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Strengthening the EU's raw materials value chains through interregional collaboration: the I4-GREEN case

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Strengthening the EU's raw materials value chains through interregional collaboration: the I4-GREEN Case

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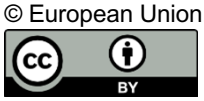

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List of Acronyms

ERDF	European Regional Development Fund
EDP	Entrepreneurial Discovery Process
EU	European Union
GVC	Global Value Chain
I3	Interregional Innovation Investments Instrument
LDR	Less Developed Region
MAs	Managing Authorities
MS	Member State
R&D	Research and Development
S3	Smart Specialisation Strategies
S3CoP	S3 Community of Practice
SME	Small and Medium Enterprise

1. Introduction

Access to sustainable and secure raw materials has become a strategic concern for the European Union (EU) and its Member States (MS) over the past decades. Raw materials underpin all industrial value chains, serving as the foundation for Europe's economic competitiveness, technological innovation, and social well-being.

In its 2020 Communication Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability, the European Commission (EC) emphasised the strategic nature of the mining sector for achieving EU autonomy. It highlighted its indispensable contribution to the green and digital transitions — from clean energy systems and batteries to digital infrastructure and advanced manufacturing.

While the mining sector is shaped by global market dynamics and dominated by multinational corporations, mining itself is fundamentally local and place based. Each mine is embedded in its regional ecosystem, dependent on local geological, environmental, and social conditions. This intrinsic localisation means that regional innovation ecosystems and SMEs play a decisive role in achieving both competitiveness and sustainability in Europe's raw materials value chains.

Despite its industrial strength, the EU remains a net importer of raw materials and has faced a continuous trade deficit in this area since 2002. This dependency exposes Europe to risks linked to supply disruption and price volatility. Meanwhile, demand for metals and minerals is expected to double by 2050, driven by the global shift to clean technologies, digitalisation, and population growth.

To mitigate these risks, the EU must simultaneously increase its domestic production capacity, develop circular economy solutions such as recycling and reuse, and strengthen regional innovation ecosystems capable of supporting sustainable mining technologies. This is particularly pressing for Critical Raw Materials (CRMs), identified by the European Parliamentary Research Service as a "fundamental prerequisite" for achieving the EU's strategic priorities.

In this context, the Interregional Innovation Investments (I3) instrument plays an increasingly important role in delivering on the EU's wider industrial and competitiveness agenda. By supporting the scaling of interregional value chains, accelerating the deployment of innovative solutions, and enabling collaboration between more and less developed regions, the I3 Instrument contributes directly to several EU strategic objectives. In fact, it helps to reduce external dependencies, strengthen industrial resilience, foster technological leadership, and build competitive, sustainable European value chains in strategic sectors — including raw materials, clean technologies, agri-food, health, and digital transformation.

Through its focus on commercial deployment and investment readiness, I3 acts as a bridge between regional innovation potential and EU-wide industrial policy priorities.

This analytical article presents the case study of the **I3 project I4-GREEN**, illustrating how it builds upon a decade-long process of interregional collaboration supported by different EU programmes — notably Horizon 2020, Interreg Europe, and the Smart Specialisation (S3) Thematic Partnerships — to contribute to greening of EU's mining industry.

The I4-GREEN initiative represents a new stage in this collaborative journey. It exemplifies how EU instruments, and particularly the I3 Instrument under the ERDF 2021–2027, can catalyse sustainable, circular, and socially responsible innovation in critical raw materials supply chains. By combining interregional collaboration, SME participation, and pilot demonstrations aligned with broader EU sustainability goals, I4-GREEN addresses some of Europe's most pressing challenges: dependency on external raw material sources, environmental degradation, and the need for circular, low-carbon industrial models.

