Mining for Climate

Euromines' Decarbonisation Roadmap and Energy Outlook

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Dear Reader,

The Clean Transition starts in the mine.

The European Union ambition to deliver the twin sustainable and green transition will inevitably lead to a growing demand of mined minerals and metals. Lithium, nickel, cobalt graphite, copper bauxite and rare earths and more commodities, as well as industrial minerals such as magnesite and potash are clear examples of what we need to build on clean technologies.

The EU mining industry provides these materials at the highest sustainability performance worldwide. At the same time, our industry is committed on its own decarbonisation pathway. For the first time, this study charts out the decarbonisation technology options and requirements, as well as changes in the policy framework conditions to ensure a competitive and climate neutral mining industry.

As this study demonstrates, we have come already a long way on this journey: wherever climate neutral technologies are available at competitive costs – they are deployed.

Yet this is not the end of the story: during the clean transition, we will see new technologies deployed – Carbon Capture and utilisation (CCU), increased share of recycling, magnetic separation, efficiency increases in electric motors and many more, and also substantive changes in the industry as a whole: In the short to medium term, demand for many metals and minerals will inevitably increase worldwide and Europe will need to secure access to those materials on its own soil across the whole value chain.

While demand for metals and minerals will increase, the clean energy transition reduces the amount of overall mining needed, compared to the status quo where most of mining is fossil fuels. This will be commensurate with a shift what materials we extract and where this mining will take place.

Europe is at the forefront how to manage this transition responsibly. Our materials demonstrate a continuous reduction in carbon footprint for a deep and encompassing decarbonisation, while ensuring access to essential, critical and strategic elements that are vital for the functioning of our society. To move to the next stage, this study shall outline the priority areas Europe needs to strengthen its energy and decarbonisation policy framework to create a sustainable business and investment case for responsible raw materials mined in Europe for Europe.

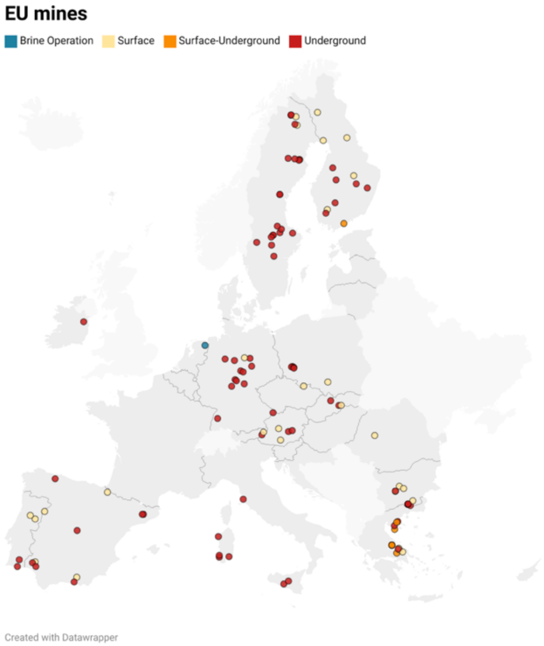
Rolf Kuby - Director General

Florian Anderhuber – Deputy Director General

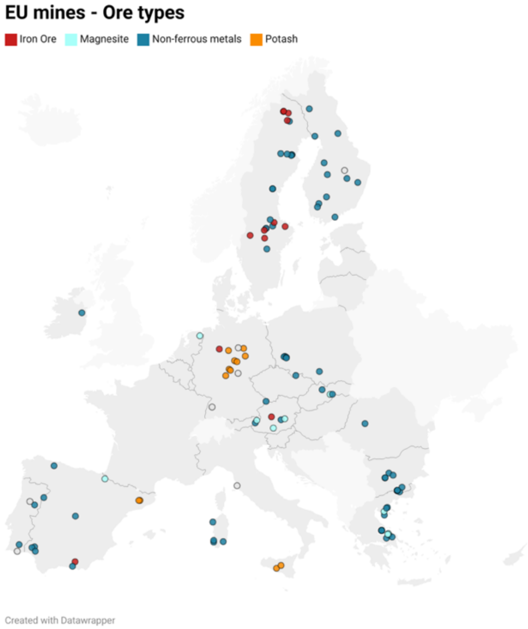
Executive Summary

EU mining profile

The mining industry in Europe is integral to the continent's economic framework and sustainability ambitions, providing essential raw materials for various sectors, including technology, energy, and manufacturing. European mining is characterized by a diverse portfolio of minerals and metals, with significant operations in non-ferrous metals, iron ore, magnesite, and potash. The EU's production landscape involves approximately 54 types of mined minerals and metals, and the industry is known for maintaining some of the lowest greenhouse gas emissions globally.



Annually, the EU mining sector consumes approximately 26 TWh of energy, with a substantial portion already electrified (almost 50% across various operations). Non-ferrous metals mining, for example, sees around 70% electrification in its processes. Despite these advancements, the sector continues to face the challenges of energy-intensive operations and the need for further decarbonisation to meet the EU's Green Deal objectives.



Towards a net 0 emissions EU mining industry

Achieving net zero emissions in the mining sector necessitates a comprehensive approach that integrates electrification, alternative energy sources, and innovative technologies.

Electrification of Mining Operations

Electrification is pivotal in reducing the carbon footprint of mining activities, particularly in material transport within mines. The shift from diesel to electric haul trucks can cut emissions significantly while enhancing operational efficiency. This transition requires substantial investments in new infrastructure—including charging stations and grid capacity—but promises long-term cost savings through reduced fuel and maintenance expenses. Electrifying transport also aligns with broader digitization and automation trends, which further enhance mine productivity and safety.

2021	Total energy use (GWh)	Electricity use (GWh)	Other energy use (GWh)	% electrified
Non-ferrous metals mining and concentration of ores (Copper, Zinc, Lead, Nickel, Gold and Silver)	11,206	7,845	3,362	70
Iron ore mining (incl. pelletisation)	4,753	2,709	2,044	57
Magnesite mining (incl. Magnesia production)	2,470	124	2,347	5
Potash (mining and salt production)	8,000	1,440	6,560	18
TOTAL	26,430	12,117	14,312	46

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Energy use and electrification rate of EU mining

Deployment of Alternative Fuels

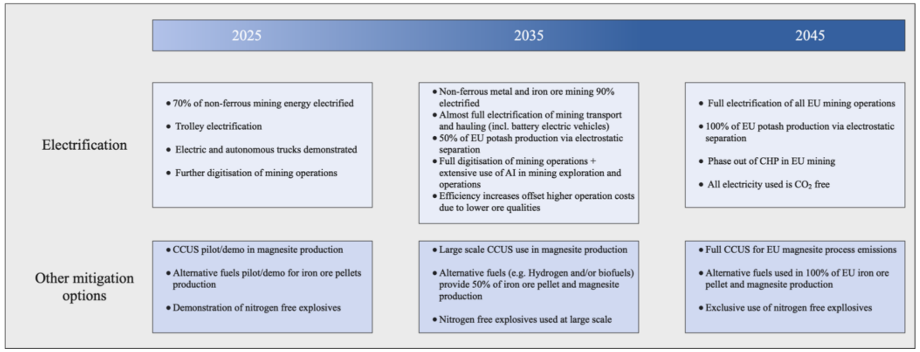
For processes that require high-temperature heat, such as those found in pelletizing iron ore and producing magnesia, alternative fuels like hydrogen and biofuels present viable solutions. Hydrogen offers a promising future when integrated into the steel production chain as a clean fuel source. Meanwhile, biofuels can serve as immediate replacements for coal and oil in existing infrastructures with minimal adjustments. The adoption of these fuels can help bridge the gap towards full electrification where direct electric solutions are not yet feasible.

Carbon Capture, Utilization, and Storage (CCUS)

CCUS technologies are crucial for mitigating emissions that cannot be eliminated through electrification or fuel substitution alone. In magnesia production, for instance, process emissions are unavoidable due to chemical transformations. Capturing and utilizing this CO_2 in products like construction materials can create new value streams while reducing environmental impact. However, deploying CCUS at scale requires significant investment in infrastructure and supportive regulatory frameworks to ensure economic viability.

Innovative Processing Techniques

The introduction of dry processing methods, such as electrostatic separation in potash mining, represents a transformative approach to reducing energy use and emissions. These techniques not only improve efficiency but also align with circular economy principles by minimizing waste generation and resource use.



	2025	2035	2045
Electrification	• 70% of non-ferrous mining energy electrified • Trolley electrification • Electric and autonomous trucks demonstrated • Further digitisation of mining operations	• Non-ferrous metal and iron ore mining 90% electrified • Almost full electrification of mining transport and hauling (incl. battery electric vehicles) • 50% of EU potash production via electrostatic separation • Full digitisation of mining operations + extensive use of AI in mining exploration and operations • Efficiency increases offset higher operation costs due to lower ore qualities	• Full electrification of all EU mining operations • 100% of EU potash production via electrostatic separation • Phase out of CHP in EU mining • All electricity used is CO_2 free
Other mitigation options	• CCUS pilot/demo in magnesite production • Alternative fuels pilot/demo for iron ore pellets production • Demonstration of nitrogen free explosives	• Large scale CCUS use in magnesite production • Alternative fuels (e.g. Hydrogen and/or biofuels) provide 50% of iron ore pellet and magnesite production • Nitrogen free explosives used at large scale	• Full CCUS for EU magnesite process emissions • Alternative fuels used in 100% of EU iron ore pellet and magnesite production • Exclusive use of nitrogen free expllosives

Transition pathways for EU mining industry

Additional investments to reach net zero emissions will be large for EU mining companies. The total capex is estimated to be 11.5-17.2 Bn EUR. Major part of that is mining electrification (9-14 Bn EUR). Investments to bring potash production to net 0 emissions will be around 1 Bn EUR. The magnesite climate transition will require around 1.5-2 Bn EUR additional CAPEX.

The impact on OPEX is mixed. Mining electrification, as stated before, will reduce overall energy use (at similar production levels and ore grade concentration). However, electricity prices will have to become more competitive to ensure the efficiency gains are translated into cost savings. For magnesite production, all scenarios point to higher operational expenditures (on top of high capex for carbon capture installations).

Considering the EU mining companies plans and transition pathways, it is possible for EU mines to reach climate neutrality (for their direct emissions) by 2040-2045. The next 10 years will see a gradual electrification of mining operations and demonstration of key climate friendly technologies in iron ore pellets, potash and magnesia production. In the period 2035-2045 this transition should be further completed with electrification of smaller mining operations and full implementation of other mitigation technologies.

Transition Challenges

The EU mining industry is facing significant challenges in its transition towards a low-carbon future, with ambitious goals to achieve net-zero emissions well before 2050. These challenges are multifaceted, involving economic, technological, and regulatory aspects that must be carefully navigated to ensure the industry's competitiveness while meeting climate goals.

Incomplete CBAM Coverage

The EU's Carbon Border Adjustment Mechanism (CBAM) aims to level the playing field by imposing carbon costs on imports. However, some sectors, like refractories, are not fully covered, potentially putting European producers at a competitive disadvantage due to import leakage.

Excessive Windfalls Inside EU ETS Indirect Costs

The EU mining industry is highly electro-intensive, and further electrification is essential to meet future climate targets. However, the current marginal pricing mechanism for electricity, which is often set by natural gas-based power production, creates disproportionate costs for consumers. This setup is unique to the EU and makes electricity more expensive, reducing the competitiveness of EU industries.

High and Unpredictable OPEX

The reduction of the ETS-cap combined with a 90% decarbonisation target by 2040 creates unpredictable operational expenses (OPEX) for the mining industry, hindering investment decisions for decarbonised technologies. This unpredictability leads to postponed capital expenditure (CAPEX) decisions, risking the achievement of the 2040 targets.

Uncertainty in Relation to Infrastructure for Carbon Capture, Utilization, and Storage (CCUS)

CCUS technologies are critical for reducing emissions in hard-to-abate sectors like mining. However, the lack of CO_2 transport, injection, and storage infrastructure, along with bans in some member states, hinders their development and implementation. Additionally, high operational costs require support mechanisms like carbon contracts for difference.

Availability of Alternative Fuels

The transition to biofuels and hydrogen faces challenges due to limited availability, high costs, and difficulties in accessing infrastructure, particularly for mining operations in remote areas.

Cost of Capital and Regulatory Uncertainty

Decarbonisation technologies require significant capital investment. High costs of capital, linked to regulatory uncertainty, prevent companies from making necessary investments. A stable and predictable policy framework is essential for long-term investment decisions.

No Lead Market for Sustainable Mining Products

The EU mining industry lacks a transparent lead market for sustainable products. Improving traceability of basic materials in final products would ensure sustainable mining practices are recognized and integrated into consumer products.

How to Make EU Mining Climate Transition Work for EU Mines?

To achieve the zero-carbon transformation of the Green Deal without jeopardizing competitiveness, this report proposes several solutions.

A CBAM Fit for Purpose

A comprehensive CBAM that covers the full supply chain, and all emissions incurred in a product—direct, indirect, and upstream—is necessary to mitigate carbon leakage.

Indirect CO_2 Cost Compensation

Mining should be included as an eligible sector for indirect CO_2 cost compensation. A new State Aid and Competition Framework should address network charges, indirect CO_2 costs, and exemptions from surcharges to subsidize electrification plans.

Decouple Fossil Fuel-Based Production from Renewable Energy Costs

The electricity market should decouple fossil-free and fossil-based generation in price-setting to reflect the cost competitiveness of low-carbon energy sources. This would incentivize further electrification and reduce electricity prices.

A Coherent Industrial Carbon Management Strategy

Development of lead markets for CCU-goods, consideration of geochemical storage in tailings, and carbon accounting for captured carbon are necessary. This approach should include the allocation of CO_2-certificates for captured carbon and consider removals with permanent storage under the ETS.

Facilitate the Underlying Business Case for EU Mines

Speeding up planning, tendering, and permitting processes is crucial for getting the necessary energy to where it is needed. Administrative facilitation and expedited deadlines can support this process.

Create the Business Case for Net Zero EU Mining

Public and private funding, social and industrial policies, and financial and legislative instruments must work together to find customers for climate-friendly raw materials. Public procurement should send a clear signal to the market, and support to private finance through mechanisms like EIB-backed guarantees is essential.

Use the Clean Industrial Deal and Industrial Decarbonisation Accelerator Act

Addressing bottlenecks that prevent a business case and investments in innovation to transform processes, improve industrial output, and enhance resilience to global supply shocks is necessary. Coupling the EU Green Deal with an Industrial Deal will empower the industry to make necessary investments to decarbonise while boosting competitiveness.

The European mining industry stands at the forefront of global sustainability efforts by leveraging advanced technologies and setting high environmental standards. Through strategic electrification, adoption of alternative fuels, and implementation of CCUS technologies, the sector can achieve net zero emissions while maintaining its competitive edge. However, realizing this vision requires collaborative efforts between industry leaders and policymakers to address infrastructure needs, refine regulatory frameworks, and stimulate market demand for sustainable products. By doing so, Europe can secure its strategic autonomy in critical raw materials while contributing significantly to global decarbonisation goals.

