D1.1 Technological, economic, market, and policy analysis

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Work Package 1 – Techno-Economic & Market Analysis

Authors: Tim Heijmann (Evenflow)

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Lead author	Tim Heijmann		Email	tim@evenflow.eu
Other authors				
Reviewer(s)	Marko Savolainen (VTT), Sebastian Teuwsen (EFTAS)			
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List of Abbreviations

Abbreviation	Meaning
A-DInSAR	Advanced-Differential Interferometric Synthetic Aperture Radar
AI	Artificial Intelligence
CRMs	Critical Raw Materials
DEMs	Digital Elevation Models
DG	Directorate-General
EIT	European Institute of Innovation and Technology
EO	Earth Observation
EU	European Union
EURODEM	European Digital Elevation Model
EUSPA	European Agency for the Space Programme
G-RAM	GoldenRAM
GIS	Geographic Information Systems
HaDEA	European Health and Digital Executive Agency
ICMM	International Council on Mining and Metals
ICT	Information and Communication Technology
InSAR	Interferometric Synthetic Aperture Radar
IoT	Internet of Things
KPI	Key Performance Indicator
ML	Machine Learning
NDVI	Normalized Difference Vegetation Index
PSI	Persistent Scatterer Interferometry
RGB	Red, Green, Blue (color model)
RM	Raw Materials
S2	Sentinel-2
SAM	Serviceable Available Market
SAR	Synthetic Aperture Radar
SOM	Serviceable Obtainable Market
SOTA	State Of The Art
TAM	Total Addressable Market
TBC	To be confirmed
UAVs	Unmanned Aerial Vehicles
VTT	VTT Technical Research Centre of Finland

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WP	Work Package
XRF	X-ray Fluorescence

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1 Executive Summary

Overview
This report aims to provide top-level insights into the geopolitical backdrop of the raw materials industry, the latest policies and regulations, and the state-of-play of technology. It also provides a market and competitive analysis, as well as an application-specific analysis for the applications foreseen to be provided as part of the GoldenRAM (G-RAM) platform. It serves as a foundational document for the G-RAM team, guiding the development of the G-RAM platform to ensure it meets user expectations and is commercially viable. The report covers key aspects such as policy and regulatory environments, technological trends, market analysis, and competitive landscape, all important for the strategic planning of the G-RAM project.

Geopolitical and Policy Context
The global raw materials industry faces significant challenges due to increasing demand, geopolitical tensions, and supply chain vulnerabilities. The demand for critical raw materials (CRMs) is driven by the adoption of renewable energy technologies, electric vehicles, and high-tech applications, creating pressure on supply chains predominantly concentrated in a few regions. Policies such as the EU's Critical Raw Materials Act and the Action Plan for Critical Raw Materials aim to secure and sustain CRM supplies by enhancing domestic production, boosting recycling rates, and fostering international partnerships. Additionally, regulatory frameworks like the EU's Mining Waste Directive and Water Framework Directive play crucial roles in ensuring sustainable mining practices and environmental protection.

Technological Trends
Earth Observation (EO) technologies are pivotal in addressing the challenges of the mining industry throughout the lifecycle of mining sites. EO solutions facilitate efficient and minimally invasive exploration, near real-time monitoring of mining sites, and adherence to environmental regulations. Technologies such as Synthetic Aperture Radar (SAR) provide high-resolution monitoring of pit slope stability and enable the early detection of instability. These technologies are also integral in post-closure management of mines and contribute to the circular economy by identifying waste materials suitable for repurposing. The digitization of mining operations through IoT, AI, and cloud computing enhances efficiency, safety, and sustainability, positioning platforms like G-RAM to integrate and analyse data seamlessly for better decision-making and resource management.

Market and Competitive Analysis
The global mining market is valued at approximately $2.14 trillion in 2023, with projections to reach $2.83 trillion by 2028. The smart mining market, the subsegment in which the G-RAM platform finds itself, presents substantial opportunities, with a serviceable available market (SAM) estimated at $1.35 billion. By capturing a portion of this market, G-RAM can leverage advanced technologies to drive efficiency, safety, and sustainability in mining

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operations. The report furthermore provides a detailed competitive analysis of platform providers and geospatial analysis companies, highlighting the potential for G-RAM to offer innovative solutions that address key pain points in the mining industry. The development of applications for mineral mapping, stability and volume change monitoring, and environmental monitoring are identified as critical areas of interest for mining companies, emphasizing the commercial potential of the G-RAM platform.

In conclusion, the report underscores the strategic importance of integrating EO technologies and advanced data analytics into mining operations to address geopolitical challenges, regulatory requirements, and market demands. By focusing on the development of fit-for-purpose solutions, the G-RAM platform is well-positioned to meet the evolving needs of the raw materials industry and contribute to sustainable and resilient supply chains in Europe and beyond.

