DINAMINE

DIGITAL AND INNOVATIVE MINE
OF THE FUTURE

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Final project results

The European economy relies heavily on critical raw materials that support rapidly growing sectors such as electric mobility, renewable energy, and digital technologies. Demand for key materials is expected to rise significantly in the coming decades. Many European mining operations still rely on resource-intensive processes and often conventional processes, which can limit productivity, reduce resource efficiency, and contribute to environmental impacts. Strengthening Europe's resilience and competitiveness therefore requires a transition toward more efficient, digital, and sustainable mining operations. In this context, the DINAMINE project addresses the needs of digitalisation as the mining industry adopts new technologies and innovative tools for smarter and more sustainable mining.

As the project reaches its final milestone, we are thrilled to showcase the core engine of our innovation: the Integrated Smart Mine Planning and Managing system (ISM-PM). This system was built with a clear vision: to provide mine operators, system integrators, and policymakers with the ultimate tool for flexibility and data-driven decision-making. The following modules of the ISM-PM were developed in the project.

The digital backbone: Smart Data Storage module

The Data Storage module is the backbone of the entire operation and serves as a central repository that speaks every language.

- Universal integration: The module acts as the pillar for data from the entire mining value chain, collecting data from chemical analyzers on conveyor belts to environmental loggers and vehicle trackers.
- Agnostic and adaptable: Whether the data consist of structured telemetry or unstructured files and documents, the system handles it all.
- Efficiency in diversity: We successfully demonstrated that a single, well-organized storage system can support both underground and

- above-ground operations. By requiring modules to "declare" their data structure in advance, we ensured that different teams and sensor types could work together seamlessly for the first time.

From data to decisions: Dashboards & Analytics module

Our Dashboards and Analytics module takes the large amounts of information stored in the system and turns it into a clear, user-friendly visual experience.

- A single source of truth: Through a centralized web-based interface, users can access real-time views of the mine, historical performance data, and specialized economic and environmental analytics.
- Granular insights: We've proven that complex factors, like financial tracking and environmental impact, can be monitored right down to the individual block level.
- Streamlining operations: By generating monthly reports directly from live data, we have significantly reduced the time that personnel spend on manual paperwork, allowing them to focus on what they do best: optimizing their mine operations.

Predicting the future: Smart Maintenance module

This module acts as proactive protection for high-value assets. By applying data-driven analysis to live sensor streams, it monitors equipment health in real-time to propose timely interventions. This approach focuses on three key goals:

- Reducing unplanned downtime: Catching malfunctions before they cause a full stop.
- Optimizing schedules: Moving away from rigid calendars to maintenance based on actual wear and tear.
- Extending lifespan: Keeping expensive machinery running efficiently for longer by monitoring environmental conditions and historical performance.

During the project, we put this module to the test on two critical pieces of equipment, chosen in collaboration with our industrial partners:

- Underground drilling machines: Monitoring essential components in harsh subterranean environments.
- Comminution equipment: Ensuring the crushers in the processing plants remain operational.