1. Priorities and call for action

1.1. Why European mining matters

This roadmap, developed by Euromines, aims to outline how the sector will navigate this transition, identifying bottlenecks and proposing new regulatory tools and incentives. It emphasizes the need for a regulatory framework that goes beyond simply increasing the cost of pollution, instead focusing on incentivizing better technologies and expediting their implementation through streamlined permitting processes.

The sustainability transition facing Europe over the coming decades presents a significant dichotomy. On one hand, it demands an increased supply of raw materials, necessitating expanded mining operations. On the other, the mining industry itself must undergo decarbonisation, which paradoxically requires material-intensive, fossil-free energy technologies. This challenge is compounded by the nature of the mining industry as a price-taker and baseload consumer, unable to pass on rising energy costs to consumers due to globally set prices. Consequently, increasing energy prices directly impact the industry's global competitiveness.

Europe's current primary energy consumption stands at 17,395 TWh, with only a third being fossil-free. The transition to clean energy technologies is driving unprecedented demand for critical minerals. By 2030, this demand could quadruple, with some minerals like lithium potentially seeing a tenfold increase by 2050. To meet these needs sustainably and maintain strategic autonomy, Europe must significantly expand its domestic mining operations and associated value chains.

European mining is poised to enable this transition, offering a value proposition that extends beyond mere resource extraction. By setting global standards for sustainable mining practices and employing cutting-edge technologies, the EU mining sector can produce raw materials with the lowest CO_2 footprint worldwide. This approach not only minimizes environmental impact but also creates new jobs, increases revenues, and fosters technological innovation.

However, realizing this potential requires overcoming substantial challenges. The industry needs access to abundant fossil-free electricity, supported by robust transmission infrastructure and a streamlined permitting framework. Managing the increased intermittency of renewable energy sources will be crucial to ensure a cost-competitive transition and thorough decarbonisation of clean technologies dependent on these raw materials.

The EU mining industry's commitment to complete decarbonisation by 2050 positions it at the forefront of global sustainability efforts. By increasing domestic mining activities and exporting EU technologies worldwide, the industry can significantly reduce the scope-3 emissions associated with raw materials and contribute to global sustainability goals.

The transition to a fossil-free mining industry presents a unique opportunity to create jobs, set global standards, and ensure long-term prosperity. However, realizing this vision requires a tailored regulatory approach that balances conflicting policy objectives, sets clear priorities, and provides a mix of regulatory, market-based, and state-driven incentives. By addressing these challenges head-on, Europe can maintain its position as a leader in innovative and sustainable mining practices, securing its strategic autonomy while contributing to global decarbonisation efforts.

This roadmap sets out how to reconcile the huge raw materials needs with the ambition to increase our strategic autonomy and the regulatory framework decisions and focus-points that lie ahead of us and need to be addressed to booster a sustainable and prosperous European mining industry in Europe.

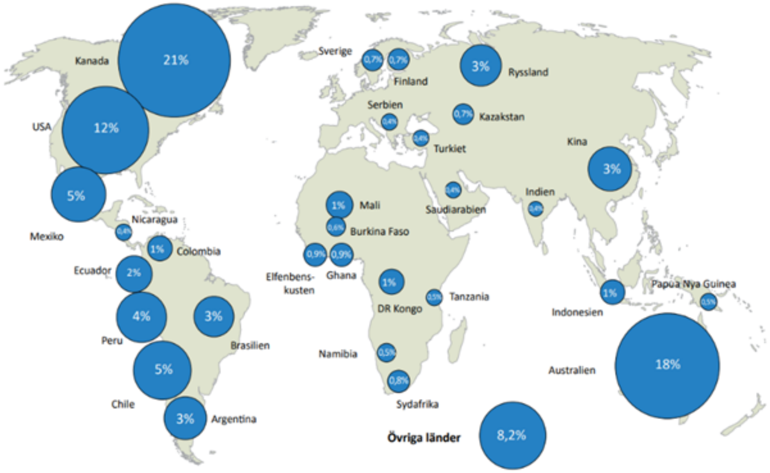


Figure 1: Relative share of global investments into mining exploration (SGU, 2022)

1.2. A call for action

The transition towards a clean, digital, and efficient society is fundamentally a commodity transition. As we shift from fossil fuels to renewable energy sources, we are effectively replacing oil, coal, and gas with copper, lithium, and nickel. The drive for efficiency through automation and digitalization, often perceived as dematerialization, is a hidden re-materialisation process, underpinned by mined minerals and metals.

A sustainable society is impossible without a sustainable mining industry. Focusing solely on deploying clean technologies without addressing the underlying raw materials base risks a climate transition "Made in China." Europe, however, boasts a robust and innovative mining industry that provides high-quality jobs and produces reliable, sustainable raw materials while upholding human, social, and labour rights. This industry forms the bedrock of a thriving, climate-neutral European economy.

The European mining sector is already making significant strides in its sustainability journey. Electrification is progressing rapidly, with some mines achieving 100% electrification. Moreover, the entire sector has committed to achieving climate neutrality between 2045 and 2050. This commitment aligns with the ongoing system integration, automation, and digitalization of the industry, all of which contribute to decarbonisation efforts. A decarbonised EU mining industry has the potential to be highly competitive while ensuring the supply of vital materials for our economy.

However, within the current legislative framework, technology availability, and cost structure, new solutions are necessary to achieve zero-carbon transformation without compromising competitiveness. This roadmap outlines essential measures to foster a competitive mining industry that can provide the material foundation for sustainable value chains.

The current system of internalizing CO_2 as an input cost and markup for electricity has reached its limits in promoting better technologies. With the 2040 Climate Target of 90% reduction effectively mandating full industrial decarbonisation, including the capture of all process emissions, a regulatory change is imperative. This change must lead to shifts in consumer behaviour and societal recognition of necessary trade-offs. Without such changes, the mining industry faces significant challenges such as high increases of capital and operational expenditures on the short term due to high electricity prices and major investment in high-cost technologies such as carbon capture.

To address these challenges, the industry calls for action in four key areas:

- *Energy and carbon efficiency*: New research and support for changes in raw materials and inputs, such as CO_2-free explosives.
- *Direct electrification*: Access to competitively priced fossil-free electricity, requiring compensation for indirect CO_2 costs in electricity prices until market design is reformed.
- *Indirect electrification and alternative fuels*: A more equitable distribution of funding and project opportunities to recognize the sector's ambition and ability in fuel blending processes.
- *Carbon Capture and Utilisation and/or Storage* (CCUS): Development of a robust framework with corresponding infrastructure, including commercialization that compensates operators for sequestered and stored/bound emissions.

Without improvements in these areas, the energy-intensive mining industry will struggle to invest in the technologies and infrastructure necessary for climate neutrality. Current mounting operating costs are already hampering the competitiveness of clean production by impeding investments in crucial areas such as fossil-free energy rollout, phasing out fossil fuels, electrifying vehicles and machinery, developing new processes like CCS and hydrogen production, and improving efficiency.

The main challenge lies in controlling costs. The industry's strong reliance on electricity exposes it to price volatility and high price levels in the electricity market. While increasing pollution costs has driven decarbonisation efforts, the potential for further CO_2 reduction through cost-driven efficiency measures is largely exhausted. Paradoxically, this cost-increase strategy has made electricity—the primary commodity for decarbonisation—more expensive, leading to reduced competitiveness rather than better technologies.

This situation creates a vicious cycle: high and unpredictable energy costs make it impossible to model reliable OPEX development, leading to more expensive investment capital and, ultimately, a lack of investment in achieving a decarbonised and competitive mining industry.

This roadmap aims to address these challenges by proposing measures to incentivize investments in fossil-free mining operations and research and development. By doing so, it seeks to ensure that Europe's mining industry can continue to play its crucial role in the sustainability transition while maintaining its global competitiveness and setting standards for responsible, climate-neutral mining practices worldwide.

2. European mining at a glance

Euromines represents a diverse portfolio of 54 land-based mined minerals and metals, ranging from bulk commodities like iron ore and copper to specialized materials such as potash fertilizers, everyday products like salt, and critical elements of the sustainability transition such as magnesite, cobalt, lithium, and precious metals including gold and platinum-group metals.

The European mining landscape is characterized by various operational setups and technologies, each tailored to specific geological and economic conditions. These include open-pit mining, conventional underground mining (utilizing drilling, blasting, and cutting techniques) and solution mining of underground deposits.

The choice of mining method is determined by several environmental and deposit-specific factors such as the depth of the deposit (surface outcrop, near-surface shallow, or deep), the rock and ore strength and the geometry of the deposit. These factors combine to make each mine unique, much like a fingerprint, and consequently influence their decarbonisation needs and strategies. Additionally, economic criteria play a crucial role in shaping mining operations. These are the initial investment cost (CAPEX) to start mining operations, the ongoing excavation and ore benefaction costs (e.g. labour, energy, services, materials) i.e. the operational expenditure and the cashflow and revenue of mining operations.

As a rule of thumb, the deeper the deposit the less economically interesting it is to use surface or open pit mining. The ore grade has a major impact on energy use for mining and ore concentration.

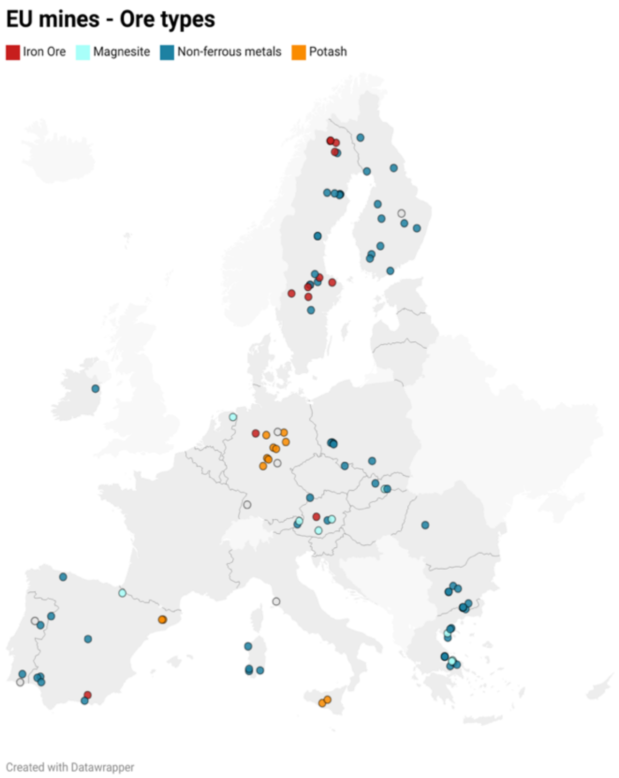


Figure 2: Location of EU non-ferrous metals, iron ore, potash and magnesite mines. (source: EGDI and desk research)

Lower grade ores require (much) more energy to be mined and concentrated. Over time deposits ore grade will decline (assuming the higher-grade ores are extracted first) and hence the specific and over-all energy use of mining will increase if not off-set by higher levels of efficiency in mining operations.

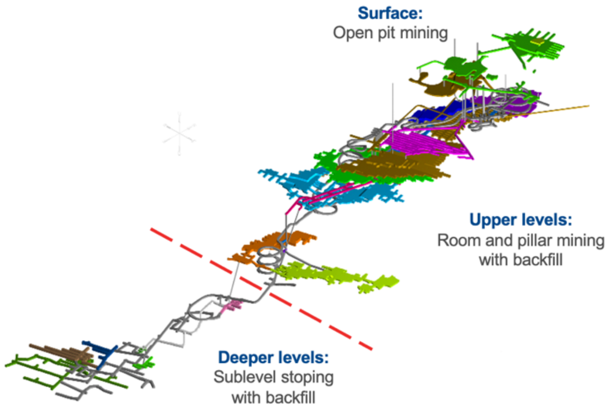


Figure 3: Cross section of EU magnesite mine (source: RHIM)

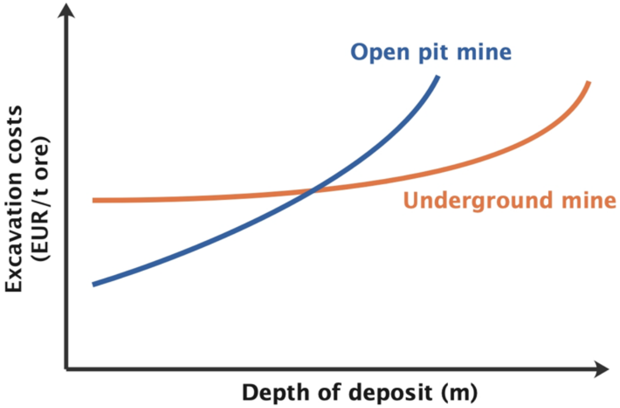


Figure 4: Energy use in open pit and underground mining versus the depth of deposits (Source: Moser et al., 2019),

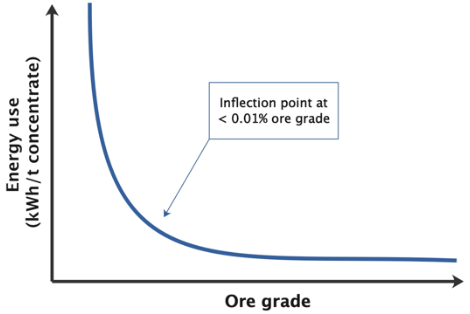


Figure 5: Energy use in mining in relation to ore grade (Source: Koppelaar et al., 2016)

As deposits evolve, mining setups adapt, leading to changes in cost structures. For instance, an open-pit mine may transition to an underground operation as depth increases, resulting in longer excavation paths and higher energy consumption and input costs.

Revenue in the mining industry is primarily determined by raw material prices, either set by global exchanges like the London Metals Exchange for commodities such as copper or through over-the-counter trading and direct negotiations for most other materials. Sustaining a mine over time typically requires either increased output or higher ore grades.

Even though sustainability measures often increase costs without generating market premiums, European mining operations maintain the lowest greenhouse gas (GHG) impact globally. This achievement is influenced by several factors:

- Processing efficiency: Optimized logistics and efficient machinery reduce fuel consumption and energy use.
- Fossil-free energy availability: The CO_2 footprint of electricity varies significantly across regions, impacting overall emissions.

- Process emissions: Some materials, like magnesite, release CO_2 during thermal decomposition, accounting for up to 50% of emissions regardless of fuel type.
- Climate-efficient raw materials: Geological conditions can affect emission levels, as seen in the energy consumption differences between magnetite and hematite iron ores.
- Share of recycling: Incorporating recycled materials can significantly reduce GHG emissions, especially in process-emission intensive sectors like magnesite production.