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2 Introduction

This document aims to provide key insights that will serve as a building block for the GoldenRAM (G-RAM) team to choose the appropriate technical and commercial avenues to pursue in the development of the G-RAM platform, ensuring that fit-for-purpose and commercially interesting and viable solutions are created in line with user expectations. It includes an overview of important policy, technological, market, and economic considerations in the raw materials industry.

The report starts with a concise geopolitical overview to establish the current context that will underpin the subsequent analysis. This includes an overview of the latest global and European priorities and policies related to the sourcing of critical raw materials, including an overview of relevant policies and acts which were recently put in place to achieve these goals, and how the G-RAM platform may support a variety of these policies.

This is followed by a wider raw materials market overview, covering the current state of the market, key trends, technology state-of-play and upcoming developments, overall market size as well as a deep dive into the subsegment of 'smart mining' in which the G-RAM platform finds itself. The deep dive will include a top-down market sizing approach that aims to provide indicative insights into the total available market (TAM), the serviceable available market (SAM), and the serviceable obtainable market (SOM) for the G-RAM platform.

3 Geopolitical Backdrop, Policies, Regulations

The global raw materials industry faces significant challenges primarily due to increasing demand, geopolitical tensions, and supply chain vulnerabilities. The surge in demand for critical raw materials (CRMs) is driven by the rapid adoption of renewable energy technologies, electric vehicles, and high-tech applications. This heightened demand puts immense pressure on existing supply chains, which are often concentrated in a few key regions. For instance, China dominates the supply of rare earth elements, creating a bottleneck that makes global markets susceptible to supply disruptions and price volatility.

To contextualise the demand increase: the world will need 6.5bn tonnes of metals between now and 2050 if it is to decarbonize[1], according to the Energy Transitions Committee, a think-tank - and not just lithium, cobalt and nickel, the much-talked-about battery metals, but steel, copper and aluminium, as well. As this demand is several times greater than today's capacity, producing it will require miners to invest more and dig faster.

[1] https://www.energy-transitions.org/new-report-scale-up-of-critical-materials-and-resources-required-for-energy-transition/

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The world's politicians have taken note, and their statements consistently emphasize the high value that governments place on critical metals. The European Union recently put in place the Critical Raw Materials Act, which similarly attempts to further secure and sustain the supply of CRMs by enhancing domestic production capabilities, boosting recycling rates, and fostering international partnerships. The United States is focused on stockpiling these resources to safeguard against potential disruptions in foreign supply, similar to its vast emergency reserves of crude oil.

The global raw materials market stands at a pivotal juncture with a multitude of challenges ahead, and many geopolitical and economic forces at play.

Resource Nationalism and Other Challenges

Many efforts are being hampered by resource nationalism. A notable issue is that many countries seek to maintain extensive control over their resources, even if it means deterring private investment. For instance, Chile announced plans last year to establish a state-owned company for lithium production. Similarly, countries like Kyrgyzstan, Madagascar, Mexico, and Namibia are imposing high royalties, export bans, and other forms of state intervention.

Geopolitical tensions further exacerbate these challenges. Trade conflicts and export restrictions can lead to sudden supply shortages and increase the strategic importance of securing raw materials. Countries like the United States and China are increasingly viewing the control of CRMs as a matter of national security, leading to policies that aim to reduce dependency on foreign supplies and promote domestic production. These geopolitical dynamics create an unstable market environment, making it difficult for industries dependent on these materials to plan for the future.

Nations are furthermore prioritizing the development of resilient and sustainable supply chains for raw materials as a strategic imperative. Countries like the United States and members of the European Union are investing heavily in domestic mining projects, recycling initiatives, and international partnerships to secure their supply of CRMs. Europe in particular faces unique challenges due to its high dependency on imports for many CRMs from countries like China and Russia.

Dedicated and fit-for-purpose technologies can support these global challenges in many ways, from mineral exploration to site closure monitoring. The G-RAM team aims to develop several solutions relevant to today's CRM challenges, in line with the ambitions of Europe and its trading partners.

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3.1 Key Policies and Regulations

To address the above challenges, the EU has implemented several policies and strategic initiatives. The Action Plan for Critical Raw Materials, introduced in 2020, laid the groundwork by outlining ten concrete actions aimed at developing resilient value chains, reducing dependencies, and promoting sustainable resource use. Building on this, the Critical Raw Materials Act of 2023 seeks to further secure and sustain the supply of CRMs by enhancing domestic production capabilities, boosting recycling rates, and fostering international partnerships. Additionally, the European Green Deal and the Circular Economy Action Plan provide broader frameworks that support these efforts by integrating sustainability and circularity principles across all sectors. These policies collectively aim to mitigate supply risks, ensure environmental protection, and bolster the EU's strategic autonomy in the raw materials market.

3.1.1 Critical Raw Materials Act

The Critical Raw Materials Act (CRMA) is a legislative initiative by the European Union aimed at ensuring the secure and sustainable supply of critical raw materials (CRMs) essential for the EU's green and digital transitions. The CRMA builds upon the foundational framework established by the Action Plan for Critical Raw Materials, which highlighted the need to reduce dependencies on single suppliers and strengthen the EU's supply chains.

