by commonly used machines (e.g. excavators, rock breakers and wheel loaders) consists mainly of the machine noise (e.g., engine and hydraulics) and operational noise (e.g., hammering a rock or loading/unloading material). Different modifications in the manufacturing process can reduce these types of noise. However, the most significant noise reduction effects depend on the specific machine. The role of different noise sources varies due to the machine's different constructions, materials and work functions. Manufacturers of working machines should understand the possible noise emissions of their products and apply the most effective mitigation measures.

07 ROTATE improvements

One of the main objectives of the ROTATE project is to decrease CO_2, dust, other gases and noise emissions. Reducing both noise and dust emissions is a very concrete method of providing the best working environment for people working day-to-day in the quarries, while also minimizing the nuisance to nearby residential areas. Decreasing CO_2 emissions is crucial for the entire M&Q industry, and this project addresses this issue through a variety of actions and tasks.

As part of the ROTATE project, Metso as an equipment manufacturer, developed technologies to decrease dust and CO_2 emissions and noise during crushing and screening processes using Metso's mobile, track-mounted machines. For demonstration and piloting purposes, Metso used two of its machines as platforms for these improved technologies: the Lokotrack mobile impactor crusher LT1213SE and the Lokotrack mobile scalping screen ST2.8E.

Another technology developed in the ROTATE project that has the potential to reduce CO_2 emissions through process improvement is the automated vision system (AVS) developed by CTM. In the study, the real-time detection and control of the materials were piloted in one of the project's pilot quarries.

As part of the Environmental Management Platform of the ROTATE project, an Emission estimation module has been created by AKKODIS and Citepa to support aggregate quarries in managing and reducing their environmental impact. The module is the practical tool for operators to estimate the emissions of dust, carbon dioxide (CO_2), and nitrogen oxides (NO_x) throughout the key quarrying operations. In addition, an emissions strategy guide will be developed by Citepa to provide an overview of the most effective measures to reduce air emissions from the main operations in open pit M&Q facilities.

The main points of the improvements are summarised as follows.

Technologies to decrease dust and CO_2 emissions and noise during crushing and screening by Metso

Dust

The development of dust emission abatement measures in quarries has focused on decreasing emissions during the material processing step. The commonly used methods for reducing dust formation were presented in Chapter 5. The industry's ambitious long-term target is to develop either completely waterless systems or systems that use a minimal amount of water for dust suppression. These systems would be usable in winter conditions and in extremely cold climates. In case of mobile units such as track-mounted crushers and screens, the dust suppression system is typically incorporated into the machine itself, which limits its size and robustness due to the requirements of the machine's mobility and the harsh operating environment. However, the scope of technological development was not limited by mobility, as separate dust suppression entities could be effective for specific applications in the crushing industry. Novel waterless solutions typically use air suction techniques to collect dust particles from mobile crusher. These systems are usually larger and heavier, suggesting that they should be used as an add-on option. During the ROTATE project, a feasibility study was conducted for an air suction-based system for dust reduction, but such a system was not built into a prototype, primarily due to its large size and excessive energy usage required for a sufficient dust separation rate.