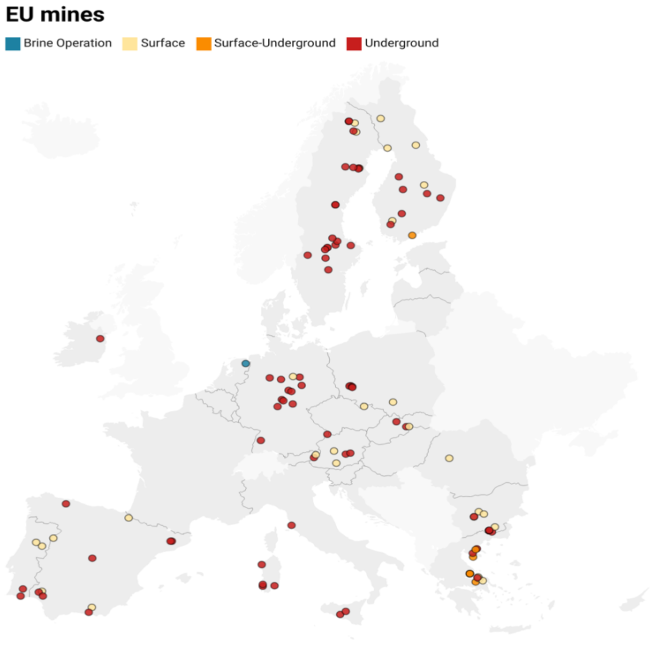


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Figure 6: Location of EU (non-ferrous metals, iron ore, potash and magnesite mines) and type of mining operation (source: EGDI and desk research)

The greenhouse gas footprint of mining operations varies widely due to these factors, some of which are beyond the control of individual mines. However, the European mining industry continues to lead in sustainability efforts, balancing economic viability with environmental responsibility.

This commitment to sustainable practices, coupled with the industry's diverse portfolio and adaptability, positions European mining as a critical player in the global transition to a low-carbon economy. By continuing to innovate and improve efficiency across all aspects of operations, from extraction to processing and recycling, the European mining sector is setting new standards for responsible resource management and environmental stewardship.

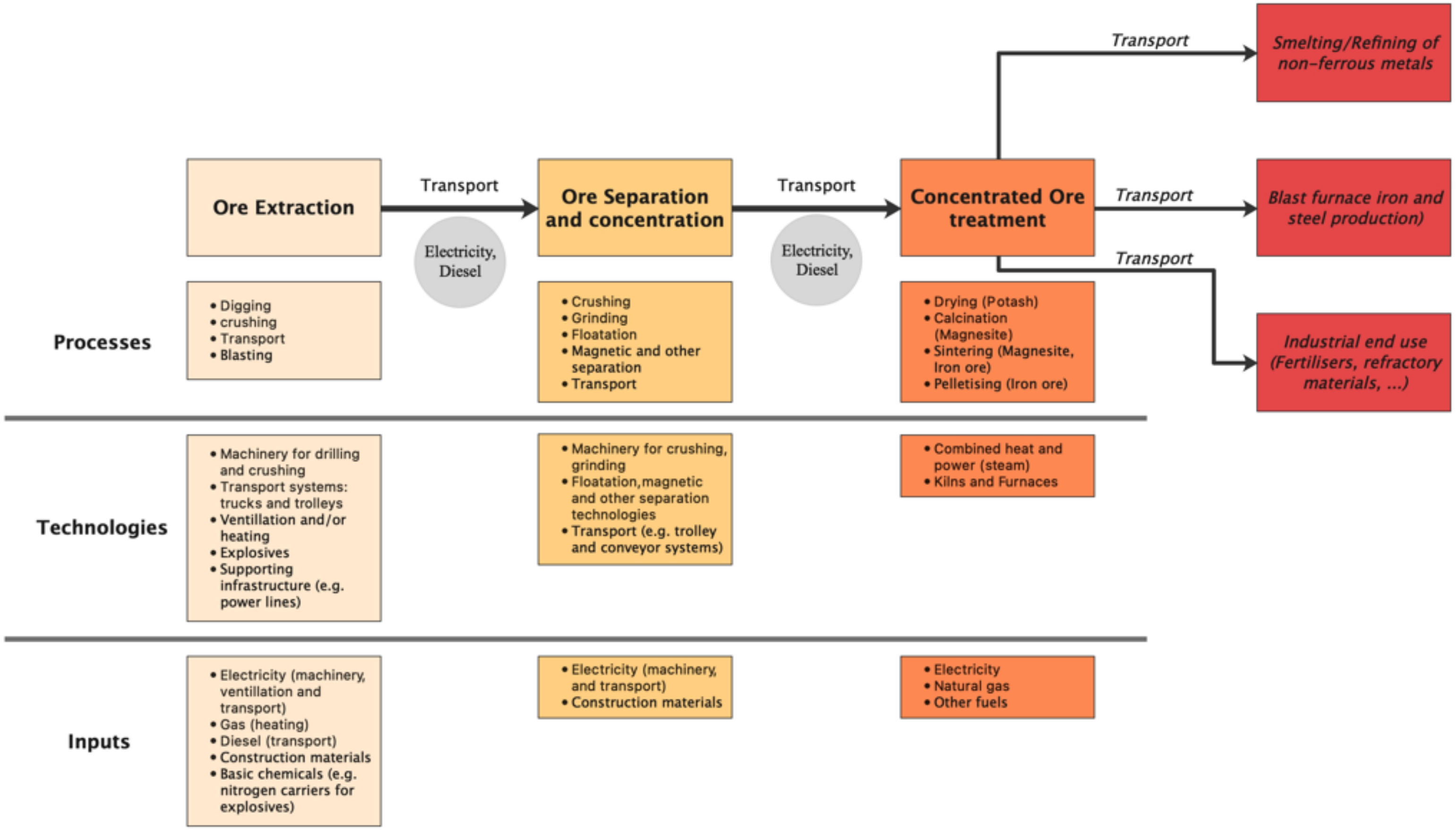

Figure 7: Mining processes from extraction to final basic materials.

NON-FERROUS METALS

3. Non-ferrous metals

3.1. Non-ferrous metals, the unsung heroes of the modern world

Non-ferrous metals are the unsung heroes of our modern world, powering everything from smartphones to renewable energy technologies. These metals, including copper, aluminium, zinc, and precious metals like gold and silver, are essential components in countless products we use daily. Their unique properties, such as corrosion resistance and electrical conductivity, make them irreplaceable in various applications, from home wiring to medical equipment. In a transition towards a more sustainable future, the importance of non-ferrous metals mining is further amplified, providing the raw materials necessary for technological advancements and clean technologies.

The European Union's Green Deal's ambitious target of carbon neutrality by 2050 hinges on industrial leadership in producing and deploying clean technologies. However, this transition faces significant challenges due to the global supply chain dynamics of critical raw materials.

China's dominance in the production and processing of these materials poses a considerable risk to Europe's economic and technological development. For instance, China accounts for more than half of the world's production of processed minerals and metals, including 90% of rare earth elements, which are crucial for many green technologies.

Future EU demand for non-ferrous metals is expected to grow, mainly driven by the transition to a net zero emissions economy. EU Demand for aluminium can increase by 4.5 Mt to 20 Mt in 2050. Demand for copper will be around 6 Mt in 2050 (+ 1Mt compared to today). For zinc and demand increase of 300Kt is expected by 2050 and for Nickel this demand increase is expected to be 450 Kt.[1]

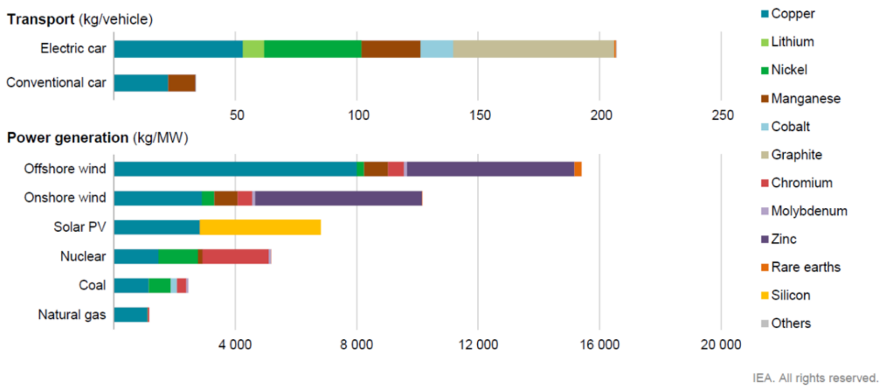

Figure 8: Non-ferrous metal use in energy technologies (source: IEA)

The EU currently extracts around 170 Mt crude non-ferrous metal ores (2021).[2] The majority of which are copper containing ores, but almost all ores contain next to copper (or other major metals) other important non-ferrous metals such as zinc, lead, nickel and precious metals.

The copper content of the mined ores in the EU is around 0.8 Mt. Zinc 0.7 Mt. Nickel 0.05 Mt and lead 0.165 Mt. [3]

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[1] Gregoir, et al. 2022

[2] Calculated amount of ore extracted. See Annex I (methodology) for more information.

[3] European Commission, Joint Research Centre, n.d.

Non-ferrous metals are mined across the EU with main mining operations happening in Poland, Finland, Sweden, Spain, Bulgaria, Portugal, Ireland, Greece and Romania:[4]

- Poland (49% of EU mined copper)
- Finland (87% of EU mined nickel, 8% of EU mined zinc, 4% of EU mined copper)
- Sweden (39% of EU mined lead, 32% of EU mined Zinc and 11% of EU mined copper)
- Spain (17% of EU mined copper, 12% of EU mined Zinc, 6% of EU mined lead)
- Bulgaria (13% of EU mined copper, 13% of EU mined lead and 2.5% of EU mined Zinc)
- Portugal (26% of EU mined zinc, 18% of EU mined lead and 5% of EU mined copper)
- Ireland (15% of EU mined zinc and 8% of EU mined lead)
- Greece almost all EU (excl. overseas terr.) mined bauxite, 11% of EU mined nickel, 10% of EU mined lead and 3% of EU mined zinc)
- Romania (1.2% of EU mined copper)

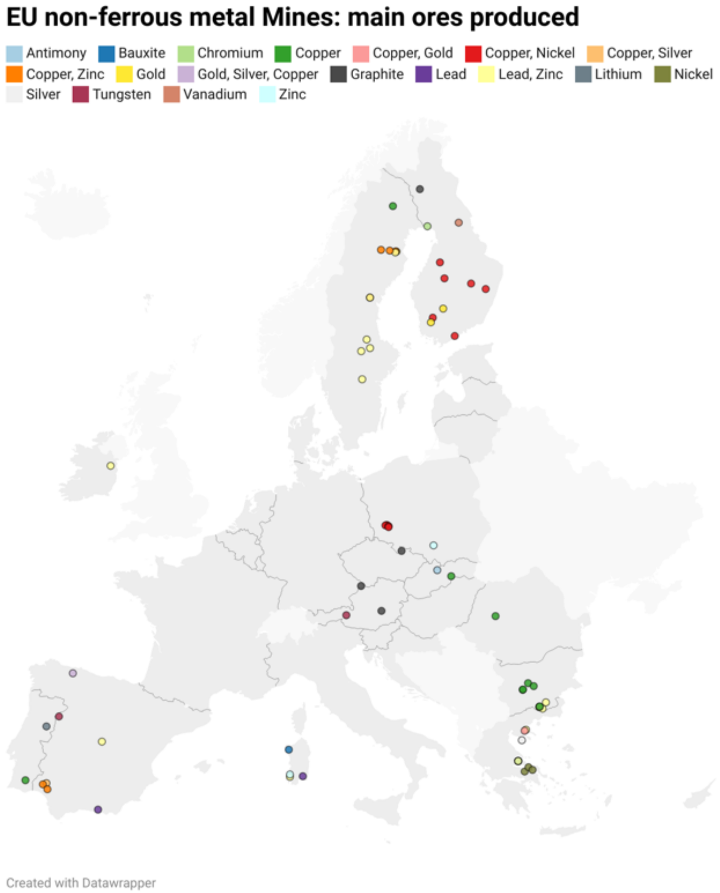

Figure 9: EU mines and (main) ore types. (Source: EGDI and desk research)

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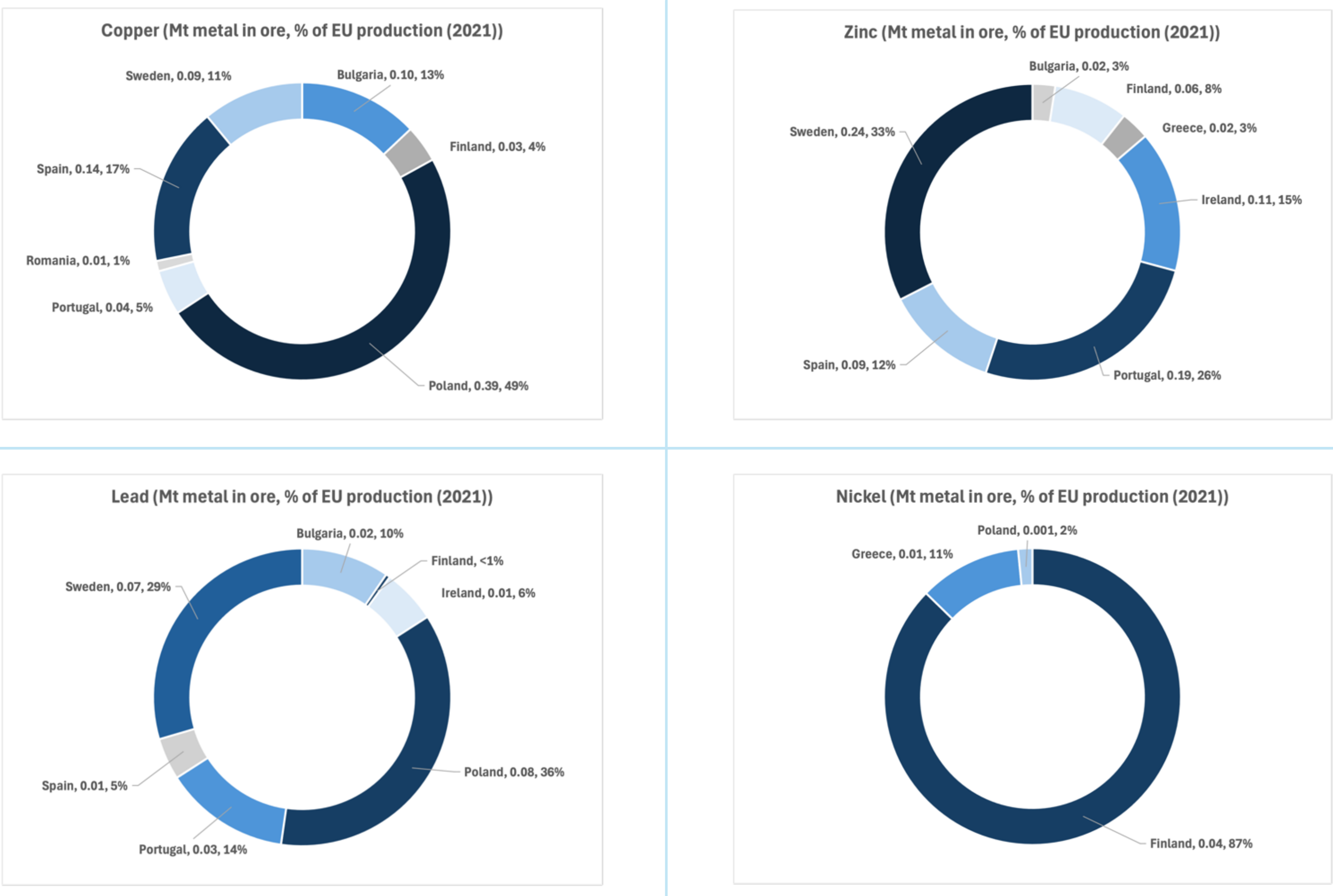
[4] Id.