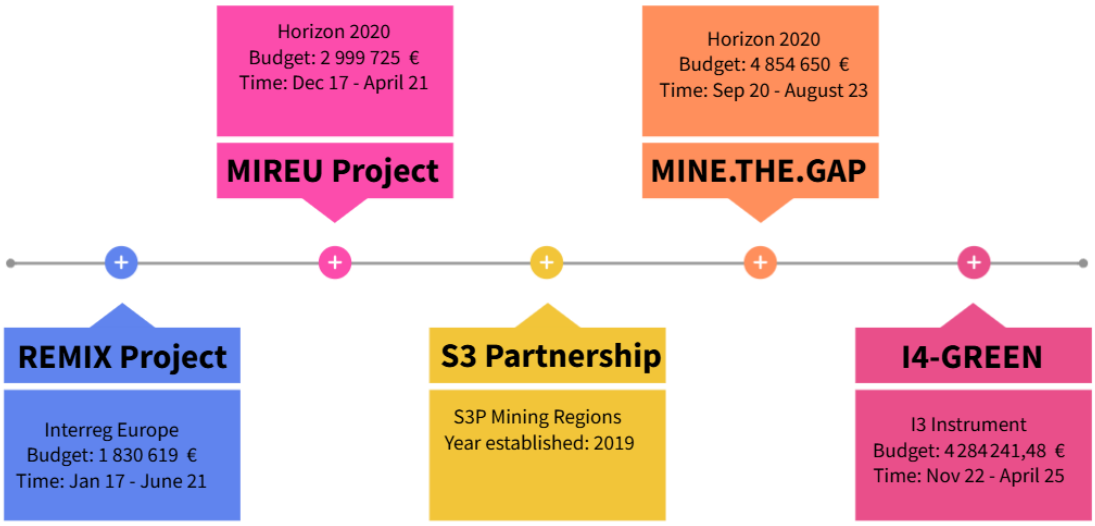
Beyond its technological achievements, I4-GREEN is a demonstration of how trust-based, interregional cooperation can evolve over time into concrete investment and deployment. The case study highlights how European regions, by working together across borders and aligning their smart specialisation strategies, can strengthen their role in the global raw materials landscape and reinforce Europe's resilience and leadership in the transition to a sustainable, circular economy.

Ultimately, the I4-GREEN experience suggests a promising model for future EU initiatives: one in which long-term collaboration, shared vision, and multi-level governance enable regional innovation ecosystems to become key actors in Europe's green industrial transformation.

2. A journey of trust and transformation: the story behind I4-GREEN

The journey leading to the *I4-GREEN* project has its roots in a decade of interregional cooperation within the EU's raw materials sector. Early collaborative efforts under Horizon 2020 and Interreg Europe laid the foundation for a shared European approach to sustainable mining (see Figure 1).

Figure 1. The I4-GREEN Journey



Source: Authors based on case study report p.61[1]

This collaboration began with two cornerstone projects under Horizon 2020 and Interreg Europe (2021 – 2027):

- **MIREU** (Horizon 2020) promoted the sustainable supply of raw materials across Europe, developed a *Social Licence to Operate* toolkit to improve community acceptance, and established networks of mining regions to share knowledge and experiences Strengthening **innovation capacity** for growth, jobs, and sustainable investment;
- **REMIX** (Interreg Europe) focused on interregional policy learning, the exchange of good practices, and embedding "smart and green mining" principles into regional innovation strategies (RIS3).

Together, these initiatives marked a **paradigm shift** — moving beyond isolated research projects towards a coordinated European approach to sustainable mining. They helped regional authorities, research organisations, and SMEs **build mutual trust**, align policy agendas, and create a shared understanding of how mining can contribute to the EU's green and digital transitions.

[1] *Evaluation study on the external coherence and synergies of Horizon 2020 within the European research and innovation support system – Final report*, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2777/90147

The policy recommendations emerging from REMIX urged regions to explicitly recognise mining as a driver of green growth, while MIREU's outcomes provided the methodological and social frameworks necessary for responsible extraction. Their combined legacy laid the groundwork for the next phase: **turning policy and research insights into concrete, interregional investments**.

Through structures such as the **Council of Mining and Metallurgy Regions (CoMMER)**, hosted within the ERRIN network, and the **European Raw Materials Alliance (ERMA)**, the community built under MIREU and REMIX has continued to coordinate policy and sustain engagement beyond individual projects. These platforms have reinforced the legitimacy and influence of regional actors in shaping EU raw materials policy.

Building on this momentum, the **Smart Specialisation Thematic Partnership on Mining Industry** was launched in 2019. This partnership — involving nine regions from five Member States — provided the collaborative framework that would eventually give rise to I4Green.

The partnership has served as a platform for:

- Facilitating **networking and knowledge exchange** among mining regions;
- Strengthening **innovation capacity** for growth, jobs, and sustainable investment;
- Supporting **SMEs** in accessing markets and integrating into global supply chains;
- Acting as a **bridge** between regions and the European Commission to co-shape raw materials strategies

This interregional collaboration became a **living laboratory of trust and co-creation**, where public authorities, research institutions, and industry partners gradually built the confidence and capacity needed to move from experimentation to deployment.