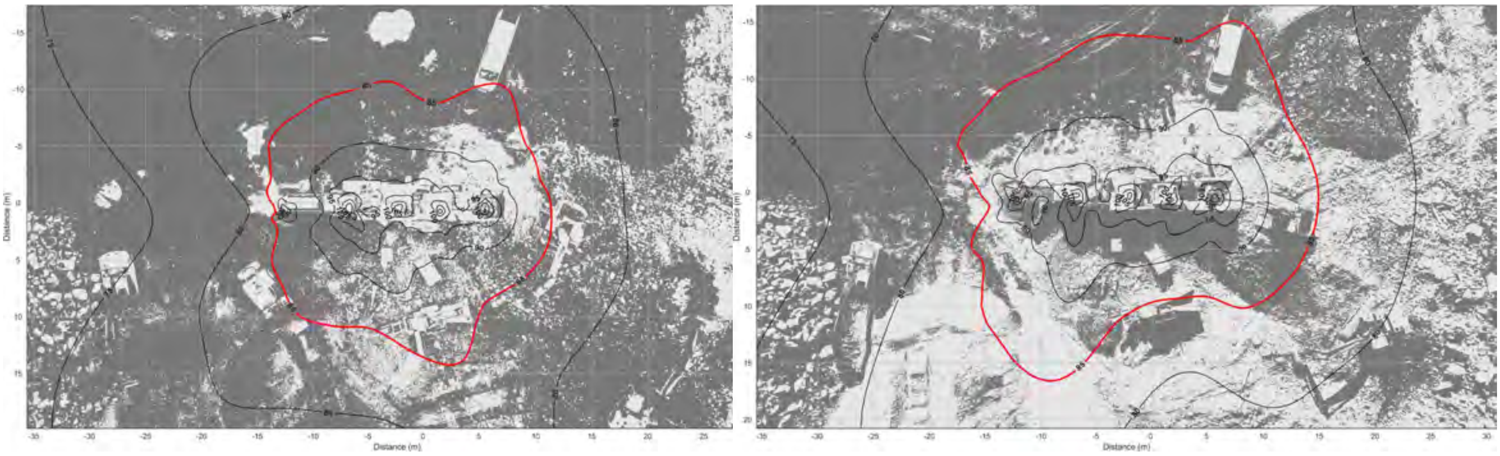
Another development within the ROTATE project by Metso has been the development of high-pressure water spraying and misting solutions to reduce dust emissions around the mobile machines. The project's target is to reduce dust emission by 50%. The dust concentration is measured and the reduction validated using a handheld aerosol monitor device. The measurer walks around the crushing site while a drone captures their location. These data are then synchronised with the video footage to produce a dust concentration map. The overall reduction is calculated based on the dust concentration values measured with and without the dust suppression system in operation. Based on the reduction in dust concentrations, the change in dust emissions can be estimated. During the piloting of dust suppression system of impactor crusher, the target of over 50% of reduction was achieved. Increasing the water pressure in the spraying system decreased dust emission levels of the harmful particle size classes of $PM_{2.5}$ and PM_{10}. Following confirmation of this finding in several field tests, work continued on the high-pressure water system with the aim of optimizing it.

Noise

During the ROTATE project, efforts to reduce noise by 50% focused on evaluating different strategies to lower the noise emitted by Metso's prototype machines. This involved measuring the machine's noise output and identifying the sources that contributed the most to the overall noise level. Some parts of the mobile impactor crusher were already encapsulated for noise reduction before the project. During the project, this system was improved by designing and building noise encapsulation for the crusher unit area of the mobile crusher. The noise reduction strategies are still under analysis and the final results are not yet ready.

In addition, a new measurement method for estimating noise levels near machines during crushing or screening was developed during ROTATE project. The method involved creating a noise map to easily show the distribution of noise in the immediate vicinity (10-20 m) of the machine. Measurements are taken by walking around the mobile crusher and recording noise levels with a handheld meter. A drone records the event from above, and the noise measurement data is synchronized with location information during the post-processing phase. The two examples of noise maps below show the mobile impactor crusher LT1213SE. The figure on the left shows the crusher with noise encapsulations, and the figure on the right shows the crusher without any noise encapsulations (Figure 2).

Figure 2: Noise level estimation using the new in-house method developed during ROTATE in Metso [images: Metso].



As can be seen in the figures, the 85 dB noise level range (red) can easily be inspected and compared to other measurements using the new method. The advantage of noise maps is that they visually represent harmful noise levels around the machine, which is not possible with typical measurement techniques. It is also possible to inspect whether the left or right side of the machine is noisier and investigate the possible reason for any deviation. Common measurement methods rely on precise microphone positioning, and even tiny offsets can alter the results. With this novel method, the project's main targets can be validated more thoroughly in piloting due to the averaging out noise level results over time while measurement errors decrease.

In the context of NRMM, the motor that provides energy to the machine is typically one of the most significant noise sources. Therefore, converting the machine's powertrain from an internal combustion engine (ICE) to electric may also affect noise levels. Mobile crushers and screens differ from many other NRMMs due to the significant noise generated during rock processing, which underscores the critical necessity of identifying and quantifying the specific noise sources and their respective contributions for each type of machine.