One of the core objectives of the CRMA is to enhance the EU's strategic autonomy by increasing domestic production capabilities and reducing reliance on non-EU sources for critical raw materials. This involves significant investments in mining and processing facilities within the EU, coupled with policies that support the development of new mining projects. The Act also emphasizes the importance of sustainable and environmentally friendly mining practices, ensuring that the extraction and processing of these materials do not come at the expense of environmental degradation.

The CRMA also promotes the circular economy by encouraging the recycling and reuse of critical raw materials. By setting clear benchmarks for recycling rates and supporting the development of technologies that facilitate the recovery of CRMs from end-of-life products, the Act aims to reduce the environmental footprint of raw material use and decrease the dependency on newly extracted raw materials.

International cooperation is another key pillar of the CRMA. Recognizing that the EU cannot achieve resource security in isolation, the Act encourages partnerships with third countries to diversify supply sources and create more resilient global supply chains. These partnerships are designed to be mutually beneficial, helping partner countries to develop their mining sectors while providing the EU with access to the critical raw materials needed for its

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industries. The Act also includes provisions for monitoring global supply chain dynamics and addressing potential supply disruptions through strategic stockpiling and other measures

Finally, the CRMA integrates environmental, social, and governance (ESG) criteria into the supply chain for critical raw materials. By doing so, it ensures that the sourcing of these materials adheres to standards of environmental protection, social responsibility, and governance transparency. This approach aims not only to support sustainable development, but also enhance the EU's reputation as a leader in responsible resource management. The integration of ESG criteria helps to address public concerns about the impacts of mining activities and ensures that the benefits of resource extraction are shared more equitably.

3.1.2 Action Plan for Critical Raw Materials

The precursor to the Critical Raw Materials Act is centred on fostering resilient value chains within EU industrial ecosystems. Its key objectives include reducing the Union's reliance on critical raw materials through circular resource utilization, promoting sustainable products and innovation, bolstering domestic raw material sources within the EU, and diversifying sourcing from external countries.

The plan also includes a strategic initiative to deploy Earth observation programmes and remote sensing technologies to enhance the exploration, extraction, and environmental monitoring of critical raw materials. Utilizing the capabilities of the EU's Copernicus Programme, remote sensing can significantly aid in identifying new CRM sites, assessing their potential, and ensuring sustainable mining practices. These technologies provide high-resolution, near real-time data that can track changes in land use, vegetation cover, and geological formations, which are essential for discovering new deposits and planning efficient extraction processes.

3.1.3 Regulations

Mining operations are often strictly regulated, aiming to ensure the sustainable and responsible extraction of mineral resources, aiming to minimise impact on the environment, and also safeguard the health and safety of works and communities. Globally, some of the more important mining regulations include the International Council on Mining and Metals (ICMM) guidelines[2], which promote sustainable development and safety practices in the mining industry. The International Labour Organization (ILO) has set conventions such as the Safety and Health in Mines Convention[3] (No. 176), which sets out safety and health requirements in the mining industry to prevent accidents and occupational diseases.

[2] https://www.icmm.com/en-gb/our-principles
[3] https://normlex.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C176

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In Europe, mining regulations are stringent and comprehensive. The EU has several directives that govern mining operations, including the Mining Waste Directive, which sets out measures for managing mining waste to prevent adverse effects on the environment and human health. The EU Water Framework Directive is also of key importance, as it requires mining operations to protect water resources from pollution. Furthermore, the EU's REACH Regulation[4] (Registration, Evaluation, Authorisation and Restriction of Chemicals) applies to mining operations by regulating the use of chemicals in mining processes.

European national regulations on mining are designed to align with EU directives while addressing country-specific needs and environmental contexts. For example, Germany's Federal Mining Act[5] (BBergG) regulates the exploration and extraction of mineral resources, ensuring sustainable resource management and requiring comprehensive environmental impact assessments before mining activities can commence. In Sweden, the Minerals Act[6] (Minerallagen) mandates that mining operations secure permits that include stringent environmental protection measures and rehabilitation plans for post-mining land use. The Portuguese General Noise Regulation[7] (RGR) is equally relevant to mining operations, which are significant sources of noise pollution due to activities such as drilling, blasting, and heavy machinery operation. Under the RGR, mining companies in Portugal must adhere to strict noise limits designed to minimize the impact of their activities on surrounding communities and the environment.

Water Management

Operational mines discharge poor quality water which impacts the environment, but also closed mines can leak contaminated water and should be monitored. Mine water is covered in the Water Framework Directive[8] which introduces river-basin management and requires that a “good” status must be achieved for all EU water. It is furthermore complemented by the Groundwater Directive[9] which sets quality standards for underground waters and introduces measures to prevent or limit the pollution of ground water. It is a challenge to meet these needs with remote sensing data. Remote sensing may indirectly address those issues by providing several indicators using gravimetry as well as interferometry techniques[10]. Satellite SAR data is capable of accurately assessing the extent of surface water within a mining site as well as water gains and losses in a tailings dam, surface run-off, or any other water body within the area of interest[11].