I4Green has also enriched its activity through synergies with other S3 partnerships, notably **Advanced Materials for Batteries for Electro-Mobility and Stationary Energy Storage**, which aligns with the new EU Batteries Regulation and promotes recycling and resource efficiency, and **Efficient and Sustainable Manufacturing and SMEs to Industry 4.0**, further connected mining innovation with broader industrial modernisation efforts.

In September 2020, the **MINE.THE.GAP** project was launched under the **INNOSUP Programme** of Horizon 2020 (*Innovation in SMEs*). While not a direct continuation of MIREU or REMIX, it represented a **spin-off initiative** that expanded the ecosystem's scope. MINE.THE.GAP connected technology providers, industrial clusters, and SMEs to **create new and improved value**

chains in the mining sector. The project placed particular emphasis on supporting SMEs in their **transition towards more sustainable and digital mining practices**. It provided innovation vouchers, financial support, and business services, enabling smaller firms to test, validate, and commercialise new solutions.

This initiative bridged a critical gap in the innovation pipeline — translating policy frameworks and research knowledge into **tangible business-led innovation**. It also deepened interregional collaboration, reinforcing the trust and cooperation developed under MIREU and REMIX by fostering **cross-sectoral partnerships** among regions, industries, and research actors.

The *I4-GREEN* project represents a **step ahead of this long collaborative journey**. Emerging from years of interregional dialogue, shared experimentation, and mutual learning, it embodies the EU's strategic ambition to translate policy coordination into industrial action.

Participation in **Horizon 2020** and **Interreg Europe** projects provided the foundation for this evolution. While Horizon 2020 fostered scientific excellence and international collaboration, Interreg promoted policy integration and interregional learning. The *MINE.THE.GAP* project complemented these by offering financial and business services to SMEs, accelerating technology transfer and market readiness.

However, as many Horizon 2020 projects concluded at lower Technology Readiness Levels (TRLs), the need arose for mechanisms that could **bridge the gap between research and industrial deployment**. To bridge the remaining gap between research and market uptake, the **Interregional Innovation Investments (I3) Instrument** under the ERDF 2021–2027 offered the mechanism to move from experimentation to investment.

Thus, the *I4-GREEN* initiative is an **industry-driven project born from years of European cooperation and trust-building**. It aims to deploy circular economy innovations in mining operations, advancing the EU's vision of sustainable resource management.

It tested and scaled up new solutions through two pilot projects:

- **Pilot 1 – Extremadura, Spain:** Development of forefront technologies to recover minerals from iron mining waste, reducing environmental impact and alleviating EU dependency on imported materials
- **Pilot 2 – Andalusia, Spain:** Implementation of advanced hydrometallurgical leaching techniques to recover essential metals from primary sulphide minerals, contributing to the sustainable supply of resources for the green transition.

By moving from policy design to **industrial implementation**, *I4-GREEN* embodies the evolution of Europe's raw materials strategy — from isolated

research and regional experimentation to **coordinated interregional investment in circular and sustainable mining technologies**.

3. The I4-GREEN journey: A case story of innovation cooperation and impact

3.1. Overview of the I4-GREEN project

Box 1. Project fiche

Full name	Interregional investment for the sustainable supply of raw materials in the EU Green Energy Transition (I4-GREEN)
Duration:	30 months (Nov 2022- April 2025)
Total budget	4,284 million EUR
Coordinator	ICAMCyL Foundation
Consortium partners	eight partners: Cluster Portugal Mineral Resources (ACPMR), ICAMCyL Foundation, Gevora, Leonore Development, Atalaya, Lain Tech, Nanofabre, Iberian Sustainable Mining Cluster (ISMC); and 16 associated partners.

The I4-GREEN project kicked-off in November 2022. It was set to address several interrelated **challenges** Europe faces:

1. **Dependence on imports of critical raw materials,** as many raw materials critical for green technologies are imported often from outside the EU.
2. **Environmental impact** of extraction, processing, waste (tailings, dumps) and unsustainable mining practices.
3. **Deindustrialization** & underdeveloped innovation ecosystems in mining / extractive regions which are also often less developed regions.
4. The need for **green, circular, and socially responsible technological innovation in raw materials production** to align with EU Green Deal, CRM Act, and sustainability goals.