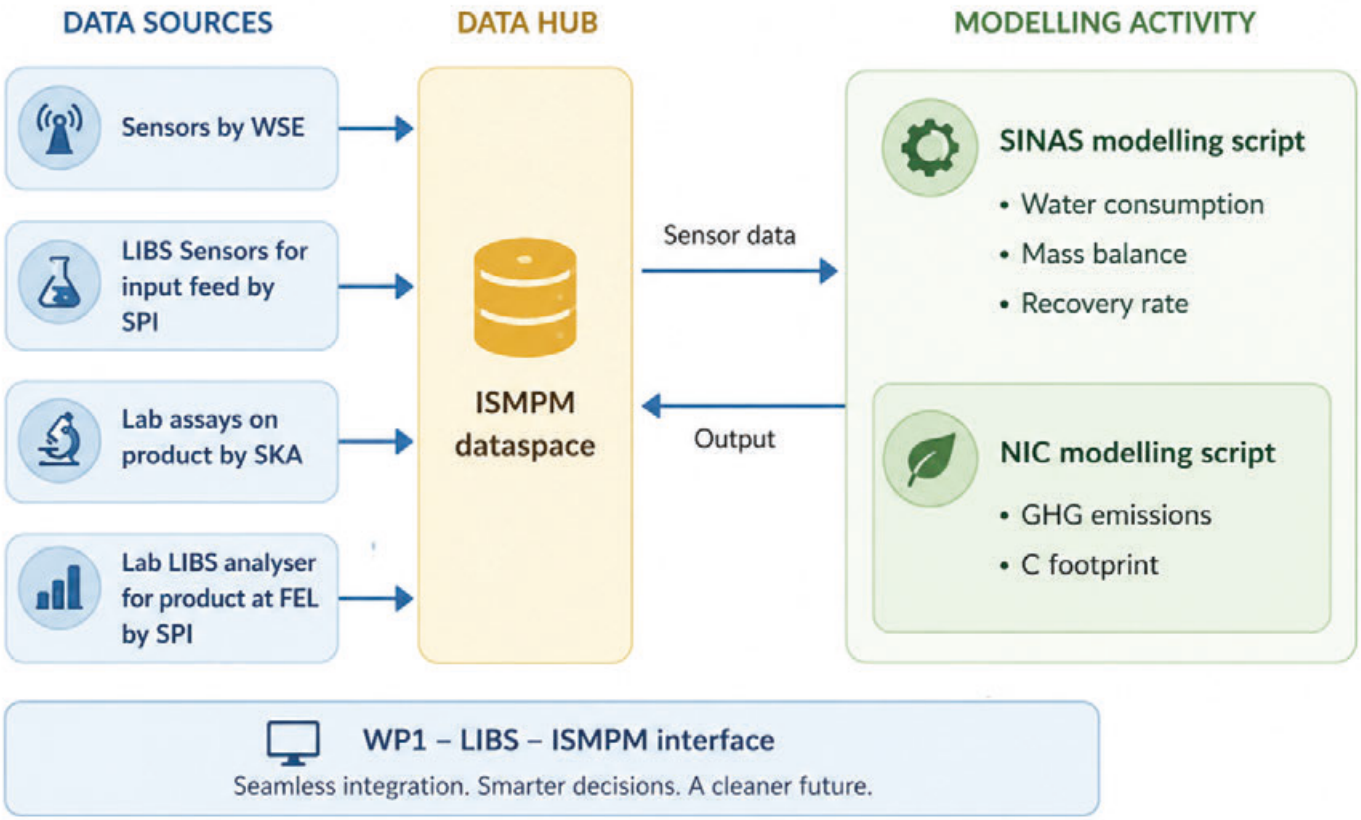
The activity successfully demonstrated the feasibility of detecting precursors of catastrophic failures using routine operational data. While the pilot highlighted the practical realities of sensor calibration and the need for high-quality data sets, it ultimately proved that data-driven maintenance is a viable tool for modern mining operations.

Mineral Processing

The dedicated Mineral Processing task developed a model for monitoring and assessing resource consumption and environmental performance across the mining and processing value chain at the two project pilot sites in Portugal (Felmica Minerais Industriais) and in Norway (Skaland Graphite). The model considers tracking material and energy flows from ore extraction through processing, quantifying resource consumption, estimating recovery rates and mass balances, and evaluating associated greenhouse gas (GHG) emissions in terms of carbon footprint. The assessment considered the distinct mining methods, processing routes, and resource requirements at each site.

From data to impact

Integrating real-world data and advanced modelling



A comprehensive sensor network had been deployed through the joint efforts of the DINAMINE team. The system includes flow meters for monitoring water consumption, load sensors for measuring feed input and product output, LIBS sensors for analysing elemental concentrations, laboratory assays for providing data at critical process points to complete the loops, vehicle tracking solutions for capturing engine revolutions and vehicle location information, and sensors for monitoring electricity and gas consumption. Data collected from these sensors are

continuously integrated into the central ISMPM data hub, where it serves as the foundation for advanced modelling activities. Following the successful deployment of the sensor infrastructure and the availability of operational data, site-specific mineral processing models were developed and demonstrated for each pilot site. The Dashboard module provides insights into process performance.