CO_2 emissions

Reducing CO_2 emissions is a critical goal for NRMMs, including mobile crushers and screens. In ROTATE, the target was to reduce 20% the emissions of CO_2. Electrifying powertrains is a key strategy, as electric motors significantly reduce CO_2 emissions compared to traditional ICEs. During the ROTATE project, a new driveline was developed for the mobile screen, including a battery that could partially replace the diesel motor. The energy consumption of screening is high, so it is not technically and economically feasible to operate the screen on only battery power full-time; it can only be used independently for very short periods. However, the new driveline provides several advantages. The battery can power the movement and positioning of the machine, reducing emissions during this stage of operation. For most of the operational screening time, the screen will be fed by an external electricity supply, e.g. from the mobile crusher of the previous crushing stage or a separate generator unit. The system was successfully piloted, by powering the screen with a mobile cone crusher in real-life process. The aim is to achieve the intended benefits by reducing the number of diesel engines and optimizing the loading of another, thereby lowering the total CO_2 emissions of the mobile crushing and screening plant. The analysis of the CO_2 emission reduction is currently ongoing, and the findings will be shared later. Several other minor improvements in process optimization technologies were made during the project, such as improving the performance of the mobile impactor crusher. These improvements enhanced the efficiency of the crushing and screening processes reducing energy consumption and consequently decreasing CO_2 emissions. One case example of these kinds of improvements is the energy-efficient windsifter, which is used to separate lightweight objects in recycling crushing. During ROTATE project, the windsifter unit was optimized to retain the performance of the old system with significantly lower energy usage. With high separation rate of lightweight objects, there is also less material in circulation in the mobile crusher, thus increasing machine efficiency.

Process improvement of the automated vision system (AVS) that have a potential to reduce CO_2 emissions developed by CTM

The technology developed by CTM aims to improve the efficiency of crushing in stationary plants, thereby reducing the total CO_2 emissions. While the AVC accounts for CO_2 emissions related to reduced electricity consumption falls under Scope 2 (indirect CO_2 emissions e.g. from the generation of purchased electricity, steam, heating etc.) consumed by the company rather than direct emissions (Scope 1), we have chosen to retain this information, as electricity savings represent a meaningful contribution to overall emission reduction efforts and are relevant to the broader decarbonization objectives of the ROTATE project.

The rock material needs to be separated and graded before crushing. This is currently done using dry/wet screens, hoppers or storage piles. The accumulation of material in these processes triggers equipment failure due to jam formation and therefore increases maintenance costs. Moreover, these processes account for approximately 50 - 75% of the total energy consumption of the crushing stage.

CTM has developed a technology within ROTATE that uses an automated vision system (AVS) to detect granulometry in real time, controlling and separating waste and material in the crusher. This technology has been tested and validated in industrial conditions at Velde facilities in Norway. After this separation stage, valuable materials are automatically introduced into the crushing equipment, thereby improving the efficiency between the drilling and crushing stages. This reduces the energy consumption and carbon footprint of the processing. It is expected to contribute to the vision of a greener and more ecological mining in European underground and open pit mines. Preliminary results have shown that optimizing the operation conditions of the secondary crusher can lead to savings of up to 18% in energy consumption and up to 8% in CO_2 emissions per ton of crushing aggregates.

The AVS tool is an advanced granulometry control system that uses an automated vision system. It continuously records images to determine whether the stone crushing mill needs to be opened or closed further. Based on the captured information and a custom-made algorithm, the system continuously calculates the volume of processed rocks, the mean area of the stones, and the minimum, maximum and average lengths and widths of the processed stones.

The AVS has been installed on the conveyor belt at the exit of the secondary crusher at the Velde grinding plant. It provided online granulometric information on the rock fragments being transported in real time. Energy consumption is also monitored in real time with a power meter. This information can be used to calculate the average energy consumed and the granulometry obtained at different secondary crusher openings, optimizing the process.

The AVS comprises commercial technological devices with specific functions, including:

- Profilometer: measuring instrument used to measure a surface's profile
- PLC (Programmable Logic Controller): specialized digital computer used in industrial settings for automation and control.
- PC (Personal Computer).
- IoT2050: industrial IoT (Internet of Things) gateway based on ARM (Advanced Risc Machines) processor technology
- Encoder: device that converts one type of data into another format
- Solenoid valve: electro-mechanical device that controls the flow of fluids (liquids or gases) by using an electromagnet
- HMI (Human Machine Interface): user interface that allows a person to interact with a machine, system, or device monitor.

The main innovation of this project is the implementation of a profilometer. This device can obtain live 3D images, enabling more precise identification of shape and size.