To do this, the I4-GREEN took a very “applied” approach, in the spirit of I3 Instrument as its core activity was about the **deployment of two industrial pilots in the mining industry in the least developed regions of Europe**, in Extremadura and Andalusia, Spain. These pilot projects were part of the proposal with the prior agreement with relevant industrial partners on their participation in the project.

The pilots approach allowed to **test, scale up and demonstrate green and circular innovations in extraction and processing industries** with their potential **replicability across similar regions** (in terms of geology) in the mining regions of Portugal and Spain.

The new solutions on recovery of rare earths, use of waste, lower-impact processing, circular mining deployed in the pilots contributed to project objective in **reduction of the environmental impact of the industry and increasing sustainability in mining**. Furthermore, I4-GREEN ensured **substantial SMEs participation** in the project, as SMEs were able to propose their innovative solutions for the two pilots and benefit from financial support, business services, and technical assistance for innovations to be developed and deployed.

Box 2. Project snapshot

Pilot 1 – IHO (Iron Holm Oak)	Pilot 2 –ATALAYA / LAIN TECH
Location: Iron District in the Iberian Peninsula, Extremadura, Spain	**Location:** Riotinto site, Andalusia, Spain
Consortium Partners leading: Gevora and Leonore	**Consortium Partners leading:** Atalaya Mining and Lain Tech
Context: the pilot to process ore of the Iron District of the Iberian Peninsula (IDSWI), which extends over 120 km through the regions of Alentejo, Extremadura and Andalusia.	**Context: the** pilot to process the ore from Cerro Colorado in Riotinto mine, a typical volcanic-hosted massive sulphide (VHMS) deposits of the Iberian Pyrite Belt (IPB), one of the most important districts for this type of deposit in the world.
Technology: advanced mineral processing, rare earth element (REE) recovery, nanofiber-based water purification, and renewable energy systems to enable circular extraction from mining waste	**Technology**: E-LIX hydrometallurgical technology for extracting strategic raw materials from low-grade ores and eco-efficient industrial water treatment
Objective: Unlock the potential of endogenous mineral resources using advanced technologies and innovative circular processes	**Objective**: Scale up hydrometallurgical processing for the recovery of essential metals, such as copper and zinc minerals needed for the green transition from complex sulphide concentrates in Iberian Pyrite Belt
Partner roles: Regional agencies and research organisations lead technological development and validation; SMEs contribute with advanced filtration and valorisation technologies; mining operators facilitate industrial implementation and pilot site access	**Partner roles:** Technology developers lead process design and scaling; SMEs provide innovative materials and environmental services; mining companies validate and adopt the technology in operational settings.

3.2. Designed for impact: success factors of the project

In addition to strategically building and drawing on synergies with other EU projects in the raw materials and mining (see section 2), the I4-GREEN project design was grounded in activities that allowed to mobilise necessary resources, partners, and ensure the innovative solutions tested in the pilots are scalable and can attract investments once the I3 project is over. The elements that allowed for this to happen are detailed below.

3.2.1. Pulling resources - partners and technologies - for the success of the pilots and their potential replicability

ICAMCyL, the International Center for Advanced Materials and Raw Materials of Castilla y León, the coordinator of the project played a critical role in bringing all relevant stakeholders into the project to ensure it yields the intended results. For this, it leveraged its position as a bridge between research and industry and built on decades of inter-regional collaboration in the sector together with the excellent knowledge of the regional ecosystems in Spain, Portugal and other European regions. In addition, clusters – **Cluster Portugal Mineral Resources, and the Iberian Sustainable Mining Cluster** – partners in the project, further strengthened the project's linkages to the industry and regional ecosystems in the field of raw materials and mining making project implementation firmly embedded in the challenges and opportunities of each region involved.

To make sure that the technologies tested through pilots are scalable and can be replicable across similar regions, the I4-GREEN mobilised **regions** from Finland (Helsinki -Uusimaa and Pohjois-ja Itä-Suomi regions) that possess a highly innovative technology they were able to transfer within the framework of the pilots. Similarly, Italian more developed region of Lazio was involved in technology transfer within the project bringing the know-how in water membrane technologies. Portugal's Alentejo region that shares geological characteristics of the Spanish regions participating in pilots was a natural partner in the project to prepare the replicability of the pilots.