Figure 10: Copper, Zinc, Nickel and Lead mining in the EU, shares and production. Source: European Commission, Joint Research Centre, n.d.



Boliden group

*With 100 years of operations, Boliden group is one of the world's leading **zinc** producers and leader in Europe in producing **copper** and **nickel**, metals **essential for the transition to a fossil-free society.** Nickel and copper, in fact, are essential for electrification and renewable electricy generation, zinc, instead, is predominately used to galvanise steel structures, which can be protect against corrosion for up to 100 years.*

Explosives play a crucial role in modern mining operations, serving as the primary means of breaking rock and accessing mineral deposits. Their efficiency and environmental impact are of paramount importance, affecting both the productivity and sustainability of mining activities. Boliden has recently entered into an agreement with Hypex Bio for the production and delivery of an innovative, environmentally friendly explosive for use in mining operations. This nitrate-free explosive significantly reduces the need for nitrogen treatment of water and improves climate performance by reducing CO_2 *emissions by approximately 400 tonnes per year. The agreement includes the establishment of a production facility at the Kankberg mine and a five-year supply and service contract starting in 2024. This development represents a significant step towards fossil-free mining operations, complementing other initiatives such as the electrification of transport and machinery.*

At the same time the journey towards fossil-free operations is accelerating. During 2025 Boliden will start the operation in Rävliden mine, a satellite mine to Kristineberg mine. The whole concept of the underground mine is a fossil-free operation, with vehicle fleet almost fully running on batteries and electricity. This mine will prove an 80 % reduction of the operational emissions, which proves that fossil-free mining is within reach.

3.2. Mining processes and energy use

Non-ferrous metals mining includes activities like drilling, blasting, digging, ventilation, and dewatering. For example, in open-pit mining, large haul trucks transport mined ore to the processing plant, while underground mining uses specialized equipment and techniques for ore extraction and transportation. Surface mining is generally more energy-efficient than underground mining, which has higher energy requirements for activities like hauling, ventilation, and water pumping. After extraction, the ore undergoes beneficiation and processing to separate the valuable minerals from the waste rock. This phase typically involves crushing, grinding, and various separation techniques like gravity separation, flotation, and magnetic separation.

The specific energy use in non-ferrous metals mining depends on various factors including the type of mine (under- or above ground), the type of ore (incl. hardness), the metal concentration in the crude ore and advantages of large-scale operational efficiencies. On average around 77 kWh of energy is used to process (mine and concentrate) one tonne of crude ore. But this can be more than 150 kWh/t or as low as 25 kWh/t.[5] Higher specific energy can indicate long distances between mines and concentrators for processing the ore. Lower specific energy can indicate a drive towards high efficiency due to low metal concentration in the ores[6].

The energy use per tonne of concentrated (copper) ore produced also depend highly on the initial copper concentration in the mined ores before processing. Here the variation in energy use is even more outspoken with mines that have ore concentrations of close to 2% having an energy use close to 1.5 MWh/t concentrated ore. Mines with low initial ore concentration can see 4-5 times as much energy use to reach concentrations of around 20-25%. On average, to mine and concentrate the equivalent of 1 tonne copper around 11 MWh is needed in the EU. [7]

In total EU non-ferrous metal mining[8] uses approximately 11.2 TWh energy per year.[9] Mining of copper containing ores make up around 80% of the total energy use[10]. Around 70% of the total energy use is electricity for drilling, ventilation, transport, dewatering and comminution (i.e. crushing, grinding and concentration of ores). Most of the electricity use is linked to the use of (electric) motors. Diesel represents around 20% of the energy use and is almost exclusively used for transport (hauling) of mining materials. Finally, for underground mining, heating is required, representing 10% of total energy use.[11]

Almost all EU metal mines receive their electricity via the national and regional power grids. Some producers have invested in their own power generation (e.g. CHP) to supply the mining operations with power (and heat)[12].

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[5] See annex I for more information

[6] SGU, 2023

[7] Calculated using the specific energy use per tonne crude ore (see Annex I) and ore concentration.

[8] Total for copper, zinc, nickel, lead, gold and silver mining

[9] See Annex I

[10] These are all ores with copper content next to other non-ferrous metals present. Copper is not necessarily the main metal present in the ores.

[11] Estimates using data from SGU, 2023, SGU 2022 and TSM Finland, 2024.

[12] For instance in copper mining in Poland by KGHM https://www.etpsmr.org/wp-content/uploads/2020/11/W1-KGHM-Just-Transition_Radoslaw-Zydok_16112020.pdf

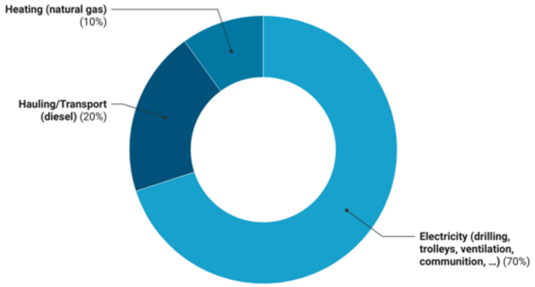

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Figure 11: Non-ferrous metal mining shares of energy use

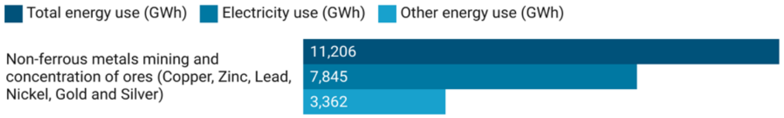

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Figure 12: Average specific energy use in non-ferrous metals mining in the EU (kWh/t processed crude ore, kWh/t produced concentrates and kWh/t metal in ore)

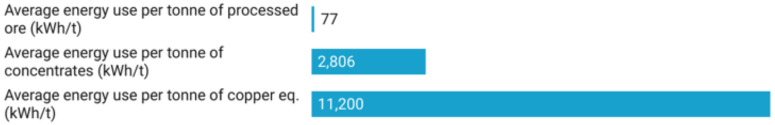

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Figure 13: Total energy use of EU non-ferrous metal ore production GWh (2021 est.) and estimated use of electricity and other energy carriers

3.3. Pathway to net zero emissions

For non-ferrous metals mining the pathway to net zero emissions goes via full electrification. Because most parts of mining and processing of ores is already electrified (i.e. around 70% of total energy use), the focus to achieve full electrification will be on transforming hauling (transport) and heating operations. It must be stressed that electrification cannot be seen as standing on its own, for modern mining operations it is an important part of enhanced digitisation and automation.

Mining electrification has advantages beyond reducing the direct emissions of greenhouse gases on site.

Electrification can eliminate the use of diesel fuel, which is a major source of air pollution in mining operations. This leads to improved air quality both within the mine and in surrounding communities. For underground mines, the elimination of diesel particulate matter can significantly improve worker health and safety. This, in turn, reduces the need for extensive ventilation, further contributing to energy savings.

Electrification can also enhance the overall efficiency of mining operations. Electric motors tend to be more efficient than diesel engines. One important factor is the hauling speed which can be increased via electric (and autonomous) trolley or other vehicles. Additionally, electric vehicles require less maintenance and have lower operating costs than their diesel counterparts.[13] There are other efficiency benefits coming from hauling electrification. Due to the lower use of diesel engines inside mines, the ventilation needs and costs will be reduced (e.g. around 20% less ventilation demand).[14]

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[13] Boliden, 2021

[14] ABB, Perenti and IGO, 2024

Metals Mining and Concentration Of Ores	Current electrified processes	Hauling/Transport	Heating of underground mines (low T heat)
Mitigation Actions	**Increase efficiency (e.g. replacement of electric motors by more efficient motors)**	**Electrification of transport (efficiency gains)**	**- Use of large-scale heat-pumps (1-5 MW capacity)** **- Improved heat recovery of other processes**
CAPEX Impact	Limited if replacement at end-of-life of existing motors or for new investments	- Higher capex vs diesel-based hauling (price gap expected to become smaller over time) - Additional infrastructure required (batteries/cables/charging/...) and grid infrastructure needs to have sufficient capacity - Estimated investment of 7.5-11 Bn EUR to electrify transport in all EU non-ferrous mines[15]	- High capex for heat-pumps - New technology still under development (esp. for MW size industrial heat pumps)
OPEX Impact	Positive – due to energy savings	Positive due to higher efficiency of electrified hauling. Specific impact depends on power prices.	Energy use compared to natural gas can be factor 3 lower (climate dependent). Power prices must be less than 3 times gas price to be OPEX neutral.

Table 1: Non-ferrous metal mining mitigation options and impact on capex and opex.

If further exploitation results in mining lower ore grades and hence higher amounts of crude ore to treat, efficiency and hence electrification will be crucial for the future competitiveness of EU mining.

Electrification can also enable mines to better integrate with electricity grids and utilize energy storage systems. This allows mines to take advantage of grid flexibility, potentially selling excess renewable energy back to the grid or participating in demand response programs.

However, electrification comes with important challenges and risks.

First, the high Initial investment costs are seen as a major barrier. This includes the cost of new electric equipment, charging infrastructure, and potential upgrades to the mine's power infrastructure. These costs will have to be recovered via increased margins due to better operational efficiencies.

Integrating renewable energy systems into existing mining operations can be technically complex. This complexity arises from the need to manage the variability of renewable energy sources, ensure grid stability, and address potential land constraints for renewable energy installations. Some mines may only find it economically feasible to electrify a portion of their operations initially.

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[15] This estimate is an extrapolation of current investments (e.g. Boliden, 2021) in electrification of mining transport in the EU. It includes the electrification of transport and supporting on-site infrastructure (e.g. charging and power transformation). It does not include upstream investment in clean power generation and grid (reinforcement) investments. The investment figure assumes similar mining production in the future, hence with increased mining operations the CAPEX in electrification of transport could be higher.

The use of innovative electrification technologies can be delayed by strict EU standards which cannot immediately be applied to new and experimental technologies.[16]

Land constraints and permitting issues can pose challenges for the installation of renewable energy infrastructure. This is particularly relevant for mines located in areas with limited land availability or complex regulatory environments.

Finally, higher levels of electrification increase the risk for exposure to high electricity prices (for instance via high CO_2 prices passed through in electricity price). This can wipe out the cost reductions via efficiency gains through electrification and hence stall the climate transition of non-ferrous metals mining.

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[16] For instance, the use of harmonized (CE) standards under the EU machines directive

IRON ORE

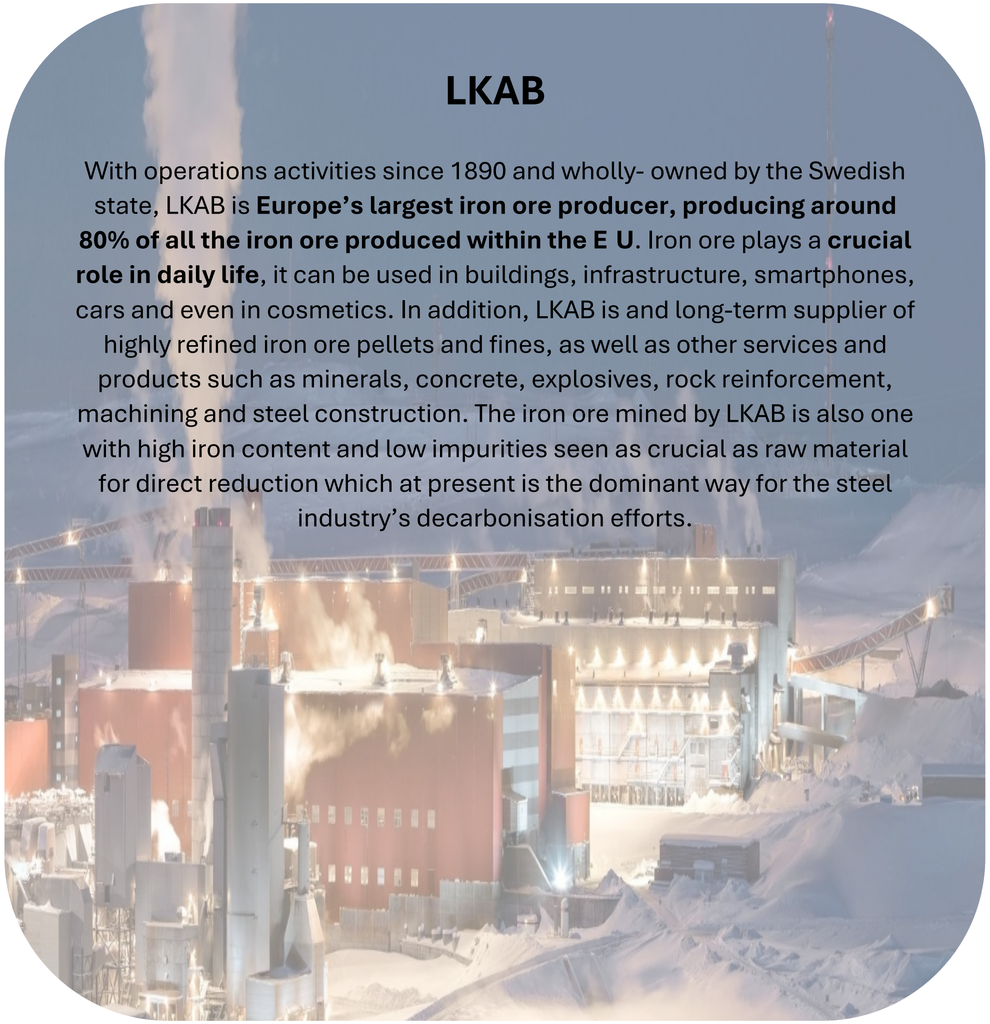
4. Iron ore mining and pellet production

4.1. Building blocks of a modern economy

Iron ore is the basic material for steel production. Even in the 21st century steel is one of the crucial building blocks of a modern economy. It is used in essential parts of the economy from construction to automotive and the basic infrastructure and machines in other parts of the economy.

Steel plays a crucial role in helping the global economy reach net zero emissions. As a versatile and recyclable material, steel is essential for building the infrastructure needed for a low-carbon future. It's a key component in renewable energy technologies such as wind turbines and solar panel frameworks. Moreover, high-strength steels contribute to lightweighting in the transportation sector, improving fuel efficiency and reducing emissions in vehicles, ships, and aircraft. In the construction industry, steel's durability and recyclability make it an ideal material for creating energy-efficient buildings and sustainable urban infrastructure, which are critical for reducing long-term energy consumption and emissions. Steel can be recycled infinitely, making it a perfect fit for a circular economy model.

While most iron ore for steel production in the EU is imported, the EU still sources around 20% of the iron ore needed for steelmaking from within its borders (mostly Sweden).[17] The EU's production of iron ore represents around 2% of global production. Main iron ore producers are Australia (36%), Brazil (17%), China (12%) and India (8%).[18]



LKAB

With operations activities since 1890 and wholly- owned by the Swedish state, LKAB is **Europe's largest iron ore producer, producing around 80% of all the iron ore produced within the E U**. Iron ore plays a **crucial role in daily life**, it can be used in buildings, infrastructure, smartphones, cars and even in cosmetics. In addition, LKAB is and long-term supplier of highly refined iron ore pellets and fines, as well as other services and products such as minerals, concrete, explosives, rock reinforcement, machining and steel construction. The iron ore mined by LKAB is also one with high iron content and low impurities seen as crucial as raw material for direct reduction which at present is the dominant way for the steel industry's decarbonisation efforts.