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02006R1907-20221217
[5] https://www.gesetze-im-internet.de/englisch_bbergg/
[6] https://www.sgu.se/en/mining-inspectorate/legislation/mineral-act-199145/
[7] https://www.ecolex.org/details/legislation/decree-law-no-92007-approving-the-general-regulation-on-noise-lex-faoc069757/
[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32006L0118

[10] https://earsc-portal.eu/display/EO4RawMaterials/Product+Sheet%3A+Ground+Water+Monitoring
[11] https://www.iceye.com/use-cases/mining/surface-water-extent-monitoring

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Nature and Biodiversity Management

Remote sensing can significantly support nature and biodiversity management in mines by providing up-to-date information on surrounding ecosystems. Through the use of satellite imagery, drones, and other remote sensing technologies, it is possible to monitor changes in land cover, vegetation health, and habitat conditions over time. This continuous monitoring allows for the early detection of environmental impacts, enabling timely interventions to mitigate negative effects on biodiversity. Additionally, remote sensing data can aid in the restoration of mined areas by assessing the success of rehabilitation efforts and ensuring that reclaimed land supports the return of native species and natural habitats.

Mining Waste

The mining waste stream is a significant portion of the total waste produced in the European Union, and it includes dangerous components[12]. The EU legislative framework for managing mining waste safely comprises: The Mining Waste Directive[13], introducing obligatory permits and setting requirements for building or modifying an extractive waste facility. If potential risk to the environment or public health exists, operators need to provide a financial guarantee and draw up emergency plans, a policy for prevention of major accidents, and develop safety management systems. EO-data driven services can help with the fast identification of potential leakages or other events are required to enable a speedy response and can furthermore monitor site remediation efforts following an event and provide a historic baseline in support of further investigations into the cause of the event.

The Seveso-III directive[14] covers risks arising from storage and processing activities in mining, particularly tailing ponds and dams used in mineral processing of ores. EO-data has been proven to help assess the stability of tailings dams over time and can be used as an early indicator of instability. SAR imagery is used furthermore to identify where exactly the waste changes on large sites have occurred. Subsequently optical imagery is acquired for the specific locations where changes have been notified. The optical imagery allows for quantitative estimations of bulk material volumes and material classes.

Standard: Global Industry Standard on Tailings Management

Mining associations work together with Programmes and other stakeholders to develop standards that support the continual improvement in the safe and transparent management of mining activities. The United Nations Environment Programme (UNEP) together with Principles for Responsible Investment (PRI), a United Nations-supported international network of investors, closely cooperated with ICMM to create the Global Industry Standard on Tailings Management[15]. This standard will drive the needs and requirements of miners that

[12] https://www.europarl.europa.eu/RegData/bibliotheque/briefing/2012/120376/LDM_BRI(2012)120376_REV1_EN.pdf
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02006L0021-20090807
[14] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0018
[15] https://wedocs.unep.org/bitstream/handle/20.500.11822/36139/GISTM_En.pdf

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aim to implement the safety and monitoring standards outlined in this standard. Remote sensing has been proven to provide valuable insights for this activity[16]. In addition to the standard, ICMM also developed a conformance protocol to help operators and independent third parties assess the implementation of the standard's requirements, and ultimately demonstrate conformance[17].

Call to Include Earth Observation in Reporting Guidance
Including Earth Observation (EO) technologies in the guidance for reporting within regulations affecting the raw materials industry is considered important, as it can ensure consistency, accuracy, and accountability across the sector. By explicitly integrating EO into regulatory frameworks, it can ensure that companies adopt standardized methods for monitoring and reporting their environmental impact, reducing discrepancies and subjectivity in data interpretation. This inclusion also signals to the industry the importance of leveraging advanced, reliable technologies for compliance, which can enhance the credibility and effectiveness of regulations. Moreover, embedding EO in guidance documents helps to future-proof regulatory approaches by aligning them with modern technological capabilities, ensuring that regulations remain relevant and robust in the face of evolving industry practices and environmental challenges.

Examples of policies/regulations that may serve as an example, which mention EO, include the EU environment action programme to 2030 (Decision (EU) 2022/591) where on p. 28 it states "satellite data and processed information taken from the Union's Earth Observation Programme (Copernicus) [...] should be utilised" and on p.35 "integrating data on environmental, health, social and economic impacts, and exploiting fully other available data and services, such as those delivered by Copernicus". Also, the Proposal for establishing a Union certification framework for carbon removals (COM(2022) 672 final) mentions the use of remote sensing technologies on p.3 "The rules laid down under the LULUCF Regulation encourage monitoring land use in a geographically-explicit way, at low cost and in a timely fashion, for example through digital databases, Geographic Information Systems (GIS) and remote sensing, including the Copernicus Sentinel satellites and services (e.g. Climate and Land Services), or commercially available services".