The mobilisation of **research institutions** across Portugal (University of Lisbon, University of Evora), Spain (University of Oviedo, University of Extremadura, University of Jaen), Finland (Business Joensuu from Karelia, Geology Survey of Finland), Greece (National Technical University of Athens), Spanish National Research Council (CSIC) and the International Raw Materials Observatory (Intraw), and the EIT Raw Materials allowed to explore and support innovative solutions for green, circular, and sustainable mining technologies deployment in the EU.

Managing authorities across regions in Portugal (Alentejo) and Spain (Andalucia, Castiila y Leon, Extremadura) were involved in the project from its conception through to its implementation. They participated in project meetings and were closely following the progress of the pilots' deployments seeing substantial benefits for the regional development, incl. S3 objectives achievement and regions' contribution to a greener Europe.

Finally, bringing on board **industrial partners** committed to innovation, such as Atalaya Mining, Gevora, Lain Tech, Leonore, Naofaber, VenturaOrts, Asimagra, N-Able was critical for the testing and enabling the scale up of novel solutions.

Figure 2. Consortium overview[2]

Partners	Type
ACPMR cluster	Cluster
ISMC Cluster	Cluster
ICAMCYL	NGO
GEVORA	Industry
NANOFABER	Industry
LEONORE	Industry
LAIN TECHNOLOGIES	Industry
ATALAYA MINING	Industry
VENTURA ORTS	Industry
Associated partners	**Type**
UNIVERSITY OF OVIEDO	RTO
INTRAW	NGO
National Technical University of Athens	RTO
GTK Mintek	RTO
Business Joensuu	Industry
University of Jaen	RTO
University of Extremadura	RTO
EIT Raw Materials Andalusia Hub	EU association
CSIC-EIT Raw materials Hub-Andalusia	NGO
ASSIMAGRA	Cluster
University of Evora	RTO
Junta de Castilla y León	Government
University of Lisboa	RTO
N-ABLE	RTO
Junta de Andalusia	Government
Supporting Institutions & Entities	**Type**
Government of Extremadura	Government
Junta de Extremadura	Government
EU Cluster Alliance	Cluster
EIT Raw Materials GmBH	EU association
AMINER	Association
S3P Mining Industry	EU association
S3P Advanced Materials for Batteries	EU association

3.2.2. Engaging SMEs to source new ideas and technologies with spillovers for the regional ecosystem's development and inter-regional collaboration

SMEs made critical contributions to the I4-GREEN project as they **developed new solutions to cover the pilots' technological needs**, and thus, helped advance the mining industry towards a greener and more circular pathway.

To engage SMEs, an **open call** was announced in June 2023 to run from July to September 2023. To facilitate the SME application, the I4-GREEN Technical Open Session was held online in September where pilot companies – the Iron Holm Oak and Atalaya/Lain Tech- shared with attendants' specific technical parameters to ensure a perfect fit to the real pilots' requirements (1-IHO Extremadura & 2-E-LIX Andalusia). As a result of the call, 12 SMEs were selected from 28 applications to support the two pilot projects, i.e., 6 SME per each pilot. The cascade funding available under the project allowed for SMEs to benefit from 30 thousand EUR each. Furthermore, the awarded SMEs did not only collaborate with the pilots through their solution's deployment but also received business services support.

The ecosystem support services were developed for the SMEs awarded the project open call. The services were aimed at informing enterprises about

[2] https://i3-i4green.eu/wp-content/uploads/2025/09/D1.9-Final-I3-I4-GREEN-Public-Report.pdf

different opportunities under the project such as webinars, B2B or workshops, etc. This additional support to SMEs included the elaboration of guides that helped SMEs to see what other support mechanisms exist at the EU and member states' level to support the testing and deployment of their innovative solutions (Box 3).

Box 3. Support materials to SMEs under I4-GREEN project

The SME Guide on Transition Support Instruments[3] contains a list of available financial instruments at EU and sub-EU levels (regional/national) that can support the transition toward circular and sustainable models in raw materials sector. Through the evaluation of Research and Innovation Strategies for Smart Specialization (RIS3) and regional policy mixes, key financial resources were identified to support sustainability of innovative projects and technology scale up. In addition, the guide highlighted the role of the cluster collaboration tools – such as the European Cluster Collaboration Platform (ECCP) and the European Strategic Cluster Partnerships (ESCP) in cross-sector partnerships and innovation and brought to forefront the insights from initiatives like INNOSUP-01 MINE.THE.GAP.