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[17] European Commission, Joint Research Centre, n.d.

[18] Id.

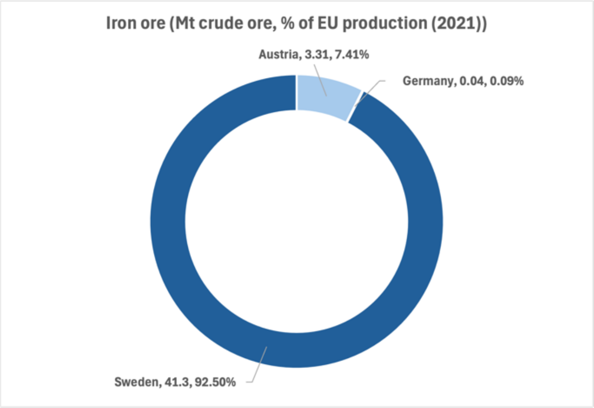

Figure 14: EU crude ore production (2021, source: European Commission, Joint Research Centre)

4.2. Iron or mining production process and energy use

Iron ore mining involves a series of steps to extract the ore from the earth and process it into a usable form for steelmaking. The process begins with extraction, which can be conducted through either open-pit or underground mining methods. Open-pit mining is more commonly employed for large, shallow deposits, while underground mining becomes necessary for deeper deposits. The choice between these methods depends on factors such as the depth of the deposit, its size, and the surrounding geology. The extracted ore is transported from the mining site to the processing plant using various methods such as trucks, conveyors, or rail systems. The selection of the haulage method is influenced by factors including the distance between the mine and the processing plant, the terrain, and the scale of the operation.

The beneficiation of iron ore begins with crushing and grinding the ore to liberate the iron minerals. This is followed by various separation techniques. Magnetic separation is commonly used to separate magnetite, a magnetic iron oxide, from other minerals. Flotation is another technique employed to separate minerals based on their surface properties, while gravity separation is used to separate minerals based on their density differences.

Iron ore pellets are created by processing the concentrated iron ore into small, uniform balls. These pellets offer several advantages over other forms of iron ore, including improved handling, transportation, and performance in the blast furnace. The pellet production process begins with slurry preparation, where the concentrated iron ore is mixed with water and additives such as bentonite, limestone, and olivine to form a slurry.

The slurry then undergoes a balling process, where it is rolled into balls, known as pellets, in a balling drum. These green pellets are then subjected to a drying and preheating stage on a traveling grate, utilizing hot air from the cooler. The next crucial step is firing, also known as induration. In this stage, the pellets are heated to high temperatures, typically between 1200-1300°C. This process serves to harden the pellets and oxidize magnetite to hematite. It's important to note that the kiln is typically heated by coal or oil, which are significant sources of CO_2 emissions. The energy needs depend on the type of iron ore being processed. Magnetite ores, for instance, require less energy for pellet production due to the exothermic oxidation of magnetite to hematite, resulting in lower CO_2 emissions compared to hematite ores.

Finally, the hot pellets are cooled in an annular cooler, and the hot air from this cooling process is efficiently reused for drying and preheating in earlier stages of the process.

EU iron ore production uses approximately 4.7 TWh energy per year.[19] This includes the energy for mining around 45 Mt iron ore and the production of 21 Mt pellets. The overwhelming majority of EU iron ore mining happens in Sweden (92%) followed by Austria (7%) and Germany (1%). At around 35 kg CO_2/t pellets[20] the total emissions from iron ore mining and pellet production in the EU is around 0.7 Mt CO_2.

While the iron ore mining operations (like non-ferrous mining) are highly electrified, the sintering and pellet production depend on fossil fuels (such as coal and fuel oil).

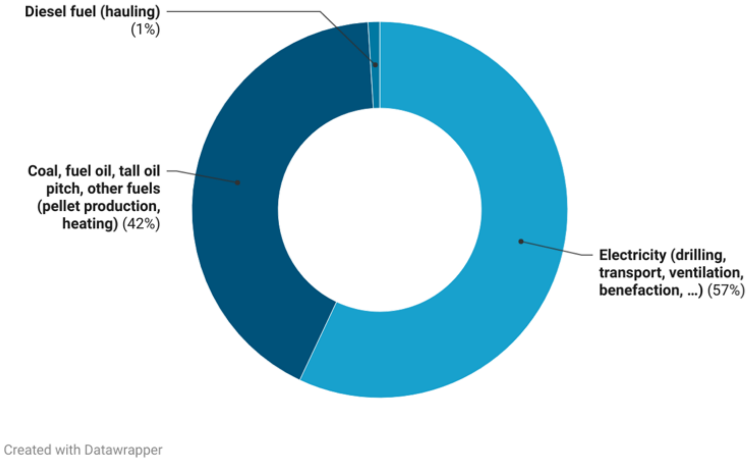

Figure 15:Iron ore mining, sintering and pelletising energy shares

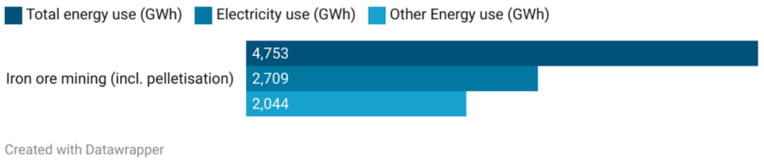

Figure 16: Energy use of EU iron ore production (incl. sintering and pellet production)

The specific energy use for iron ore mining including pellet production is 170-180 kWh/t pellets. It is estimated that the energy used for mining, grinding and benefaction is around 80-90 kWh/t pellets and the energy for sintering and pellet production around 90-100 kW/t pellets. Overall, the share of electricity use in iron ore production is around 57%.[21]

4.3. Pathways to net 0 emissions

For iron ore mining (including pellet production) to achieve net 0 emissions a similar approach as non-ferrous metals mining will have to be taken. This includes the electrification, digitisation and automation of mining processes as discussed before.

Improving the efficiency of existing processes is an important first step in mitigation of greenhouse gas emissions. The grate-kiln process is generally less energy-efficient than the straight grate process. Additionally, process integration and waste heat recovery strategies, such as using waste heat from the cooling stage to preheat the pellets, can further reduce fuel consumption and associated emissions.

When it comes to the production of pellets, the main option will be the use of alternative fuels. Achieving temperatures of 1200 ˚C in the rotary kiln is at this moment difficult via electrification technologies. However,

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[19] See Annex I for sources and methodology
[20] Ecofys et al., 2009
[21] SGU, 2023. SGU, 2022 and LKAB, 2023

electrification via the use of plasma is being considered and tested at small scale. Alternative fuels include bio-oil and the use of hydrogen. These alternatives come with their own challenges which boil down to availability and costs.

For hydrogen, infrastructure will need to be present for production and transport. This includes not only the electrolysers and storage of hydrogen but also either adequate (clean) power through the power grid or via renewable energy generation close to the mine. These are capital intensive investments, that even with low-cost renewables will see higher operational expenditures versus current operations.

Bio-oil requires changes to existing pelletising plants (e.g. due to corrosiveness of the oil) and nearby storage tanks. The use of bio-oil in an existing pellet plant has been successfully demonstrated. The investment costs are smaller compared to switching to hydrogen.

However, over time, hydrogen could become a go to fuel for pelletising if it is integrated into the new steel production value chain built upon hydrogen based direct reduction of iron ore (DRI) based sponge iron.

The EU's largest iron ore and pellets producer is committed to achieving 2045 net zero emissions for its processes and products.[22]

IRON ORE (INCL. SINTERING, PELLETISATION)	MINING OPERATIONS	PELLET PRODUCTION
Mitigation options	**Electrification of transport**	**Replacement of coal/oil with biomass or hydrogen**
CAPEX impact	Estimated at 2-3 Bn EUR investment for full electrification of transport.[23]	For replacement with hydrogen high CAPEX investments could be required (esp. if local production of H2 is included) For bio-fuel CAPEX investments will be lower given that it can be used in existing kilns with relatively small adjustments.
OPEX impact	Lower OPEX expected due to efficiency improvements but highly dependent on future electricity price	The OPEX for hydrogen use can be significantly higher and mostly depends on electricity prices for the electrolyser process. The OPEX for bio-fuel will be highly dependent on sourcing and availability but is expected to be higher compared to coal or natural gas.

Table 2: Iron ore mining, sintering and pelletisation mitigation options and impact on capex and opex.

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[22] See: https://lkab.com/en/what-we-do/our-transformation/carbon-free-sponge-iron/

[23] Estimate using limited CAPEX information on electrification of non-ferrous mining transport. The estimate counts on annual transport of around 45 Mt of crude ore. The estimate includes on site infrastructure (e.g. transformers, charging) but does not include off-site power generation investments and reinforcement of grid infrastructure.

MAGNESITE

5. Magnesite and minerals

5.1. Magnesite, the industrial enabler

Magnesite is the unsung hero of the sustainability transition. Magnesite transformed to various forms of magnesia is necessary for steelmaking, the production of non-ferrous metals, glass, and ceramics. More than half of the critical and strategic raw materials of the EU depend on magnesite as input factor.[24]

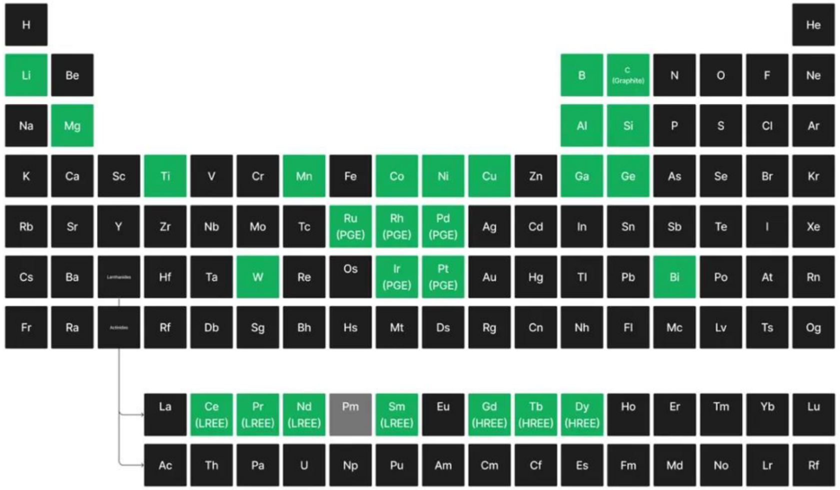

Figure 17: Non-ferrous metals that depend on magnesite as input factor in production

Magnesite/magnesia finds its main application in refractory materials, that are sintered at very high temperature, hence the energy consumption and reliance on fossil fuels to achieve these temperatures.

Shaped and unshaped Magnesia products come in different grades:

- Caustic Calcined Magnesia
- Sintered Magnesia
- Fused Magnesia

The Shaped Magnesia products are differentiated in:

- fired: Magnesia & Magnesia Chrome Bricks
- unfired: Magnesia Carbon Bricks

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[24] RHI Magnesita, 2024

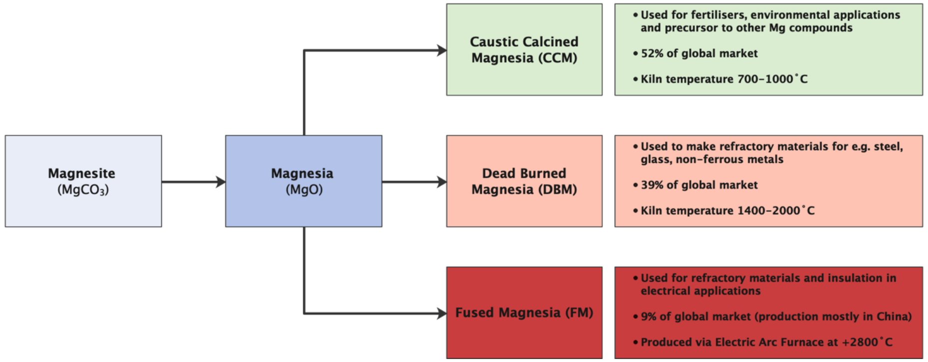

Figure 18: From magnesite to different types and applications of magnesia.

The EU still has important magnesite ore reserves (almost 11% of global ore) and magnesite ore mining with 10.5% of global production in 2021 (or almost 3Mt of ore). China has the largest amount of magnesite mining globally (64.5%) and produces almost 70% of all magnesia. The EU is, at a distance, the second largest producer of magnesia with 7.6% (1.3 Mt) of global production.[25]

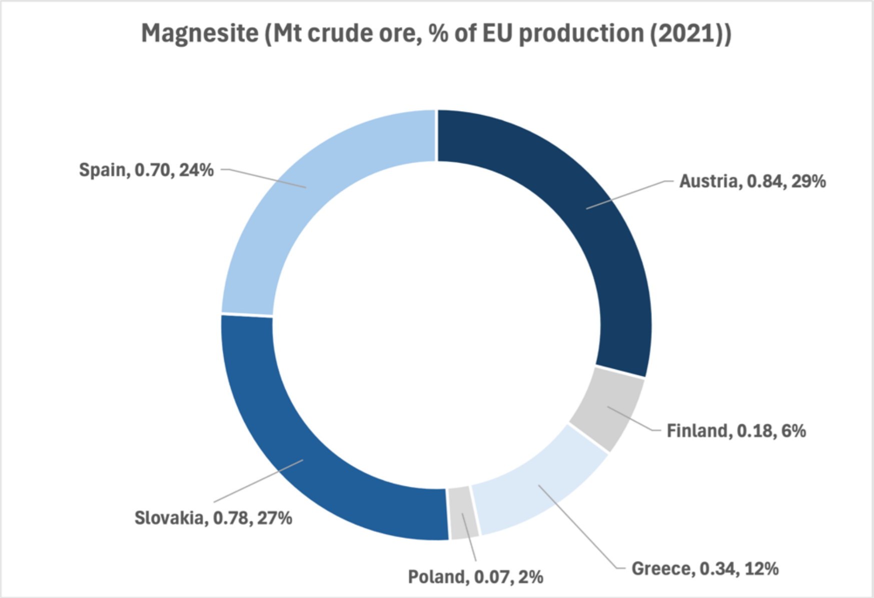

Figure 19: EU magnesite crude ore production (2021, source: European Commission, Joint Research Centre)

Main magnesite ore producers in the EU are Austria (29% of EU production), Slovakia (27%), Spain (24%), Greece (11.5%), Finland (6.2%) and Poland (2.3%).[26]

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[25] European Commission, Joint Research Centre, n.d.

[26] Id.

RHI Magnesita A Key Player in the Refractory Industry

With almost 200 years of experience, RHI Magnesita is a **global Austria-headquartered leader in refractory products, used in all the world's high-temperature industrial processes**, as steel, cement, lime, non-ferrous metals, glass, energy, environment and chemical industries. With 20,000 employees worldwide (5,000 in Europe), the company mines key raw materials and produces specialty industrial ceramics essential for modern civilization. RHI Magnesita operates over 50 plants globally, including 27 plants and mines across several European countries.