4 Technology State of Play and Trends

4.1 Earth Observation Applications for Mining

[16] https://earsc.org/2021/02/09/eocafe-earth-observation-the-raw-materials-sector/
[17] https://www.icmm.com/en-gb/our-principles/tailings/tailings-conformance-protocols

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Earth Observation (EO) technologies are able to address several challenges faced by the mining industry, in different stages over the course of the lifetime of mining sites. Generally, EO solutions are able to deliver data and insights that boost the efficiency and sustainability of raw material exploration, extraction, and management.

For example, the combination of satellite imagery, other remote and in-situ sensing, and geospatial data analysis, facilitates the discovery of new mineral deposits, enabling more precise, efficient, and minimally invasive exploration techniques. This diminishes the ecological impact of exploration activities, aiding in the preservation of natural habitats, and importantly, improves the bottom line.

Furthermore, EO supports the sustainable practices by offering near real-time monitoring of mining sites and their surrounding ecosystems. This ongoing surveillance ensures adherence to environmental regulations, enables quick interventions in case of ecosystem degradation, and also aids in the post-closure management of mines (e.g. enabling the detection of leaking waste rockpiles).

In the area of safety, space-based Synthetic Aperture Radar (SAR) data enhances mining operations by providing precise, high-resolution monitoring of pit slope stability. Capable of detecting millimetre-level ground deformation over large areas and under all weather conditions, SAR enables early identification of instability, supports frequent and continuous monitoring, and integrates with other systems (such as ground-based radars) for comprehensive risk assessments. Historical data analysis and timely data acquisition aid in informed decision-making and emergency response planning, helping prevent catastrophic slope failures and ensuring the safety of mine workers and equipment.

EO data also enhances the circular economy by tracking raw materials, pinpointing hotspots of waste materials suitable for repurposing or recycling, contributing to the EU's objectives of resource efficiency and reduced import dependency.

Lastly, regulatory agencies and government authorities also leverage EO data to monitor remote sites and curb illegal mining activities by detecting and tracking disturbances caused by such activities.

Overall, integrating EO into the raw materials sector strengthens the EU's capacity to maintain a sustainable and resilient supply chain, in line with broader policy goals such as the Critical Raw Materials Act and the European Green Deal.

4.2 Upstream Satellite Technologies

Satellite remote sensing technologies are well established sources of information in the mining industry, providing comprehensive and precise data important for various stages of

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mining operations. For example, these technologies utilize a range of sensors to capture high-resolution images and spectral data of the Earth's surface, useful for mineral exploration activities. Multispectral and hyperspectral imaging, for instance, can identify mineralogical compositions and anomalies that indicate the presence of valuable deposits. By analysing these images, geologists can pinpoint promising areas for further exploration, reducing the need for extensive ground surveys and increasing overall efficiency.

The future evolution of multi- and hyperspectral satellites promises noteworthy advancements for the mining industry and other sectors relying on precise Earth observation data. Hyperspectral satellites are expected to evolve with higher spatial, spectral, and temporal resolution capabilities. This means that future satellites will be able to capture more detailed images across a wider range of wavelengths, allowing for even finer discrimination of mineral types and composition, increasing their effectiveness to support e.g. exploration activities.

As previously mentioned, SAR data can detect surface deformations, aiding in the assessment of geological structures and stability, which is vital for safe mining operations. SAR technology is also foreseen to evolve in the near future: upcoming SAR satellites will feature higher resolution imaging and, as more satellites are launched, more frequent revisit times, offering continuous monitoring capabilities that are beneficial for detecting and analysing surface changes over shorter periods of time. Enhanced SAR systems will furthermore provide better penetration through vegetation and soil, making it easier to map and monitor subsurface features and geological structures. Furthermore, advancements in interferometric SAR (InSAR) will improve the detection of ground deformation and subsidence with greater precision. The integration of SAR data with other remote sensing technologies, like hyperspectral imaging and LiDAR, will offer comprehensive datasets that enable a more holistic approach to resource management and environmental monitoring.

4.3 Data Processing, Analysis, Consumption

Data processing and analysis are critical components of leveraging remote sensing technologies in the mining industry. Once raw data is collected from satellites, it must undergo several stages of processing to become actionable information. This process typically starts with data pre-processing, which includes steps like radiometric correction, geometric correction, and atmospheric correction to ensure the data is accurate and consistent. Advanced software tools and platforms such as Geographic Information Systems (GIS) are then used to integrate and analyse the data. These tools enable the extraction of meaningful patterns and features, such as mineral compositions, vegetation health, and land use changes, which are essential for decision-making in exploration, site management, and environmental monitoring.