The study on SME and ecosystem integration was developed and published in 2023 to ensure I4-GREEN project effectively contributes to S3 objectives and aligns with RIS3 areas in the regions of Castilla y León, Andalusia and Extremadura in Spain and Alentejo in Portugal [4]. It also provided an analysis of the potential for green processing tech and mining SMEs engagement in I4-GREEN project activities.

The review of sustainable practices[5] provides the review of relevant databases and resources, drawing on the outputs from key projects (i.e., H2020-MIREU and Interreg REMIX), and builds on it to provide sustainable practices and technologies successfully implemented in the mining sector worldwide (e.g., recycling and reprocessing, renewable energy integration, use of digital technologies, etc.). The report also contains a selection of practices and tools applicable to SMEs in I4-GREEN project based on their feasibility, potential impact on sustainability, and adaptability to SMEs and different operational contexts. The practices were showcased and mainstreamed in pilot projects under i4-GREEN and its dissemination activities

3.2.3. Enabling scalability of innovative solutions demonstrated through pilots and pathways for pilots' sustainability

To ensure that the project results into 1) two pilots attracting further private sector investment, 2) pilots are replicated in other EU regions, the I4-GREEN conducted strategic dissemination activities, replicability and foresight studies, and

[3] https://i3-i4green.eu/wp-content/uploads/2025/04/D5.3-SME-Guide-on-Transition-Support-Instruments_I4-GREEN_vfinal.pdf

[4] https://i3-i4green.eu/wp-content/uploads/2024/07/I4-GREEN_D2.1_SME-and-ecosystem-engagement-report.pdf

[5] https://i3-i4green.eu/wp-content/uploads/2025/04/D5.2-Review-of-Sustainable-Practices_vfinal.pdf

developed a Pilot Action Plan and Portfolio of Investment Leads. Altogether, these activities prepared a solid ground for the project results' sustainability beyond the I3 project financing cycle.

When it comes to **strategic dissemination activities**, for instance, the I4-GREEN partners - Iberian Sustainable Mining Cluster (ISMC) and ICAMCyL, organised the *Strategic European Investment Forum for the Critical Raw Materials Sector* on June 17, 2024 in Seville. It allowed to not only showcase the I4-GREEN project results among key players of the ecosystem but also showcase sustainable and circular practices in mining.

More than forty companies participated in the event, with ten of them having presented their innovation projects to European experts in investment opportunities from the European Investment Bank (EIB). The project concluded on the 10 April 2025 at the *high-level event held at Club Financiero Génova* in Madrid showcasing the results of the two pilots in raw materials recovery.

When it comes to **replicability of the I4-GREEN pilots,** several studies provide an in-depth analysis of the potential of innovative mining technologies tested in two pilots under the project and beyond (Box 4). For instance, taking into account the geology and the ore of the deposits which have been used as a basis for the pilots, a list of 24 sites has been selected by their potential replicability for E-LIX and IHO pilots. For E-LIX pilot, the replicability study carried out in I4-GREEN has identified 13 ongoing mines or mining projects with a clear potential to replicate the E-LIX technologies, especially in Andalusia and Alentejo but also in similar deposits of Extremadura and Castile & Leon. Regarding the IHO pilot, the replicability study identified 11 closed mines and mining projects, with the suitable geological characteristics to replicate the technologies implemented in the pilot. Of these, 9 are located in the Alentejo and Extremadura, and an example of different type of deposit but similar ore has been also selected from Extremadura and Castile & Leon. The replicability study contributed to reflection on improvements in current processing techniques for metal recovery and re-evaluation of closed mines.

The final project report also suggests that in Spain, the Andalusia region, particularly rich in metallic sulphides in Iberian Pyrite Belt in parts of the Huelva and Seville provinces, the volcano-sedimentary complexes in the Northern part of Cordoba province, and the metallogenic zone of Linares-La Carolina in Jaen province would be a perfect region for replication of pilots. In Portugal, the E-LIX technology application in mineral deposits and mining tailings could be applied in the region of Alentejo, the Ossa-Morena Zone and the Cambrian and Silurian formations.