Refractories are critical for industrial value chains in Europe, serving as the backbone for producing steel, copper, cement, aluminum, chemicals, glass, and other materials that require very high temperatures. These highly technical ceramic materials protect plants and people from extreme heat and chemical attack during manufacturing processes. Despite representing only 0.5% to 1.5% of their building blocks' cost, refractories are indispensable for industrial production. For example, producing 1 tonne of steel requires 10-15kg of refractories, while 1 tonne of copper needs about 3kg.

Magnesia, the raw material for making refractory producs derived from magnesite, is a globally traded good crucial for the EU's green technology. It's essential for producing steel, aluminum, copper, glass, and other materials vital to Europe's industrial ecosystems. The EU currently depends on Chinese magnesia imports to meet its industrial demand, highlighting the strategic importance of European magnesia production.

RHI Magnesita is committed to achieving Net Zero by 2050, aligning with the EU's Green Deal agenda. The company has already reduced its CO_2 emissions from 6.2 million tonnes to 4.6 million tonnes in 2022 through increased recycling and optimized energy use. However, refractory production remains energy and emission-intensive, with 1 ton of refractory matierals produced typically emitting 1.7 tons of CO_2 (scope 1,2 and 3 emissions).

The company focuses on developing novel recycling technologies and researching new methods to abate emissions. They've reached a recycling rate of 15% in Europe, with potential to increase to 20-25%. RHI Magnesita is also exploring carbon capture, utilization, and storage (CCUS) technologies, collaborating with partners to develop innovative solutions.

5.2. Production process and energy use

The magnesite mining process involves extracting cryptocrystalline magnesite from open-pit or underground mines. Beneficiation processes are then employed to increase the magnesite concentration and remove impurities. These processes include crushing, grinding, and various separation techniques such as flotation.

The production of magnesia primarily follows two distinct methods: the natural procedure and the synthetic procedure. The natural procedure utilizes magnesite ($MgCO_3$) as the raw material. This process involves heating magnesite to high temperatures, causing it to decompose into magnesia (MgO) and carbon dioxide (CO_2).[27] The natural procedure can be further categorized into single-stage and multiple-stage firing processes. The single-stage firing process directly produces the desired magnesia product in one firing step, while the multiple-stage firing process involves several firing steps with intermediate processing.

In contrast, the synthetic procedure utilizes alternative raw materials such as magnesium hydroxide, magnesium chloride, dolomite, or lime. This method involves a series of chemical reactions and transformations to produce magnesia. One notable example is the production of brine-based magnesia. Here magnesium is extracted from brine operations through magnesium chloride, and the transformation to magnesium hydroxide and calcium-chloride. The EU has one brine-base magnesia producer in the Netherlands where brine is extracted from 2000m below the surface.

This magnesium-rich brine is pumped to the surface for further refinement and processing. This method allows for efficient extraction, as the magnesium salts dissolve preferentially over sodium chloride. The production process includes dissolving the magnesium salts followed by purification, turning the magnesium chloride into solid form, removal of Boron and sulphates and finally calcination and the production of magnesium rich briquettes which are sintered to create dead burned magnesia.[28]

Around 3 Mt magnesite ore is mined yearly in the EU.[29] This ore produces around 1.3 Mt magnesia. EU magnesite mining and magnesia production use approximately 2.7 TWh energy per year. Electricity use covers only 5.5% total energy demand (0.14 TWh), the remainder energy use is mostly covered by natural gas.[30] Production of magnesia is highly energy intensive due to the high temperatures (1400-2000 ° C) required in the process. Around 1.8 MWh energy is needed to produce a tonne of sintered (dead burned) magnesia. The European magnesia industry primarily relies on natural gas, followed by petroleum coke, fuel oil, and a small percentage of other fuels. The share of electricity is around 5.5% and diesel use for hauling represents 2.5% of the total energy use.[31]

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[27] The chemical reaction can be represented as: $MgCO_3(s) \Rightarrow MgO(s) + CO_2(g)$.

[28] https://www.nedmag.com/about-us/what-does-nedmag-do

[29] European Commission, Joint Research Centre, n.d.

[30] See Annex I for methodology

[31] Trojer, 2009

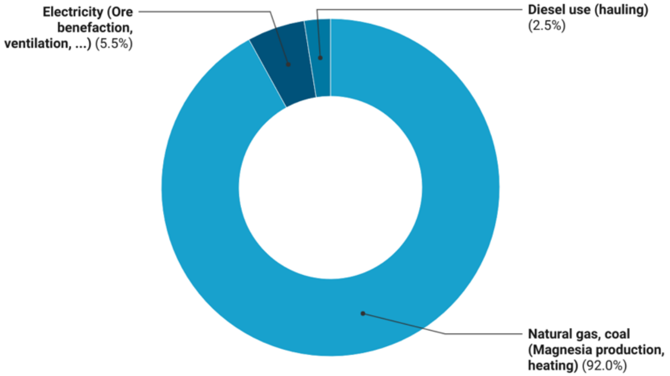

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Figure 20: Share of energy carriers in Magnesite mining and magnesia production

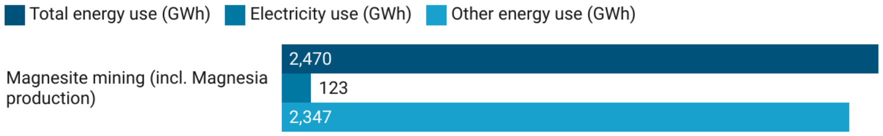

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Figure 21: Total estimated energy use of EU magnesite mining and magnesia production, electricity use and use of other energy sources (2021)

The production of magnesia generates substantial CO_2 emissions, which can be attributed to two primary sources: process emissions and emissions from energy use. Process emissions are inherent to the chemical decomposition of magnesite into magnesia and carbon dioxide. These emissions are considered unavoidable and are directly proportional to the production level. The amount of CO_2 released during the decomposition process depends on the raw materials' composition and the desired type of magnesia. The European magnesia industry primarily relies on natural gas (53%), followed by petroleum coke (37%), fuel oil (8%), and a small percentage of other fuels, potentially including coal. Emissions from energy use constitute the second major source of CO_2 in magnesia production. The production process requires significant energy input for the thermal treatment, primarily for firing the kilns. The type of fuel used for this process heavily influences the resulting CO_2 emissions. Fossil fuels such as coal, natural gas, and oil contribute significantly to these emissions. Total direct emissions (i.e. process and energy) are around 1t CO_2/t magnesia.[32]

5.3. Pathways to net 0 emissions

Achieving net zero emissions for magnesia production will be challenging. The sector faces a daunting two-fold task. First, the reduction of unavoidable process emissions which are caused by the embedded carbon in the magnesite ore. Secondly, the elimination of emissions coming from the combustion that is required to provide energy for the extremely high temperatures (up to 2000 °C) in the sintering process.

Currently the only realistic option for process emissions mitigation in magnesia production is the capturing of CO_2 emissions. From a cost optimal perspective, it is most interesting to use the captured CO_2 on or close to the production site to make construction materials via carbonation.[33] The alternative, i.e. the transport and storage of CO_2 will be logistically more challenging and more expensive. In all cases the capturing of CO_2 will increase the operational expenditure (e.g. 50-100

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[32] Trojer, 2009.

[33] https://mcicarbon.com

EUR/t CO_2 captured)[34]. In case of utilisation (via carbonation) part of this cost could be recovered if the resulting products can be adequately valorised. The latter will require the recognition of the industrial minerals produced via CCU as carbon-free from a regulatory perspective, especially because here the CO_2 is (almost permanently) fixed in the product.

The emissions from fuel use can also be captured but here alternative fuels such as biofuel or hydrogen can be used for the high-temperature processes. Again, hydrogen production will come with its own challenges and costs related to the availability and price of clean electricity together with the infrastructure needed to produce and transport hydrogen. However, many industries – especially those operating outside of large industrial clusters in decentralised operations such as magnesite mines – currently struggle to access hydrogen infrastructure and sufficient volumes at the required price level. Synthetic and biofuels are also viable options to reduce emissions in magnesia production. However, as with hydrogen, the OPEX impact is negative with alternative fuels costing 5-6 times more than currently used fossil fuels. [35]

While electrification is an option to electrify the mining processes, it is currently not a technically viable option to reach the high temperatures required in parts of the magnesia production process. Electrification can be economically interesting if the efficiency gains outweigh the higher electricity price compared to use of natural gas and/or other fuels. On average natural gas is currently around 3 times less expensive than electricity.

Finally, the sector is also implementing recycling strategies for refractory materials with the goal to reach a 20-25% recycling rate in the future. [36]

RHI Magnesita estimates that preparing its sites for reaching net 0 emissions will require an investment of 500 million EUR.[37] Extrapolating this cost for all EU magnesia production would imply an investment of 1.5-2 Bn EUR.

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[34] Kearns et al., 2021

[35] RHI Magnesita, 2024

[36] Id.

[37] Id.

MAGNESITE MINING AND MAGNESIA PRODUCTION	PROCESS EMISSIONS	ENERGY (HIGH T HEAT)
Mitigation options	**Carbon capture (amine-based absorption) +** **Transport and storage of CO_2 +** **Utilisation of CO_2 (valorisation)**	**Natural gas replacement by biogas, synfuels or hydrogen and/or use of carbon capture**
CAPEX impact	- CO_2 separation/capture is capex intensive investment - CO_2 transport and storage requires additional infrastructure (best is to use synergy with large industrial CO_2 source) - Utilisation of CO_2 (carbonation/silica) requires new process plants	- Carbon Capture (see left) - Limited capex impact of biogas/biofuel/synfuel use but availability is currently limited - Hydrogen use might require changes to existing calcination/sintering plant - Additional infrastructure needs for hydrogen
OPEX impact	- CO_2 separation is always negative on OPEX, however potential for waste heat use in amine desorption process - CCU can be electro-intensive. Requires sufficient (clean) power	- Carbon capture (see left) - Biogas/biofuel can be more expensive vs natural gas -Synfuel significantly (5-6 times) more expensive compared to fossil fuels - (green) Hydrogen opex will be higher compared to fossil fuels (esp. in Europe)

Table 3: Magnesite mining and magenesia production mitigation options and impact on capex and opex.

POTASH

6. Potash mining and production

6.1. Potash, an essential nutrient

The mineral potash plays a crucial role in various sectors, primarily agriculture and industry.

Potash, representing the nutrient form of potassium (K), is one of the three key macronutrients vital for plant growth, alongside phosphorus and nitrogen. Due to its essential role in plant nutrition, approximately 92% of potash production is dedicated to manufacturing fertilizers. This underscores the importance of potash in ensuring global food security by supporting agricultural productivity and crop yields. There is a lack of viable alternatives to potash, making it an irreplaceable input for agriculture. Manure and glauconite are no substitutes due to their low potassium content.

While most of the potash is used for fertilizer production, about 8% is utilized in manufacturing various potassium-bearing chemicals. These chemicals find applications in a wide range of industries, including Pharma (Potassium compounds are used in various pharmaceuticals and medical treatments), food, chemicals industry, water treatment, etc.

Canada, Russia, and Belarus are the world's leading potash producers, collectively accounting for over 60% of global production, followed by China, Germany and Israel.[38] The increasing global demand for potash to secure global food production underscores the EU's need to strengthen a stable and sustainable supply of this mineral, including via higher domestic production.

The annual EU production is approx. 6 Mio. tonnes/year (88% in Germany and 12% in Spain), which meets the EU demand of 5 Mio. tonnes/year.

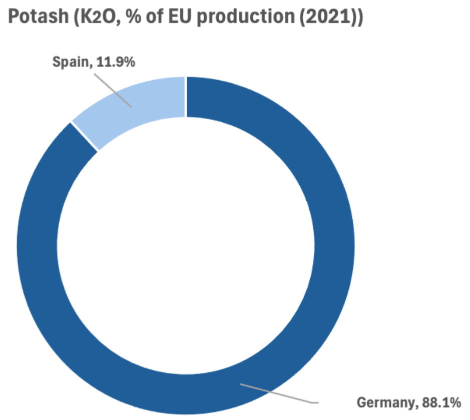

Figure 22: EU Potash (K_2O) production. Source: European Commission, Joint Research Centre n.d.

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[38] European Commission, Joint Research Centre, n.d.

6.2. Potash mining, production process and energy use

The potash mining and production process is an integral operation that begins with the extraction of potash ore from underground deposits. Potash is typically found in deep underground deposits, often at depths of 500-1300 meters. Two main methods are employed for potash extraction depending on the geology and ore body: conventional mining and solution mining[39]. In the EU Potash is typically extracted via conventional mining methods (drilling and blasting, room-and-pillar mining).

Once the potash ore is extracted, it undergoes a process that separates the valuable potash minerals from other salts and impurities. The specific processing technologies employed vary depending on factors like ore composition, grade, and the presence of impurities. The common separation methods are:

- Flotation: This method utilizes the different surface properties of minerals to separate them. Reagents are added to the ore slurry, causing the potash minerals to attach to air bubbles and float to the surface, while unwanted minerals sink.
- Electrostatic Separation: This method exploits the differences in the electrical conductivity of minerals. Particles are charged, and those with different charges are separated using an electric field.
- Thermal Dissolution-Crystallization: This process involves dissolving the potash minerals in hot brine and then cooling the solution to crystallize the potash, leaving impurities behind. It is energy-intensive but effective in treating ores with high clay and magnesium chloride content.

After processing, the concentrated potash product is typically dried, compacted or conditioned, and packaged for use, primarily as a fertilizer.

The EU's Potash mining energy use is around 8 TWh per year to produce raw materials with around 6 Mt Potash content.[40] Most of the energy in the form of natural gas is used in combined heat and power units (CHP) and in the drying process. Electricity use represents around 20% of the total energy input.

Potash mining reduced its CO_2 emissions by approximately 80% since 1990 mainly through replacing coal/oil use with highly efficient combined heat-and-power generation units running on natural gas, the application of other energy efficiency measures and closure of in-efficient operations.

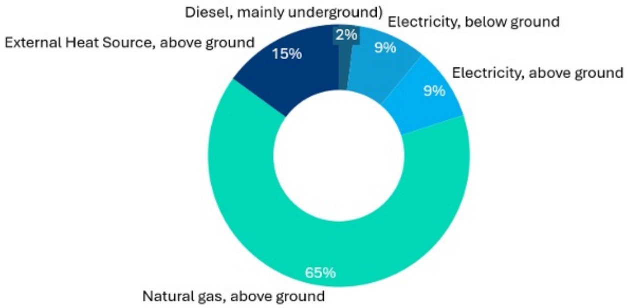

Figure 23: Energy use in Potash production (%, source: Experts interview)

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[39] Solution mining, predominantly used in Canada and the US, involves injecting heated water into the deposit to dissolve the potash. This creates a brine solution that is pumped to the surface for further processing.

[40] This gives an estimated 1.3 MWh/t K2O produced, including the drying of salts. Underground mining operations make up around 10% of the energy use.