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The future evolution of data processing in for mining applications, as the volume and complexity of remote sensing data continue to grow, will require the integration of more sophisticated AI algorithms. For instance, machine learning models will likely become better at identifying subtle geological patterns and predicting mineral deposit locations, reducing the uncertainty and costs associated with exploration. In addition to the algorithm advancements, the evolution of computer hardware, particularly advancements in semiconductor technology and the development of powerful chips, has dramatically enhanced geospatial analysis capabilities. The shift from traditional CPUs to specialized GPUs and TPUs has significantly accelerated data processing and complex computations, enabling the efficient handling of vast amounts of geospatial data. The combination of these algorithm and hardware improvements will rapidly enhance the capabilities of AI and ML applications for geospatial analysis, allowing for more sophisticated data modelling, processing, and predictive analytics.

Moreover, the adoption of cloud-based platforms such as GoldenRAM will improve how the data is processed, shared, and analysed. These platforms will offer scalable computing resources and advanced analytics tools, making it easier for mining companies to manage and interpret large datasets.

4.4 Digitisation of Mining Operations

Mining operations are increasingly digitizing their processes, leveraging advanced technologies such as IoT (Internet of Things), AI (Artificial Intelligence), and cloud computing to enhance efficiency, safety, and sustainability. By integrating these technologies, mines can automate various tasks, monitor equipment in real-time, and collect vast amounts of data from sensors and machines. This digital transformation allows for predictive maintenance, reducing downtime and operational costs. Additionally, digital twins (virtual replicas of physical assets) – enable operators to simulate and optimize mining processes, leading to better resource management and improved decision-making.

As mining operations become more digitized, they are better positioned to utilize solutions provided by platforms such as GoldenRAM. These platforms offer a centralized and accessible repository for relevant data, enabling a more seamless integration and analysis. For instance, satellite imagery and remote sensing data can be easily ingested into these platforms, providing near real-time insights into environmental changes or slope stability. Cloud-based platforms also facilitate collaboration across different teams and locations, ensuring that stakeholders have access to the latest data and analysis tools.

5 Raw Materials Market

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First some contextual background is provided on the global mining market as a whole, after which a more detailed market analysis is performed for the Smart Mining Market, in which the GoldenRAM platform finds itself.

The global mining market was valued at approximately $2.14 trillion in 2023 and is projected to reach $2.28 trillion in 2024, growing at a compound annual growth rate (CAGR) of 6.5%[18]. This growth is driven by technological advancements, increased investments, and favourable government policies supporting the mining sector. The market is anticipated to expand further to $2.83 trillion by 2028, at a CAGR of 5.5%, fuelled by rising infrastructure development, increased merger and acquisition activities, and the growing implementation of autonomous equipment.

In Europe, the mining market is estimated to be worth around €250 billion as of 2023[19]. This market is significantly driven by the demand for critical raw materials essential for high-tech industries, automotive manufacturing, and renewable energy projects. The European market is expected to grow at a CAGR of approximately 4-5% over the next five years.

The global raw materials and mining market is a vast and diverse industry encompassing a wide range of materials including metals, minerals, and aggregates. This market is driven by the demand for metals and minerals used in various industries such as construction, manufacturing, technology, and energy. Key materials include iron ore, copper, gold, and critical raw materials (CRMs) such as lithium, cobalt, and rare earth elements, which are essential for the green and digital transitions.

The market has experienced significant growth over the past decade, largely due to the increased demand for CRMs in renewable energy technologies, electric vehicles, and electronics. Asia-Pacific remains the largest market, driven by the industrial activities in China, India, and other emerging economies. North America and Europe are also significant markets, with substantial investments in mining technologies and sustainability practices. The market is expected to continue growing, with a projected compound annual growth rate (CAGR) of around 5-6% over the next five years, driven by ongoing industrialization, urbanization, and the global push towards green technologies.

5.1 Mining User Communities

Associations play an important role in setting guidelines and standards for the mining industry. As the industry's foremost advocate, they help promote and enhance the contribution of mining, minerals, and metals to sustainable development. Their

[18] https://www.researchandmarkets.com/report/mining
[19] https://www.statista.com/statistics/443828/top-mining-companies-in-europe-by-revenue/

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responsibilities include providing leadership and opportunities to their members while fostering social, economic, and environmental progress.

- International Council on Mining and Metals (ICMM)
  - One of the largest global user communities in Raw Materials is the ICMM, which unites about a third of the global metals and mining industry with the mission to "drive leadership, action, and innovation for a safe, just, and sustainable world."[20].
  - The ICMM promotes sustainable development within the mining sector, enhancing social and environmental standards while addressing challenges such as mine closure, pollution, and waste management.

- Euromines
  - Euromines is pivotal in Europe's mining sector, serving mainly as a liaison between Europe's extractive industry and European authorities, as well as international and intergovernmental organizations.
  - Euromines addresses environmental user needs by emphasizing environmental sustainability, including initiatives to reduce carbon emissions, lower energy intensity, and decrease discharges to water and emissions to the atmosphere.