Box 4. Studies on the replicability of I4-GREEN results

The Priority Sector Report for the Raw Materials Sector in I4-GREEN Regions[6] provides a strategic analysis of the raw materials sector across four core regions involved in the I4-GREEN project: Andalucía, Extremadura, Alentejo, and Castilla y León. Establishing regional profiles, it focuses on regions' readiness for sustainable and circular mining practices and benchmarks regional assets and innovation capacities. It establishes a comparative overview of ecosystem dynamics in the raw materials sector, highlighting shared characteristics, regional complementarities, and offering a maturity assessment to support cross-regional strategy development and targeted investment planning. Strategic recommendations contained in the report aim to strengthen cross-regional collaboration, foster joint innovation initiatives, enhance policy alignment, and mobilise public and private investment in support of the raw materials sector within the I4-GREEN territories. The report shows how I4-GREEN project is aligned with other European Commission Tools for regional innovation and S3, such as Regional Innovation Scoreboard (RIS), S3 Platform, S3CoP, EIP on Raw Materials Monitoring and Assessment Framework. The proposed metrics, leverage points and visual benchmarks contributed to the RIS.

The Mirroring Strategy[7] report analyses the capacities of Alentejo, Andalusia, Extremadura and Castile and Leon to promote and replicate, i.e., "mirror", the mining projects similar to I4-GREEN pilots. The analysis placed Andalusia on the top due to the management of mining issues it practices and the potential to develop projects. The assessment was done based on the regions' availability of replication sites, inclusion of mining in the RIS3 strategies and membership of the regions in the TSSP Mining, as well as available support for the mining projects development and the network of regional stakeholders. The study results highlighted the importance of the regions' membership in TSSP Mining and presence of dedicated actions in the RIS3 strategies as levers to encourage the development of mining projects and to mobilise funding opportunities.

Finally, the **Pilots Action Plan** and **Portfolio of Investment Leads**[8] was developed to further support the pilots scale up beyond the project lifecycle. The Pilots Action Plan covered a set of potential sites for replication of the I4-GREEN pilots and a combination of measures to promote their deployment. The Portfolio of Investment Leads highlighted that TPPS Mining Industry and Global Value Chains would be the best positioned to lead investments for the replication sites. It also drew on the overlaps identified in the TPPS and I4-GREEN project and included two groups of investment opportunities: 1) the list of potential sites for pilot replication and 2) the I4-GREEN as a project model for other mineral resources. The first contains 24 sites, including 7 potential sites from Alentejo, 9 from Andalusia and 6 from Extremadura, as well as 2 other sites from the fourth I4-GREEN region –Castile and Leon. The second defined I4-GREEN project as

[6] https://i3-i4green.eu/wp-content/uploads/2025/09/D6.4-Priority-Sector-Report.pdf

[7] https://i3-i4green.eu/wp-content/uploads/2025/09/D6.1-Mirroring-Strategy.pdf

[8] https://i3-i4green.eu/wp-content/uploads/2025/04/D6.2-Pilots-Action-Plan-Portfolio-of-Investment-Leads_v4f_Submitted28062024.pdf

model for projects addressing other mineral deposits outside the Iberian mining districts, probably with different typologies but similar ores. Finally, the document outlines the main funding opportunities for identified projects across I3, Interreg and Horizon Europe, linking the project results to European-level mechanisms available to support the progress in green and circular mining.

3.3. Outcomes & Impacts

The main outcome of the I4-GREEN project was the **successful implementation of the two industrial pilots in Andalusia, Spain** strengthening interregional value chains and delivering key tools to foster sustainable mining practices across Europe.

The **IHO pilot**, led by Gevora and Leonore Development, developed a fully synchronised process plant that enables simultaneous iron ore production and REE separation, minimising waste and maximising efficiency. It achieved the production of high-grade iron ore (71% Fe) and the recovery of rare earth elements from waste, extracting concentrates with 17,000 ppm TREO which represents an essential contribution to green steel manufacturing across Europe and a significant breakthrough for resource recovery.

IHO includes a comprehensive environmental strategy for a significant reduction of water (by means of a closed-loop water cycle), the integration of renewable energy, advanced process automation, and improved logistics, significantly lowering the project's overall carbon footprint. In addition, the circular approach for tailings allows the reuse of waste materials, not only as additional minerals recovered from these tailings, but also as repurposed materials for use in construction and cement production.

Finally, IHO's next steps put the focus on scaling to full industrial operation. The long-term vision includes not only the production of iron ore and REE concentrates but also the conversion of REE oxides into marketable carbonates and the development of new value chains around pyrite and other critical raw materials such as copper, nickel and cobalt.