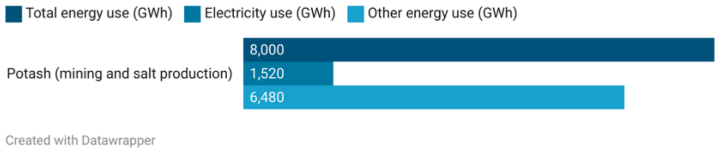

Figure 24: Total energy use in EU potash production (GWh), electricity and other fuel sources shares (Source: expert interviews)

6.3. Pathways to net 0 emissions

For potash production to reach net 0 emissions, the main challenge will be to reduce the emission associated with generating heat for the processing technologies and heating needed for drying the concentrated minerals. The electrification of mining (hauling) and ore processing, as mentioned before is already improving and is expected to increase over the next 2 decades to reach full decarbonization.

The implementation of dry electrostatic separation technology is a novel approach in potash processing that promises to dramatically reduce the energy footprint and related greenhouse gas emissions of potash production. Electrostatic separation is a physical separation method that exploits differences in the electrical properties of materials. In the context of potash processing, this technology offers several advantages over traditional wet processing methods. [41]

The main advantage is reduced Water Usage. Unlike traditional wet processing methods, electrostatic separation is a dry process, significantly reducing water consumption and associated wastewater issues. A dry process requires less energy compared to conventional methods, contributing to reduced CO_2 emissions. By enabling more precise separation, this technology minimizes the generation of solid and liquid residues, which can increase the use of backfilling in mining operations. Improved separation efficiency leads to higher recovery rates of valuable minerals from the ore.

The main potash producers in Europe switched to the use of combined in heat and power (CHP) already decades ago. A next switch from gas-fired CHP installations to so-called power-to-heat installations using green electricity is technically feasible, once the power price drops below 6ct/kWh. However, it is not yet possible due to the lack of green electricity availability and due to the duration of construction and permitting processes for high power and grid connectors which can take up to ten years. Therefore, it is expected that gas-fired CHP installations in the potash sectors will still be in use over the next decade and will be gradually phased out by 2040-2045. Potash production in the EU is committed to reach net 0 emissions within the next 20 year.[42]

The capital investment (CapEx) of electrifying potash production in the EU is estimated to be above 1 Bn EUR. Depending on the availability and price of clean electricity this investment will increase OPEX significantly compared to non-EU producers. Therefore, low energy prices, public funding and financial incentives are necessary for a competitive decarbonisation.

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[41] K+S, 2022

POTASH PRODUCTION	K_2O SEPARATION AND CONCENTRATION (ENERGY)
Mitigation options	- Electrification via electrostatic separation (efficiency gains) - Power-to-Heat applications like electrode boilers, heat pumps and electrical dryers
action	- CAPEX intensive transformation. Est. around 1 Bn EUR investment for full decarbonization
impact	- Lower CO2-footprint and higher costs compared to non-EU competitors - Early mover effect creates a chance for entering lead market for green products

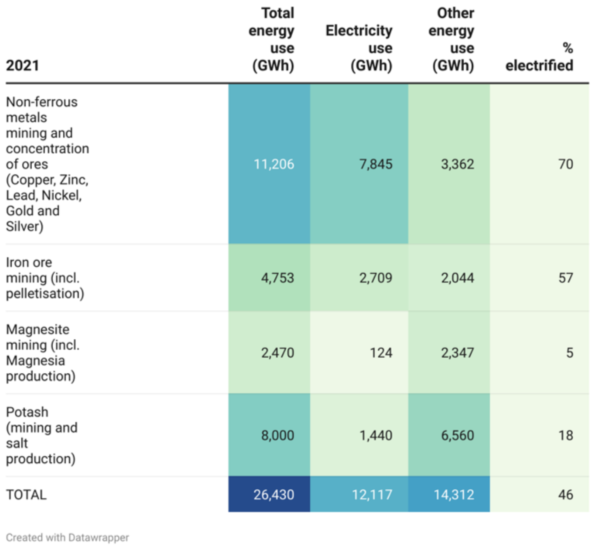
Table 4: Potash mining mitigation options and impact on capex and opex.

TRANSITION PATHWAYS

7. Mining transition pathways overview

The EU mining industry[43] uses around 26.5 TWh energy per year. Out of this total around 12 TWh (or 46%) is electricity and the remainder, consisting of fossil fuels is around 14.3 TWh (or 54%).

Electrification is highest in non-ferrous mining (70%) followed by iron ore production (57%). The mining operations requiring high amounts of heat in the processing stage still see lower levels of electrification (e.g. almost 20% for Potash and 5% for magnesia production).



2021	Total energy use (GWh)	Electricity use (GWh)	Other energy use (GWh)	% electrified
Non-ferrous metals mining and concentration of ores (Copper, Zinc, Lead, Nickel, Gold and Silver)	11,206	7,845	3,362	70
Iron ore mining (incl. pelletisation)	4,753	2,709	2,044	57
Magnesite mining (incl. Magnesia production)	2,470	124	2,347	5
Potash (mining and salt production)	8,000	1,440	6,560	18
TOTAL	26,430	12,117	14,312	46

Created with Datawrapper

Figure 25: Total energy use of EU mining (non-ferrous metals, iron ore, potash and magnesite) and levels of electrification.

When it comes to mining operations the major remainder part to be electrified is hauling and transport of ores. For non-ferrous metals mining, the electrification of transport will eliminate most of the direct mining operation emissions. Achieving net zero emissions will hence fully depend on the access to sufficient clean electricity.

Full electrification of non-ferrous mining operations will reduce the overall energy use due to important efficiency gains via improved hauling operations and reduction of ventilation demand. In this context electrification must be seen as going together with enhanced digitisation and optimisation of mining operations.

For iron ore mining, including pellet production, the mining electrification options are similar to these of non-ferrous metal mining. In addition, alternative fuels will be needed to provide heat for sintering and pellet production.

Potash mining will not only electrify its mining operations but also its separation process (via electrostatic separation). The fact that this is a dry process will generate important energy savings.

Magnesia production sees the biggest challenges in moving to net zero emissions. Investments will be required to capture and use the unavoidable process emissions. Due to the extreme heat required to produce dead burned magnesia, electrification is not immediately an option. Alternatives such as hydrogen and synthetic fuels are not certain to be available at mining operations outside of major industrial hubs.

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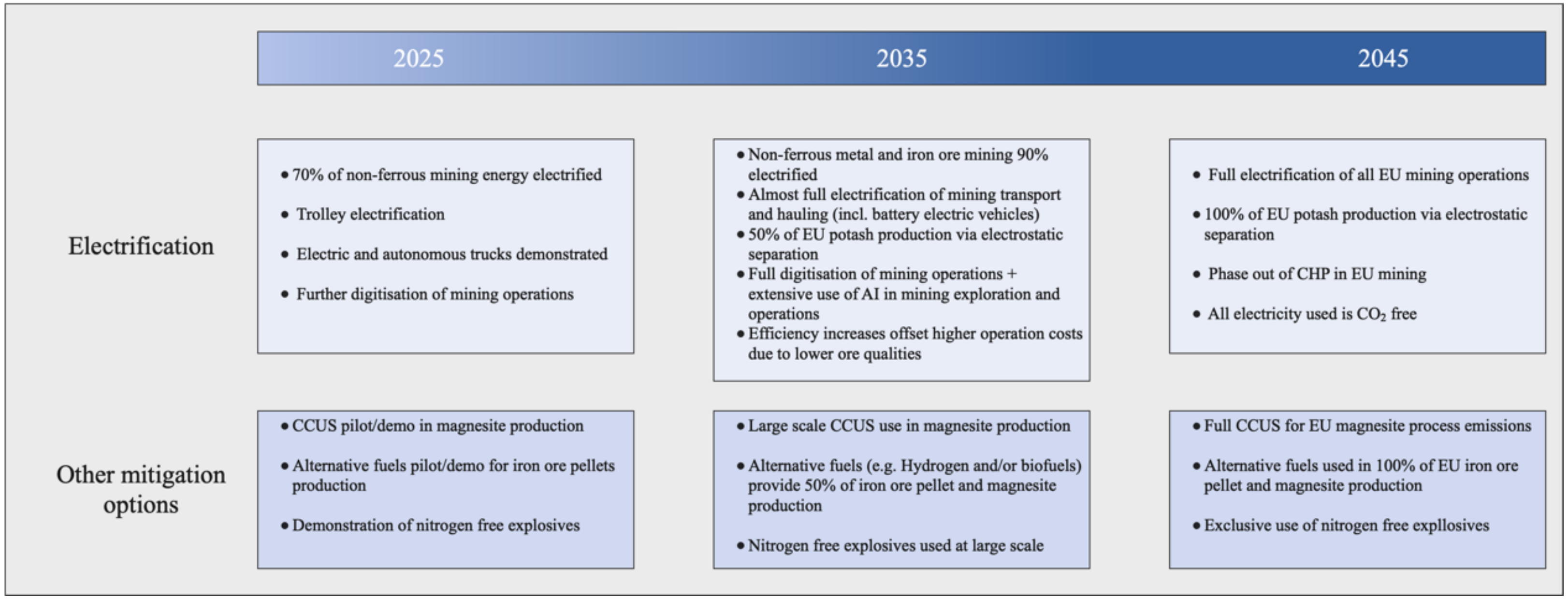
[43] For this report specifically non-ferrous metals mining, iron ore mining and pellet production, potash mining and Potash salt production and magnesite mining and magnesia production.

Additional investments to reach net zero emissions will be large for EU mining companies. The total capex is estimated to be 11.5-17.2 Bn EUR. Major part of that is mining electrification (9-14 Bn EUR). Investments to bring potash production to net 0 emissions will be around 1 Bn EUR. The magnesite climate transition will require around 1.5-2 Bn EUR additional CAPEX.

The impact on OPEX is mixed. Mining electrification, as stated before, will reduce overall energy use (at similar production levels and ore grade concentration). However, electricity prices will have to become more competitive to ensure the efficiency gains are translated into cost savings. For magnesite production, all scenarios point to higher operational expenditures (on top of high capex for carbon capture installations).

Considering the EU mining companies plans and transition pathways, it is possible for EU mines to reach climate neutrality (for their direct emissions) by 2040-2045. The next 10 years will see a gradual electrification of mining operations and demonstration of key climate friendly technologies in iron ore pellets, potash and magnesia production. In the period 2035-2045 this transition should be further completed with electrification of smaller mining operations and full implementation of other mitigation technologies.



	2025	2035	2045
Electrification	• 70% of non-ferrous mining energy electrified • Trolley electrification • Electric and autonomous trucks demonstrated • Further digitisation of mining operations	• Non-ferrous metal and iron ore mining 90% electrified • Almost full electrification of mining transport and hauling (incl. battery electric vehicles) • 50% of EU potash production via electrostatic separation • Full digitisation of mining operations + extensive use of AI in mining exploration and operations • Efficiency increases offset higher operation costs due to lower ore qualities	• Full electrification of all EU mining operations • 100% of EU potash production via electrostatic separation • Phase out of CHP in EU mining • All electricity used is CO_2 free
Other mitigation options	• CCUS pilot/demo in magnesite production • Alternative fuels pilot/demo for iron ore pellets production • Demonstration of nitrogen free explosives	• Large scale CCUS use in magnesite production • Alternative fuels (e.g. Hydrogen and/or biofuels) provide 50% of iron ore pellet and magnesite production • Nitrogen free explosives used at large scale	• Full CCUS for EU magnesite process emissions • Alternative fuels used in 100% of EU iron ore pellet and magnesite production • Exclusive use of nitrogen free expllosives

Table 5: Overview of transition steps for EU mining operations.

8. Challenges and Solutions for EU mining transition

8.1. Transition Challenges

EU mining industry has ambitious and achievable pathways to reach net 0 emissions well before 2050. The industry faces significant challenges in its transition towards a low-carbon future. These challenges are multifaceted, involving economic, technological, and regulatory aspects that require careful navigation to ensure the industry's competitiveness while meeting climate goals.

Incomplete CBAM coverage

Carbon pricing is a crucial mechanism for driving change in energy-intensive industries. However, rising carbon prices and the gradual phase-out of free allowances under the EU Emissions Trading System (ETS) pose significant challenges for companies with high (process) CO_2 footprint with no-short term mitigation options such as magnesia producers. The increasing costs associated with carbon emissions can impact the competitiveness of European producers in the global market, especially when competing with countries that have less stringent environmental regulations[44]. The EU's CBAM aims to level the playing field by imposing carbon costs on imports. However, some sectors (e.g. refractories) are not fully covered by this mechanism, potentially putting European producers at a competitive disadvantage via import leakage. This gap in coverage highlights the need for a more comprehensive approach to ensure fair competition while promoting decarbonisation efforts.

Excessive windfalls inside EU ETS indirect costs

EU mining is already highly electro-intensive (e.g. non-ferrous and iron-ore mining). Further electrification will be essential to meet 2040 and 2050 climate targets. It is also likely that declining ore concentration together with increased mining activities to meet demand will increase future energy needs. The way the CO_2 cost related to power production is currently passed through via marginal pricing is disproportional compared to the actual climate impact of power generation. Even if most of the electricity is produced via clean sources, the marginal power price is most of the time set by natural gas-based power production, including the CO_2 cost.[45] This creates a windfall for some power producers and an unnecessary cost for consumers.

The pay-as-produced electricity market based on marginal price setting ensures that gas-based electricity with internalized CO_2-costs will set the price until 2035 – accounting for disproportionately high prices. Renewable and low-carbon electricity is much cheaper, yet this cost competitiveness is not reflected in the current pricing mechanism. As the EU is the only place in the world that internalizes CO_2-costs into electricity, making the main commodity for decarbonisation more expensive, this leads to higher production costs and lower competitiveness for EU industries. Our industry is a baseload consumer, requiring a constant stable supply of lower-carbon electricity. Given the increased volatility from renewables and the need for balancing, increases price-swings – times of low renewable electricity generation require balancing from gas fired power plants or even more expensive storage solutions – which risks the security of supply: at several instances, suppliers when needed to balance by buying electricity off the spot market had to default on their contracts or entered arbitration.

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[44] Euromines, 2019

[45] Draghi, M., 2024

The ideal solution would be a full decoupling of fossil-free and fossil-based electricity generation in the price-setting to reflect the cost competitiveness of low carbon energy sources, maintaining the price signal while incentivizing the demand side to electrify further.

High and unpredictable OPEX smothers investments
With the continued reduction of the ETS-cap – combined with a 90% decarbonisation target by 2040, this will require a nearly fully decarbonised industry – with a fully decarbonised energy sector well beforehand. The investment decisions to achieve that will have to be taken now, yet the cost curves are in the current set up so unpredictable that a business case is not possible to foresee. While increasing the costs of pollution over time has brought us a long way on the path to decarbonisation – yet at the same time the strategy of increasing costs made the main commodity to decarbonise – namely electricity – more expensive given that the marginal price setting mechanism ensures that the highest costs prevail. The mining industry is at a point, where these costs do not lead to more efficient and carbon free technology – yet simply to more costs that make investments into carbon-free technologies unfeasible. Unpredictable OPEX leads to postponed CAPEX decision that would bring us on the way to achieve the scenario of the end of the ETS and a 90% 2040 Target.