The Life Cycle Assessment (LCA) methodology was used to estimate CO_2 at this stage of the process. Velde has a Norwegian-certified tool to calculate Environmental Product Declarations (EPDs) (www.Lca.no). An EPD is a document that describes the environmental impact of a product or service and offers a transparent, quantifiable and comparable presentation of environmental performance. The EPD Generator was used, which is a time- and cost-effective way of developing verified and published EPDs, developed according to specific standards. Velde has defined an industry-specific database in cooperation with LCA.no. The database contains environmental data for relevant raw materials, energy, transport and waste in the company. Velde has registered the product composition, transport information, energy consumption and waste from production. The system automatically calculates environmental impacts adapted to the EPD format.

AVS technology offers numerous benefits and advantages. Real-time monitoring of aggregate granulometry enables more precise adjustment of the crusher's opening, optimizing energy consumption and resulting in estimated energy savings and reductions in the carbon footprint. Remote monitoring, mapping, and inspections enhance safety by protecting mine workers from dangerous working conditions. Using AVS in mining improves accuracy by providing real-time data monitoring instead of analysing small samples by manual mechanical sieving. The AVS tool's unique perspective enables the collection of data points that are impossible to obtain using traditional inspection techniques. The system can provide energy cost savings of over 15% per working day, and an estimated 25% reduction in equipment failures due to rock size. Additionally, surveys are straightforward to conduct and can be repeated as required, thereby increasing survey frequency.

Emission estimation module (AKKODIS, Citepa) and Emissions strategy guide (Citepa)

One of the important elements of the ROTATE outputs is the software on dust, NO_x and CO_2 emission estimation in a quarry as a part of the Environmental Management Platform and the

Emissions Strategy guide. The guide provides an overview of the most effective measures to reduce CO_2, NO_x and dust emissions during extraction and processing of materials at open M&Q facilities and strategies of emission reduction in quarries.

- **Air emission estimation module**

As part of the Environmental Management Platform of the ROTATE project, an Emission estimation module has been developed by AKKODIS and Citepa to support aggregate quarries in managing and reducing their environmental impact. This practical tool, based on the last methodological improvements, enables operators to estimate within the site emissions of dust, carbon dioxide (CO_2), and nitrogen oxides (NO_x) throughout the key quarrying operations, including drilling and blasting, processing, handling, transportation and storage in stockpiles.

The tool is intended to support operators in:

- demonstrating compliance with relevant local, national, and EU-level emission regulations,
- facilitating the preparation and communication of annual emissions to competent authorities, clients, or other stakeholders,
- setting and monitoring progress toward site-specific environmental objectives, such as quantified emission reduction targets for dust, NO_x or and CO_2 emissions, and
- enhancement of quarry operational efficiency.

By integrating emission factors and activity data in a transparent and structured manner, the Emission estimation module contributes to the systematic assessment of emissions and supports continuous environmental improvement at the site level. It also allows users to model the implementation of emission reduction measures and assess their impact on overall emissions.

Ultimately, this module equips the aggregates sector with a structured, evidence-based approach to emissions management, supporting the transition to more sustainable industrial practices.

- **Emission strategy guide**

Citepa has developed an emissions strategy guide to provide an overview of the most effective measures to reduce CO_2, NO_x and dust emissions from the main operations in open-pit M&Q facilities. This guide is based on Citepa's long-standing experience of working with the mining and quarrying industry (UNICEM) to improve the estimation of air emissions and the measures used by the industry to reduce emissions. It also draws on Citepa's extensive knowledge of emission abatement techniques applied to industrial installations and an additional desk study of the up-to-date information on emission reduction measures applied in quarries and process improvements implemented at five pilot sites, including their impact on emissions as available. This analysis will lead to recommendations and best practices to be applied to the different types of M&Q facilities for the different steps of the processes (e.g. drilling and blasting, material processing, internal transport, handling operations).

08 Conclusions and recommendations

Extractive industries such as quarries generate various direct air pollutants and greenhouse gases (GHG) including dust, NO_x, and CO_2 among others. The main sources of air pollution within the quarries are on-site transportation (haul roads), mineral processing (e.g. crushing and screening), mineral extraction (including drilling and blasting), materials handling (e.g. loading onto haul trucks or conveyors), and stockpiling and exposed surfaces.