- European Raw Materials Alliance (ERMA)
  - ERMA was announced in September 2022 as part of the Action Plan on Critical Raw Materials, aiming to secure access to critical and strategic raw materials, advanced materials, and processing expertise for EU Industrial Ecosystems.
  - With its mission to "bolster the creation of environmentally sustainable and socially equitable innovations and infrastructure," ERMA is expected to drive innovation adoption among miners.

- EIT RawMaterials
  - EIT RawMaterials is the largest consortium in the raw materials sector globally, with a mission to enable sustainable competitiveness of the European minerals, metals, and materials sector along the value chain by fostering innovation, education, and entrepreneurship. It brings together over 120 core and associate partners and more than 180 project partners from leading industries, universities, and research institutions.
  - Its extensive reach and strong emphasis on innovation and entrepreneurship highlight its clear connection to the mining industry's needs, making it a potentially powerful partner for the GoldenRAM team.

[20] https://www.icmm.com/en-gb/our-story/our-members

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5.2 Smart Mining Market Analysis

The global smart mining market is experiencing significant growth, driven by the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and automation into mining operations. In 2023, the market was valued at approximately $12.9 billion and is projected to grow to $33.8 billion by 2031, at a compound annual growth rate (CAGR) of 11.3%[21]. Another study similarly estimates the 2023 "mining software" market size at $11 billion[22]. The forecasted growth is fuelled by the increasing need for efficient, safe, and environmentally sustainable mining practices. Smart mining technologies, including automated equipment, advanced sensors, and data analytics platforms, are enhancing operational efficiency, reducing costs, and improving safety across mining operations worldwide.

In North America, particularly the United States, the smart mining market is growing due to the adoption of cutting-edge technologies and substantial investments in AI and machine learning. These technologies are revolutionizing traditional mining processes by providing data analysis, predictive maintenance, and improved decision-making capabilities. The Asia-Pacific region is also seeing rapid growth, driven by expanding mining activities and governmental support for safety and environmental regulations. Europe follows with a strong focus on sustainable mining practices and advanced technological infrastructure. Overall, the global smart mining market is poised for substantial expansion, reflecting a broader trend towards digitalization and automation in the mining industry.

Total Addressable Market (TAM)

The Total Addressable Market (TAM) represents the overall revenue opportunity available if the G-RAM platform could achieve a hypothetical 100% market share globally in the smart mining industry. Given the projected growth of the smart mining market to $33.84 billion by 2031, we will use this figure as the basis for our TAM.

- Global Smart Mining Market (2031): $33.84 billion
- Estimated TAM for the G-RAM Platforms: It is estimated that data platforms could potentially capture 10% of the total smart mining market (considering the integration of data analytics, AI, and automation solutions into the broader mining ecosystem):

$$TAM = 0.10 \times 33.84\ billion = \$3.38\ billion$$

Serviceable Available Market (SAM)

[21] https://www.skyquestt.com/report/smart-mining-market
[22] https://www.marketresearchintellect.com/product/global-mining-software-market-size-and-forecast/

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The Serviceable Available Market (SAM) is the segment of the TAM targeted by the G-RAM platform that the platform can address with its specific offerings. At the beginning of the century, Europe accounted for about 40% of global mining output. Now, that is down to 3%[23]. Therefore, it is of vital commercial importance to branch outside of Europe already in the early stages of the commercialisation and exploitation of the G-RAM platform, and the first additional target market is foreseen as North America. This would result in the following SAM:

- Europe ($102b[24]), Canada ($55.5b[25]), and the US ($701b[26]) represent approximately 40% of the global mining market. If we target these geographic regions and extrapolate their market share to the smart mining market, this represents an opportunity of:

$$SAM = 0.40 \times 3.38\ billion = \$1.35\ billion$$

Serviceable Obtainable Market (SOM)

The Serviceable Obtainable Market (SOM) is the portion of the SAM that the G-RAM platform realistically expects to capture, considering factors such as competition, market penetration strategies, and business capacity.

- Market Penetration Rate: Assuming a market penetration rate of 5% for the initial years:

$$SOM = 0.05 \times 2.71\ billion = \$67\ million$$

[23] https://www.euronews.com/business/2024/03/12/heres-why-europe-needs-to-revive-its-mining-sector
[24] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Businesses_in_the_mining_and_quarrying_sector&oldid=627700
[25] https://www.thebusinessresearchcompany.com/report/mining-global-market-report
[26] https://www.statista.com/statistics/193416/gross-output-of-total-us-mining-industry-since-1998/

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Summary

- TAM: $3.38 billion
- SAM: $1.35 billion
- SOM: $67 million

These numbers are, of course, estimates and need to be considered an 'order of magnitude' estimation of the market potential for a data/AI platform focused on the smart mining market in Europe. However, the analysis indicates there is a significant opportunity. By capturing a portion of this growing market, the platform can leverage advanced technologies to drive efficiency, safety, and sustainability in mining operations across the continent.