Meanwhile, the DINAMINE team demonstrated the potential benefits of Selective Ore Transportation by employing real-time elemental characterisation and ore classification. Elemental analysis was performed using a LIBS sensor, developed by project partner Spectral Industries, which offers the advantage of measuring light elements such as lithium alongside other key elements while enabling rapid, on-line characterization without sample preparation. Rock samples from Felmica's Gonçalo Álvares quarry, including lithium-rich lepidolite ore, dark rock, white rock, and waste material, were analysed and classified into low, medium, and high-grade categories based on key indicators such as lithium and iron content. This information provides a practical basis for distinguishing valuable ore from lower value material before transportation and processing. This can reduce unnecessary material handling, lower fuel consumption and transportation costs, improve resource efficiency, and ultimately contribute to more sustainable mining operations with reduced environmental impact.

The DINAMINE team demonstrated the potential benefits of selective ore transportation at Felmica's Gonçalo Álvares quarry.

Digital tracking of mine tailings and integration to the mine planning

A digital tailings characterization tool was developed for real-time monitoring of 14 chemical elements and compounds present after ore processing. Using statistical modelling methods, the tool classifies tailings and continuously tracks their chemical composition. This enables mine operators to obtain a quantitative overview of tailings quality, supporting environmental permit compliance and responsible tailings management. Fully integrated into DINAMINE's digital ecosystem, the tool directly links tailings quality with the processing plant feed and ore quality across different parts of the mine.

Valorisation potential of mine tailings and waste rock

The valorisation potential of mining residues was assessed, focusing on whether tailings and waste rock can be reused as secondary raw materials in construction and other circular-material applications. The study combined chemical, mineralogical, mechanical, and environmental characterisation of Skaland Graphite tailings and Felmica waste rock. Results showed that both material streams have relatively stable and predictable compositions, an important requirement for future reuse applications. Although the materials exhibited limited chemical reactivity and would require mechanical or chemical activation for partial cement replacement, their environmental performance was promising. The findings support several realistic valorisation pathways, including use as fillers in mortars and blocks, partial binder replacement in low-strength cementitious products, fine aggregate substitution, secondary aggregates for non-structural applications, mine backfill, geotechnical fill, and land reclamation. Overall, the results provide a technical basis for reducing reliance on virgin raw materials, lowering disposal demands and supporting circular economy strategies within the European mining sector.

Skaland Graphite tailings and Felmica waste rocks were assessed as potential secondary raw materials for construction, geotechnical uses and other circular-material pathways.

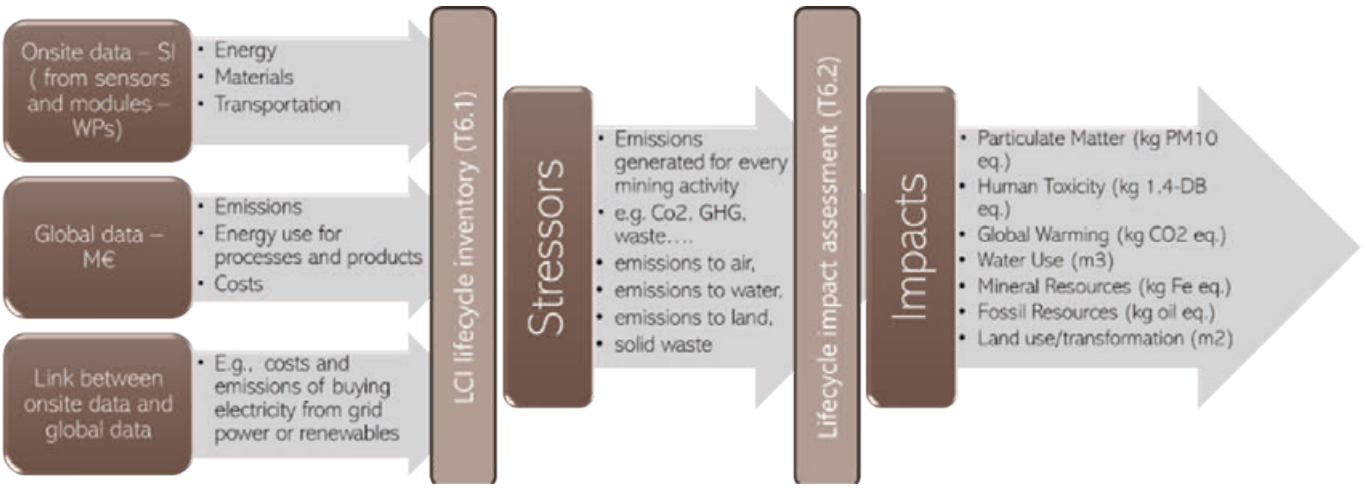
Techno-economic assessment of low-emission transportation alternatives

The DINAMINE team studied the technical and economic aspects of transitioning from fossil fuel to low- and zero-emission mining transport systems. The team assessed carbon-neutral transport solutions, including the evaluation of power demand, infrastructure constraints, and total cost of ownership for technologies such as battery-electric systems. In a public deliverable, we present the key activities required to develop and propose optimal low-to-zero-emission transport solutions tailored for small and medium-sized mining operations and provide a structured framework for identifying, assessing, and recommending sustainable transportation strategies that align with environmental objectives and operational efficiency. The report is published on the project website.