The uncertainty around the compounded effects of a cap convergence to 0 and an ambitious 2040 target require a policy debate how to re-design the system in a way that it a) incentivizes industrial decarbonisation in addition to increasing costs for pollution b) ensures burden sharing c) creates premiums for a sustainable security of supply.

Uncertainty in relation to Infrastructure for Carbon Capture, Utilization, and Storage (CCUS)
CCUS technologies are critical for reducing emissions in hard-to-abate sectors like parts of the mining industry. However, the lack of CO_2 transport, injection, and storage infrastructure in the EU, combined with bans on the technology in some member states, hinders the development and implementation of these crucial solutions. Furthermore, CCUS can come with high operational expenditures requiring some form of OPEX support such as carbon contracts for difference.

The Evaluation Report of the Federal Government of Germany on its national CO_2 Storage Law[46] from December 2022 lists Slovenia, Latvia, Lithuania, Finland, Ireland, Estonia, Austria, Germany, and Denmark as countries where CCS on industrial scale (or in total) is banned or other limitations apply.

So far, there are so far only two commercial CCS sites on industrial scale (Norway), the infrastructure, transportation means, and pipeline networks still need to be built and not all Member States signed the London Protocol making it impossible to export CO_2.
As for the business case for Carbon Capture and Use (CCU), the delegated act on the methodology for assessing recycled carbon fuels (RCFs) under RED II introduces a sunset clause so that this will no longer be considered as avoided emissions which jeopardizes the commercial viability of projects utilizing industrial CO_2 that are being launched by our industry.

Carbon management ignores geochemical storage
Also, carbon management is mainly focused on geological storage for which a permitting framework needs to be developed, considering not only the geological and technical feasibility of such a site but also the public acceptance. Geochemical storage, for example in tailings, is

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[46] Deutsche Bundesregierung, 2024.

overlooked, even though it also has an important potential. Carbon utilization in materials requires an adaptation of standards (e.g. for construction materials) as well as lead markets that can absorb the additional costs of several hundred Euro OPEX per ton of CO_2 sequestrated. Also, CCU/S combined with biomass leads to a situation where CO_2 molecules can be categorized differently: bio energy carriers whose emissions are captured and used or stored cannot be set on par with "ordinary" fossil-based CO_2 as it is already absorbed carbon that is never released and stored. This requires a new way of accounting for carbon capture and removal not only at the point of capture, but along the value chain.

The next CCUS Strategy needs to ensure that this technology can be proven as efficient business case, certified, allowed as well as systematically used and monitored by all Member States. To ensure the competitive uptake of this both CAPEX and OPEX intensive technology, we will need the creation of lead markets of CCU-goods, the consideration of geochemical storage in tailings, and carbon accounting that allows for the allocation of CO_2-certificates for captured carbon.

Availability of alternative fuels:
The shift to biofuels and hydrogen faces substantial challenges. Limited availability and higher costs of biofuels and synthetic fuels, coupled with difficulties in accessing hydrogen infrastructure for companies operating outside large industrial clusters, impede the transition. This is particularly problematic for mining operations often located in remote areas[47].

Bio-based energy carriers are a valuable resource that can boost the climate transition by replacing fossil carriers as reduction agents. Comparing the emissions of these carriers along the entire value chain to fossil-based reduction agents in combination with CCUS and a life cycle assessment that ensures that a tree has captured as much as CO_2 as its later use will emit demonstrate that this may even lead to negative emissions if the accounting of this carbon is correct: turning a 70 year old tree into biochar and later use it as a reduction agent is carbon neutral, while the subsequent capture and use to create for example synthetic fuels is carbon-negative as the use prevents the emission of other carbon sources. Yet the uptake of these carriers however is inhibited by regulatory hurdles such as allowing for the concept of "green carbon" in carbon accounting and the possibility to use forestry products to create biochar or the cascading principle of wood use.

To ensure that the climate positive effect of bio energy carriers as reduction agents are recognised along the life cycle and the value chain, it is necessary to ensure the carbon accounting takes up the compounded savings of CO_2 and that the use of captured "green carbon" in synthetic fuels remains a possibility under Renewable Energy Directive beyond the sunset clause in in 2035.

Cost of capital and regulatory uncertainty
Implementing decarbonisation technologies requires significant capital investment. Full electrification of mining will imply additional investments of multiple billions EUR across the EU over the next 2 decades. On top of this investments will be required for other mitigation technologies such as CCUS and shifting to alternative fuels and related infrastructure.

A high cost of capital is linked to regulatory uncertainty can prevent companies make such investments. The mining industry requires a stable and predictable permitting, energy and climate change policy

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[47] Euromines, 2022

framework to make long-term investment decisions. Frequent changes in regulations or inconsistent policies across EU member states can hinder the industry's ability to plan and implement decarbonisation strategies effectively.

Regardless of the climate transition, the EU mining industry will need to keep investing to keep current operations afloat and to expand EU mining in line with goals under the critical raw materials act.

No lead market for sustainable mining products
The EU mining industry strives towards implementing the highest sustainable and social standards in the world. However, a transparent lead market for our mining products is still not present. Improving the traceability of basic materials in final products would be a first step ensuring sustainable mining finds a better way into final consumer products.

8.2. How to make EU mining climate transition work

Within the setting of the Fit-for-55 package, technology availability and cost structure, new solutions are necessary to achieve the zero-carbon transformation of the Green Deal without jeopardizing competitiveness. The following solutions will help to tackle mounting energy and CO_2-costs to stay competitive in global markets and incentivize productivity gains rather than carbon leakage.

A CBAM fit for purpose
Carbon leakage can be further mitigated via a CBAM fit-for-purpose, covering the full supply chain, equipped with an export solution, and all emissions incurred in a product – direct, indirect and upstream.

Indirect CO_2 Cost Compensation for EU mining operations
Including mining as eligible sector by making use of the flexibility clause: The main avenue for mining to decarbonise is the use of electricity – in direct form or indirectly through hydrogen. As the only place in the world, Europe adds CO_2-costs onto electricity prices making the main energy carrier more expensive than for global competitors. A New State Aid and Competition Framework needs to tackle this issue in a broader sense, covering also network charges, indirect CO_2 costs, and exemptions from surcharges, fees and levies to help subsidise electrification plans.

Decouple fossil fuel-based production from renewable energy production costs
The pay-as-produced electricity market based on marginal price setting ensures that gas-based electricity with internalized CO_2-costs will set the price until 2035 – accounting for disproportionately high prices. The ideal solution would be a full decoupling of fossil-free and fossil-based electricity generation in the price-setting to reflect the cost competitiveness of low carbon energy sources, maintaining the price signal while incentivizing the demand side to electrify further.

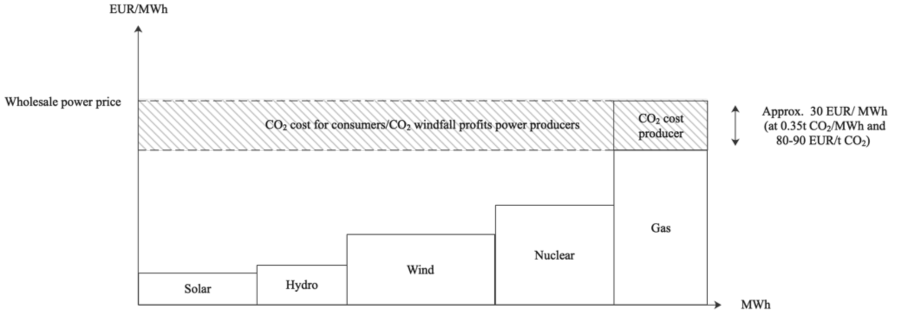


Figure 26: Marginal price setting of power production. Marginal fossil fuel based power production and carbon pricing generate significant windfalls for power producers and costs for consumers.

A dramatic reduction in indirect EU ETS costs and hence reduction of electricity prices can be achieved by making end-users and not power producers responsible for CO_2 emissions from power generation. If fossil fuel-based power producers are not responsible for purchasing EU ETS allowances the CO_2 cost will be removed from the wholesale electricity price. It will hence also abolish the related windfall profits (large striped box in figure 22). When consumers are responsible for covering their indirect emissions via EU ETS allowances, the cost will reflect the real CO_2 pollution cost (small striped box in figure 22), excluding the windfall profits. This approach would be similar to the functioning of EU ETS 2 (for transport and other non-ETS sectors) and does not change the EU ETS cap or allowance auctioning volumes. This relatively small change to the functioning of the EU ETS could be a quick win for industrial electrification through reduction of electricity prices, while not changing the climate ambition level.

A Coherent Industrial Carbon Management Strategy
CCU and CCS are main pillars for the decarbonisation of process emissions in the mining industry – yet for technical reasons, costs and access to infrastructure not yet ready for wide industrial deployment. To ensure the competitive uptake of this both CAPEX and OPEX intensive technology, we will need the creation of lead markets of CCU-goods, the consideration of geochemical storage in tailings, and carbon accounting that allows for the allocation of CO_2-certificates for captured carbon, and to consider removals with permanent storage to be accounted for under the ETS.

Facilitate the underlying business case for EU mines
To support the development, production and diffusion of European clean tech and speed up planning, tendering and permitting processes are crucial to get the energy where it is needed. This includes administrative facilitation, expediting deadlines, and making better use of overriding public interest principles.

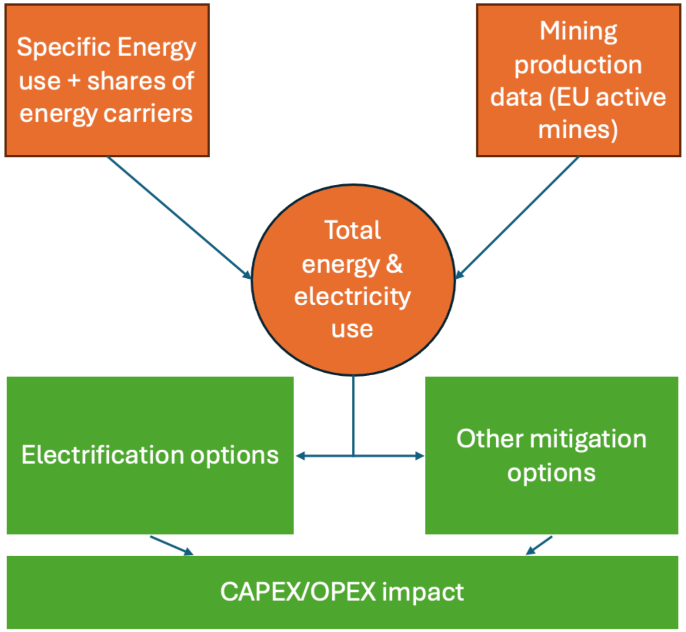
Create the business case for net zero EU mining
internal and external lead markets, public and private funding, social and industrial policies, financial and legislative instruments all need to work in lockstep to find customers for climate friendly raw materials that can absorb the costs of more expensive production technologies and the high investments. This includes maximising the impact of public finance to guide investments to clean solutions through tax rules and financial markets consistent with the green agenda. Public procurement can send a clear signal to the market and deserves full attention within the Clean Industry Deal as can support to private finance, such as through EIB-backed guarantees.

A Clean industrial Deal and industrial decarbonisation accelerator act will need to address the bottlenecks that prevent a business case and investments into innovation to transform processes, improve industrial output, and foster our resilience to global supply shocks, namely: costs, red-tape and compliance and regulatory hurdles to conduct business. Coupling the EU Green Deal with an Industrial Deal will empower industry to make the necessary investments to decarbonise while boosting competitiveness. Tackling the issue of merging competitiveness, security of supply of vital raw materials with the climate ambition of the EU, a few fundamental elements need to be amended to ensure the attractiveness of the EU for investments.

Annex I: methodology

General approach

To calculate the energy use of mining operations (i.e. non-ferrous metals, iron ore, magnesite and potash) in the EU the starting point was to determine the specific energy use of ore production (including the share of electricity use and use of other energy sources). This figure was next multiplied with the production data.



To determine the electrification options and other mitigations options scientific and other (e.g. company based) literature was used. Where available CAPEX and OPEX figures were derived from these sources.

Specific energy use

For non-ferrous metals mining the specific energy use was calculated using company data (e.g. reported via CSR reports or via national mining statistics). [48] [49] This energy use includes the extraction and concentration of ores. Data of 14 EU non-ferrous mines was used to estimate the EU average specific energy use. This gives an average of 77 kWh/t crude ore extracted for mines with annual production below 20 Mt and 50 kWh/t crude ore for mines with annual production above 20 Mt.

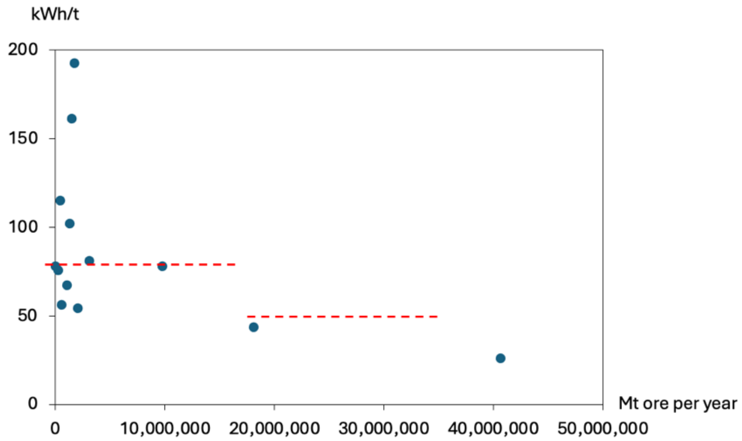


Figure 27: Specific energy use of 14 non-ferrous metals mines in the EU

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[48] SGU, 2023 and SGU, 2022

[49] Data collected and extracted via reports available on TSM Finland https://kaivosvastuu.fi/en/company/mining/

Shares of electrification and use of other energy sources were derived from same company CSR reports and used as EU average.

For iron ore mining a similar approach was used but here the specific energy use includes the energy use for sintering and pelletisation. For iron ore mining and pelletisation specific energy use at company level was available via the Swedish Geological Survey.[50]

For magnesite[51] and potash[52] production the specific energy use was derived from literature.

Mining production data

EU mining production was calculated using multiple sources. For Sweden and Finland national aggregated (and mine level) data was available. For other countries the annual ore production was calculated using company data where available (e.g. technical reports or production data reported on website). Finding active EU mines required the development of an up-to-date EU mine map using the EGDI[53] database as a starting point. This database was next manually checked and corrected (removing closed mines and adding missing mining operations).

If no production data was available via mining company websites or reports the European Commission-Joint Research Centre[54] using US geological survey reported production data (expressed as tonnes of metal in ore) was used. To derive the total crude ore production from the metal content in ores the average national ore concentration was used or if available via technical reports the actual ore concentration. The production year used in almost all cases was 2021.

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[50] SGU, 2023 and SGU, 2022

[51] Trojer, M., 2009

[52] Katta, A., et al., 2020

[53] EGDI, n.d., https://www.europe-geology.eu

[54] European Commission, Joint Research Centre, n.d.

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