The European Green Deal and, in particular, the Zero Pollution Action Plan have modernised and expanded the European Union's regulatory framework for tackling pollution, placing increased attention on key sectors, such as mining and quarrying, due to their significant environmental footprint and role in the sustainable supply of raw materials.

The latest EU legislation on air emissions and noise had to adapt to new challenges due to the tightening of WHO air quality limits, enhanced climate change and the geopolitical situation, which has triggered a scarcity of energy resources in recent years. This includes updated EU Directives and Regulations regarding air emissions and noise, as well as air quality, air pollutant and greenhouse gas emission reporting relevant to the quarrying sector.

Existing methodologies and tools for estimating air emissions have been identified and analysed to determine their relevance for use in the EU in quarry operator's level. It has been found that methodologies related to quarry activities mainly focus on particle concentration rather than particulate emissions. Several approaches to calculate particulate emissions from quarries have been developed by different countries and by the European Union. These are based on the AP-42 approach of the US EPA, with some further refinements. There are also some Excel-based tools available to estimate air emissions, including diffuse dust and also other sources of air pollutants and GHG. The EMEP methodology, adapted for use in the EU and UNECE regional contexts for national inventory compilation, is considered the most appropriate for assessing air emissions from mining and quarrying in the EU. However, common EMEP guidelines have not yet been developed to address diffuse dust and non-road mobile machinery (NRMM) emission, nor the guidelines to estimate the emissions associated with the use of explosives. French approach and tool exist to assess diffused or channelled dust emissions, as well as fuel and explosive-related air emissions with the focus on compliance with EU and domestic legislation. So, the approach combining the experience of the team and a desk study was suggested using an improved method based on the French approach and tool to assess diffuse and channelled dust emissions, as well as fuel- and explosive-related air emissions, adapted for use at EU level.

The state of the art in terms of mitigation measures to reduce diffuse and channelled dust, as well as emissions associated with the use of fuels and explosives, demonstrates the availability of such measures at site, equipment, or solutions level. In addition, there are numerous primary and secondary measures to tackle air emissions from the main sources within quarries, which are specific to quarry operations (e.g. drilling and blasting, processing). Using them in combination could significantly reduce air emissions in quarries and surrounding areas.

The development of the dust suppression system in ROTATE shows that significant improvements in dust suppression can be obtained by further developing existing technologies, such as the water spraying system.

The Artificial Vision System in ROTATE, which monitors the granulometry of aggregates in real time, has shown significant improvements in energy consumption and reduction of carbon footprint. Pilot tests have been conducted to optimise the operation conditions of the secondary crusher, achieving the savings of up to 18% in energy (electricity) consumption and up to 8% in CO_2 emissions per tonne of crushed aggregate.

The emission estimation module, together with the emission strategy guide developed within the ROTATE project, can be used by quarries to identify the dust, CO_2, and NO_x emission hotspots, and to build a strategy of emission reduction, selecting the appropriate measures to abate air pollution.

Concerning noise pollution, multiple activities in the quarrying environment produce excessive sounds (e.g., blasting, drilling, crushing and screening). It is crucial to measure noise emissions according to standards in order to maintain safe working conditions for the operators and develop improved noise reduction solutions for all machines of the quarry site. The need for such solutions will become increasingly significant in future as crushing operations move closer to urban areas. Noise maps are a very practical tool for estimating noise levels and identifying noise sources in different worksites and quarries. Regarding noise of mobile machinery, the most efficient abatement is achieved by thorough enclosure of the critical parts producing highest levels of noise. In the context of mobile crushing, this can translate into encapsulation of e.g. the crusher unit, motor module or other relevant sections of the machine. In order to identify the noise sources to be enclosed to achieve the most efficient outcome for abatement, measurements are needed along with estimations on the noise distribution to the nearby environment.

The ideal system would combine the best methods known for abatement of air emissions and noise. This would improve the working conditions in quarries and on construction sites, while reducing air pollution and noise in surrounding areas. Various research projects and development initiatives are continuously undertaken in the quarrying industry to address these issues. While not everything is technically and economically feasible, significant steps have already been taken, and technologies and environmental systems developed will be adapted.