Impact assessment

The Life Cycle Assessment (LCA) module developed in the project collects all data that are needed to calculate the environmental impacts of the DINAMINE tools dynamically. The data are sourced both from on-site sensors and external databases. The module has improved conventional life cycle inventory building, which is data intensive and time consuming, through a combination of several analytical modules integrated in the ISMPM platform. The module is capable of automatically updating shift-specific data within minutes. Furthermore, interpretation of the analysis results has been simplified by exporting the life cycle impact results to an interactive and user-friendly dashboard, also developed within the project to integrate mining information for on-site decision making in the respective operations. The module also supports reporting needs for operational management.

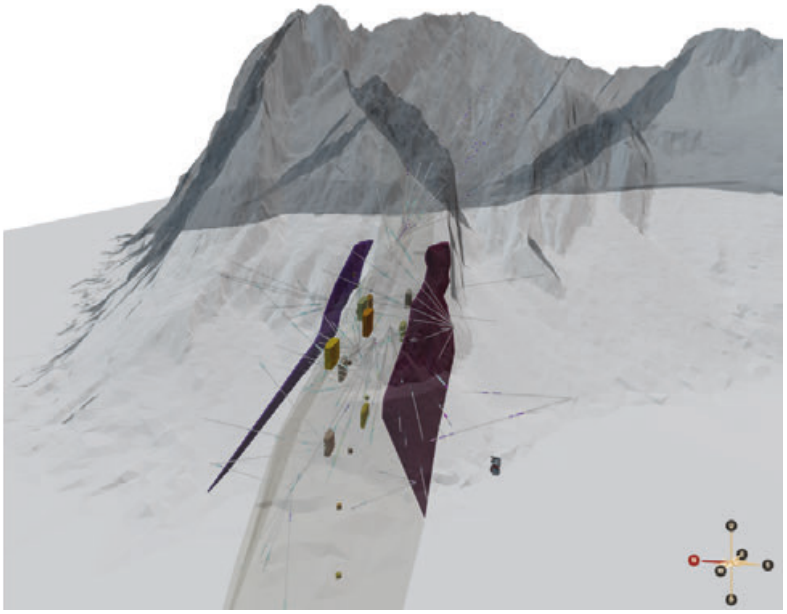
The input and output data are represented, where the global activity is also considered to obtain the stressors and the impacts, which include the contribution to climate change, smog, water resources, land resources, etc.



DINAMINE Results

As the project draws to a conclusion, the numerous results achieved have significant potential for long-term impact and value to the mining sector. Among the results are the cloud-based software modules, the analytical algorithms and new sensor solutions, and the new knowledge produced in the form of open reports and scientific publications. The result exploitation strategy places strong emphasis on modularity, interoperability, and ESG compliance, making DINAMINE results well-positioned to support the transformation of the European mining sector, driving adoption and delivering long-term value to stakeholders. DINAMINE key exploitable results include:

- the Mine Information Model package, which embeds several software modules, including the geological mapping and risk assessment tools, the tailings information model and the short-term and long-term analytics, planning and scheduling tools. Together the modules constitute the core of the DINAMINE concept, providing mine operators, managers and technicians with a solution for holistic management of mining processes. This integrated solution covers operational, environmental footprint and economic factors.



DINAMINE's Mine Information Model, developed by project coordinator NGI, visualises geological, operational and drilling data within a unified digital management environment designed for real-time mine monitoring, planning and scheduling of activities.

- the ‘Semi-automated Jumbo Drill’, a drilling machinery, which was developed for drilling at the tunnel face during mine development operations, using an automated boom guidance system.

DINAMINE’s semi-automated jumbo drill, developed by project partner AMV, has been validated in underground mine operation through several dedicated test periods over the last year of the project.