6 Competitive Analysis

This section will provide an overview of potential competitors in the submarket of Smart Mining, which provide platform services similar to GoldenRAM.

6.1 Mining Platform Providers

Platform providers are considered to provide a digital platforms and services designed to enhance the efficiency, safety, and productivity of mining operations through the integration of advanced technologies. These platforms typically support a range of functionalities, including:

1. Data Analytics and Visualization: Tools for collecting, processing, and analysing large volumes of data from various sources such as sensors, equipment, and environmental monitoring systems. The platform visualizes this data to support decision-making processes.
2. Automation and Control: Systems that enable the automation of mining processes and equipment, reducing the need for manual intervention and increasing operational efficiency.
3. Remote Monitoring and Management: Capabilities for monitoring mining operations in real-time from remote locations, allowing for centralized control and oversight.
4. Predictive Maintenance: Features that utilize machine learning and AI to predict equipment failures and maintenance needs, thereby reducing downtime and extending the lifespan of machinery.
5. Safety and Compliance: Tools that help ensure compliance with safety regulations and standards, often including features for real-time tracking of personnel, hazard detection, and emergency response management.
6. Supply Chain Optimization: Solutions that enhance the management of the supply chain, from the extraction of raw materials to their processing and delivery, improving overall efficiency and reducing costs.

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7. Sustainability and Environmental Management: Platforms that support sustainable mining practices by monitoring environmental impact and managing resources more efficiently.

Many service providers/competitors aim at providing holistic, multi-purpose platforms, suitable for a wide range of mining operations, from fleet management to safety and compliance. An overview of such mining platform providers is provided below:

Table 1 Overview of General Smart Mining Platforms

Platform Provider	Description
Power of One platform (Hexagon Mining)	The platform autonomously connects key mining ecosystems, such as exploration, planning, drill and blast, material movement and mine monitoring.
MineRP	MineRP 4.0 is a platform for mining companies to optimize their operations through data integration and analytics, including digital twins.
GEOVIA (Dassault Systèmes)	GEOVIA's "mine operations management solution" fuses together software — including operational control, material reconciliation, and asset performance programs.
RPMGlobal	Supplies enterprise solutions tailored for specific applications (e.g. managing emissions, shift scheduling, asset management) and specific mines
Maptek	Offers software, hardware, and services for spatial analysis, surveying workflows, and operational planning.
Seequent	Provides solutions tailored to different mine life cycle stages, from discovery to restoration, including 3D modelling, drillhole and sample data management, mine monitoring (e.g. slope stability), etc.
Micromine	Micromine Nexus aims to make mining projects more accessible, manageable, and collaborative with enhanced workflow designs, AI and cloud computing, advanced file administration, flexible task management and automated team notifications.
Wenco International Mining Systems	Offers fleet management, machine guidance, and asset health solutions to enhance productivity and safety in mining operations.

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7 Conclusions

This report highlights the complex interplay between the raw materials industry's geopolitical, technological, and market dynamics. The increasing demand for critical raw materials (CRMs) driven by advancements in renewable energy technologies, electric vehicles, and high-tech applications underscores the need for innovative and sustainable solutions. Policies like the EU's Critical Raw Materials Act and Action Plan for Critical Raw Materials are pivotal in addressing supply chain vulnerabilities and ensuring a steady supply of CRMs. The G-RAM platform, by integrating advanced Earth Observation (EO) technologies and data analytics, stands to play a crucial role in this evolving landscape, providing stakeholders with the tools needed for efficient and sustainable mining operations.

The market analysis reveals substantial growth opportunities within the smart mining sector, with the global mining market projected to expand significantly in the coming years. The G-RAM platform's potential to capture a portion of this market is evident through its innovative approach to integrating EO data with advanced analytics. By offering solutions tailored to critical operational scenarios such as mineral mapping, stability monitoring, and environmental impact assessment, the platform addresses key pain points for mining companies. The detailed competitive analysis further highlights the unique value proposition of G-RAM in providing a comprehensive, user-friendly platform that goes beyond traditional service contracts, leveraging cutting-edge technologies to meet the diverse needs of the mining industry.

The application-specific analysis underscores the practical relevance and commercial viability of the G-RAM platform's offerings. By engaging directly with mining companies, the report identifies specific areas where EO technologies can make a significant impact, such as mineral prospectivity mapping and tailings storage facility monitoring. The willingness of mining companies to invest in these solutions, coupled with the platform's foreseen ability to deliver high-quality, actionable data, enables the team to meet the robust demand for innovative mining technologies. Moving forward, the G-RAM platform's focus on developing fit-for-purpose solutions, validated through extensive field testing and user feedback, will be critical in ensuring its success and scalability. In conclusion, the G-RAM project is well-positioned to drive advancements in the raw materials industry, fostering sustainable and resilient supply chains in alignment with broader European and global objectives.

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