09 References

Acoustical Society of America. (2023). *The safe noise level to prevent hearing loss is probably lower than you think:* The safe noise level to prevent hearing loss is probably lower than you think

American Speech-Language-Hearing Association. (2023). *Loud Noise Dangers:* Loud Noise Dangers

Berndt, A. (2019). *Drilling down into noise reduction best-practice*. GeoDrilling International. Drilling down into noise reduction best-practice

Cecala, A. B., O'Brien, A. D., Schall, J., Colinet, J. F., Franta, R. J., Schultz, M. J., ... Ellis, M. (2019). *Dust control handbook for industrial minerals mining and processing (2nd ed.)*. Pittsburgh, PA: National Institute for Occupational Safety and Health (NIOSH).

Cesbron, O., & Air Breizh. (2018). *Émissions des poussières des carrières dans l'air : Étude des émissions de poussières autour de quatre carrières de granulats dans trois régions françaises*. UNPG. AAP CORTEA 2015: EMCAIR - Emission des Carrières dans l'AIR.

Citepa. (2021). *Notice d'aide à la déclaration annuelle des émissions de polluants atmosphériques à l'attention des exploitants de carrières et d'installations de premier traitement des matériaux à partir de l'outil Carrières*. Ministère de la Transition écologique.

Cusano, G., Roudier, M., Delgado Sancho, L., & Tinetti, B. (2017). *Best available techniques (BAT) reference document for the non-ferrous metals industries (EUR 28648 EN)*. Publications Office of the European Union. Best available techniques (BAT) reference document for the non-ferrous metals industries - Publications Office of the EU

Dernoncourt, J.-R. (2008). *Gaz à effet de serre, efficacité energetique: vers la maitrise des impacts environnementaux des explosifs*.

Environment and Climate Change Canada. (n.d.). *Pits and quarries supplementary guidance*. Government of Canada. Pits and quarries reporting guide - Canada.ca

European Commission. (2023a). *Emissions from non-road mobile machinery*. Non-road mobile machinery - European Commission

European Commission. (2023b). Directive 2000/14/EC on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors. Directive 2000/14/EC - noise - equipment for use outdoors | Safety and health at work EU-OSHA

European Commission. (2023c). *Environmental Noise Directive*: Environmental Noise Directive - European Commission

Euopean Commission. (2023d). *Noise - overview*. Noise - European Commission

European Commission. (2023e). *Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration)*. Directive 2002/44/EC - vibration | Safety and health at work EU-OSHA

European Environment Agency. (2023). 2.A.5.a Quarrying and mining of minerals other than coal. In EMEP/EEA air pollutant emission inventory guidebook 2023: EMEP/EEA air pollutant emission inventory guidebook 2023 | European Environment Agency's home page

European Environment Agency. (2025). *Emissions of major pollutants into the air by extractive industries (Indicator)*. European zero pollution dashboards: Emissions of major pollutants into the air by extractive industries (Indicator) | European zero pollution dashboards

European Environment Agency - Joint Research Centre. (2025). *Zero pollution monitoring and outlook 2025* (EEA Report No 13/2024). Zero pollution monitoring and outlook 2025 | European Environment Agency's home page

European Commission. (2025). *The Fourth Clean Air Outlook*. European Commission. EUR-Lex - 52025DC0064 - EN - EUR-Lex

European Union. (2002). *Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration)*. Directive - 2002/44 - EN - EUR-Lex

European Union. (2006). Regulation (EC) No 166/2006 of the European Parliament and of the Council of 18 January 2006 concerning the establishment of a European Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC. Regulation - 166/2006 - EN - EUR-Lex

European Union. (2016a). *Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC*. Directive - 2016/2284 - EN - EUR-Lex

European Union. (2016b). *Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC*. Regulation - 2016/1628 - EN - EUR-Lex

European Union. (2023). *Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652*. Directive - EU - 2023/2413 - EN - Renewable Energy Directive - EUR-Lex

European Union. (2024a). *Directive (EU) 2024/2881 of the European Parliament and of the Council of 13 March 2024 on ambient air quality and cleaner air for Europe. (recast)* Directive - EU - 2024/2881 - EN - EUR-Lex

European Union. (2024b). *Directive (EU) 2024/1785 of the European Parliament and of the Council of 24 April 2024 amending Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC on the landfill of waste.* Directive - EU - 2024/1785 - EN - EUR-Lex

European Union. (2024c). *Regulation (EU) 2024/1252 of the European Parliament and of the Council of 24 April establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020.* EUR-Lex - 02024R1252-20240503 - EN - EUR-Lex