Digitalisation in mining operations: Challenges, best practices and lessons learned

One of the outcomes of the DINAMINE project is to share knowledge that will foster and accelerate the transition toward a digitalised mining future in small- and medium- sized mining operations. The digital solutions implemented in the project aim to address real-time monitoring and automation needs in the mining industry, while realising environmental, safety and economic benefits of a holistic digitalisation approach. Developing and demonstrating these technologies provided tangible examples of the opportunities and challenges faced in adoption of new digital tools for planning, monitoring and managing small- and

medium-sized mining operations. The DINAMINE project summarised the challenges, lessons learned and some best practices towards the digitization in the mining sector in a report, published on the project website at this link.

EVENTS

Vision for a Digital Mining Future – Cross-Project Event on Digitalization and Innovation in Mining

On 19 May 2026, representatives from leading Horizon Europe projects, research organizations, and industry stakeholders came together in Brussels for the hybrid event "Vision for a Digital Mining Future". Bringing together projects from the DIGIRAW and SmartEcoMine Hub clusters, the event created a valuable platform for collaboration, knowledge exchange, and discussion on the future of digitalization in mining. Participants explored how innovation can support safer and smarter mining operations while strengthening Europe's strategic raw materials ambitions. The programme highlighted cutting-edge developments in cyber-physical systems, advanced sensing technologies, data-driven modelling approaches, and digital solutions for operational optimization and sustainability. A dedicated session on market uptake and exploitation also addressed how research results can be translated into practical industrial applications. Read the press release!

DINAMINE represented at Mine.io Final Event

Project partner PNO Innovation represented the project at the event 'Sustainable Mining Practices in the Future: From Demonstration to Market Perspectives' organised by the Mine.io project. PNO presented the project's solutions that are being developed into commercial products for the mining industry. The workshop brought together project partners, academic communities, stakeholders, and the wider mining and raw materials community who contributed to stimulating and constructive discussions on the future of the industry. DINAMINE and Mine.io are sister projects and are both part of the SmartEcoMine Hub cluster. Both projects are supporting digitalisation of the European mining industry by developing innovative solutions and have participated in international working groups addressing the development of standards and standardization approaches to harmonising the digitalisation efforts in the industry.

DINAMINE was presented at Mineraldagene (Mineral Days) 2026

Mahdi Shabanimashcool (NGI) presented the project results and the solutions that are being developed into commercial products for the mining industry. The Mineral Days conference brought together local communities, decision-makers, academic communities and industry players in Norway to shed light on framework conditions and technological opportunities within critical minerals – a topic that shapes the societal debate through geopolitics and security of supply. The program spanned two days: one day with current political issues and one day where experts met to delve into technical challenges and opportunities.

DINAMINE was in Helsinki for the third Nordic Forum on Raw Materials

DINAMINE was in Helsinki for the third Nordic Forum on Raw Materials! Project technical lead Dr. Mahdi Shabanimashcool and project coordinator Dr. Sean Salazar participated in the Helsinki Summit, which brought together key stakeholders shaping the future of the Nordic mining and raw materials sector. The theme of the event included circular solutions in the mining industry and the skills and technology needed for the future. In the main plenary session, Dr. Shabanimashcool presented “DINAMINE Insights: Digitalization from Mine to Port”. The presentation outlined the approach developed in the DINAMINE project for the digitalization of small-to medium-sized mines in Europe. The event was attended by almost 200 representatives from industry, national organizations,

geological surveys, as well as from policy and finance, serving as a unique platform for discussions on the raw materials sector's most pressing challenges.

DINAMINE partners met in Oslo for a technical workshop

In February 2026, DINAMINE partners met in Oslo for a technical workshop. The workshop focused on interpreting sensor data from our project pilots, the mineral processing and carbon footprint models and visualizing results of the mine planning, economy and environmental impact reporting.

Consortium

NGI

Skaland Graphite

FELMICA Minerais Industriais, S.A. Uma empresa do Grupo MCS PORTUGAL

WORLD SENSING

SINTEF

KEMIJSKI INŠTITUT

AMV EST. 1860

PNO INNOVATION

SPECTRAL INDUSTRIES

Stay tuned for more updates as we continue on our mission to create a mining industry that is greener and more sustainable!

www.dinamine-project.eu @DinamineP /company/dinamine/

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