European Union. (2024c). *Regulation (EU) 2024/1244 of the European Parliament and of the Council of 24 April 2024 on reporting of environmental data from industrial installations, establishing an Industrial Emissions Portal and repealing Regulation (EC)* No 166/2006. Regulation - EU - 2024/1244 - EN - EUR-Lex

European Union. (1998). *Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels, as amended by Directives 2003/17/EC, 2009/30/EC and (EU) 2015/1513, Commission Directives 2000/71/EC, 2011/63/EU and 2014/77/EU, and Regulation (EC) No 1882/2003.* Directive - 98/70 - EN - EUR-Lex

European Union. (2022). *Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting.* Directive - 2022/2464 - EN - CSRD Directive - EUR-Lex

European Commission. (2006). *Reference Document on Best Available Techniques on Emissions from Storage*. Institute for Prospective Technological Studies, Joint Research. Emissions from Storage | EU-BRITE

Hakala, I., & Laurila, J. (2010). *Environmental management in aggregates production*. Helsinki: Finnish Environment Institute (SYKE).

Health and Safety Executive. (1993). *Control of noise in quarries*. HSG109. https://www.hse.gov.uk/pubns/priced/hsg109.pdf

Institute of Air Quality Management. (2016). *Guidance on the Assessment of Mineral Dust Impacts for Planning*. London, UK: Institute of Air Quality Management.

International Organization for Standardization. (2023). ISO 3740:2023 — Acoustics — Determination of sound power levels of noise sources — Guidelines for the use of basic standards. ISO 3740:2019(en), Acoustics — Determination of sound power levels of noise sources — Guidelines for the use of basic standards

Lambrecht, U., Ntziachristos, L., & Hausberger, S. (2023). *1.A.4 Non-road mobile machinery*. In EMEP/EEA air pollutant emission inventory guidebook 2023: Part B – Sectoral guidance chapters. European Environment Agency. 1.A.4 Non road mobile machinery 2023 — European Environment Agency

Metso. (2022). *Crushing and Screening Handbook*, (7th ed.).

Minnesota Pollution Control Agency. (n.d.). Air emissions calculators. Air emissions calculators | Minnesota Pollution Control Agency

Ntziachristos, L., & Boulter, P. (2023). *1.A.3.b.vi-vii Road tyre and brake wear*. In EMEP/EEA air pollutant emission inventory guidebook 2023. European Environment Agency. EMEP/EEA air pollutant emission inventory guidebook 2023 | European Environment Agency's home page

Pinasseau, A., Zerger, B., Roth, J., Canova, M., & Roudier, S. (2018). Best Available Techniques (BAT) reference document for waste treatment: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control) (EUR 29362 EN). Publications Office of the European Union. https://doi.org/10.2760/407967

UNECE (United Nations Economic Commission for Europe). (n.d.). Air pollution. United Nations. https://unece.org/environmental-policy-1/air

UNECE (United Nations Economic Commission for Europe). (1984). *The 1984 Geneva Protocol on Long-term Financing of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP)*. EMEP Protocol | UNECE

UNITAR (United Nations Institute for Training and Research). (2006). *Guidance Document for the Implementation of the European PRTR*. UNITAR PRTR Platform

U.S. Environmental Protection Agency. (n.d.). *AP 42, Fifth Edition, Volume I, Chapter 11: Mineral products industry*. AP 42, Fifth Edition, Volume I Chapter 11: Mineral Products Industry | US EPA

U.S. Environmental Protection Agency. (2022). *Fugitive dust control measures and best practices*. Fugitive Dust Control Measures and Best Practices

U.S. Environmental Protection Agency. (1980). *Miscellaneous sources – Explosives detonation*. In AP 42: Compilation of air pollutant emission factors (5th ed., Vol. I, Chapter 13).

Visschedijk, A. P. (2004). *Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP)'*. In Proceedings of the PM emission inventories scientific workshop (pp. 163-174). Lago Maggiore, Italy: Joint Research Centre (JRC).

WHO (World Health Organization). (2021). *WHO global air quality guidelines: Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide

WHO (World Health Organization). (2023, September 18). Air quality and health. https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/types-of-pollutants

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CIRCULAR ECOLOGICAL ESSENTIAL & CRITICAL RAW MATERIALS

Horizon Europe research and innovation programme (Nº 101058651)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement Nº 101058651).

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ISBN 978-84-122438-5-7