The **ATALAYA / LAIN TECH** achieved industrial validation of the E-LIX™ hydrometallurgical process for extracting strategic raw materials — including copper (Cu), zinc (Zn), cobalt (Co) and platinum group metals (PGMs) — from low-grade ores (complex sulphides). E-LIX integrates a unique process that dissolves complex sulphide concentrates, followed by solvent extraction and electrowinning (SX-EW), successfully overcoming the long-standing challenge of passivation in sulphide leaching, offering a commercially viable and environmentally sound alternative for low-grade, polymetallic ores. In fact, it showed considerable potential for replication across the Iberian Pyrite Belt and similar polymetallic deposits.

By implementing no fossil fuel usage and adopting circular resource strategies, the project achieved up to 90% CO_2 reduction and positioned E-LIX as a model for responsible sourcing and sustainable mining in Europe. According to the ISO 14040-compliant Life Cycle Assessment, E-LIX achieved a Carbon footprint reduction of 46% per tonne of feed, a water use reduction of 10%, and a fossil resource use reduction of 22%. These reductions contribute directly to the EU's Green Deal objectives, positioning E-LIX as a model for responsible sourcing and sustainable mining in Europe.

In addition to advancing technology in the field of raw materials extraction and positive environmental impact, two pilot projects achieved and have the potential to yield significant **socio-economic impacts**.

Thus, thanks to the pilot, the Lain Tech plant created 72 jobs. Post-I3, the scale up of the Elix technology is expected to generate more than 150 direct jobs in Atalaya and potentially 1000 indirect jobs over its first years of operation. Lain Tech is expected to reach about 100 direct and 550 indirect additional jobs within 5 years if the process recovery plant approach is mirrored and replicated in other deposits across Andalusia region. When it comes to IHO pilot, by reactivating dormant mining operations in economically challenged regions, it is expected to generate local employment and promote social inclusion through integration of women in mining. Additionally, a dedicated social reinvestment fund has been established drawing on generated mineral sales, to support community needs affected by mining activity.

Together with the replication pathways developed by the project, the pilot results could be scaled across mining regions of Spain, Portugal, Greece and other EU countries **multiplying the environmental, social and economic impacts** of I4-GREEN Project. These results can also **contribute to stronger ecosystems**, capable to engage in complex inter-regional collaboration, and include the following learnings:

- SMEs engagement through cascade funding under I3 not only allowed SMEs to develop their technologies within pilot projects but strengthened SMEs' capacities to engage in EU projects, even as complex as I3. This contributes to fostering regional ecosystem and its linkages with other regional ecosystems.
- Job creation and social inclusion initiatives demonstrated by the I4-GREEN project pilots prove that it is possible to deliver economic value in raw materials sector while respecting both people and the planet. In addition, these effects make a substantial contribution to social acceptance of mining projects in the region where development of mining activity is often stigmatised by the population.
- Clusters that were critical for the successful implementation of I4-GREEN project strengthened their contribution to regional ecosystem

development, including financial. In addition, clusters increased their capacities to engage in similar complex inter-regional projects.

Finally, the project has generated several **policy impacts** that have implications for the development of the policy mechanisms in the CRM field. In addition to showcasing the value of the I3 instrument in supporting progress towards EU's strategic objectives, the project:

- Through its study of the mining dumps and wastes deposits in the I4-GREEN regions in Portugal and Spain, provided evidence for policy decisions on support to sustainable mining in the regions while unlocking economic potential from mining wastes, aligning with EU directives and regional investment strategies.
- Through its study on mirroring possibilities and continuation of the alliances created within the ecosystem, traced the pathway and provided concrete solutions for replication of two pilots and collaboration mechanisms in other geographical contexts and industrial sectors.
- Through the Pilot Action Plan and Portfolio of Investment Leads provided evidence for investments from the private sector into the raw materials in I4-GREEN regions and links such investments and innovative projects could make with the European programme in this area (e.g., other projects under I3, Interreg POCTEP programme and Horizon Europe clusters 4 and 5).
- Building critical networks for interregional collaboration on CRM through strategic meetings and relationship-building with leading figures from the mining sector, analysts, and diplomatic representatives from Uzbekistan, Canada, Australia and Morrocco under the umbrella of the Investment Club Genova (e.g., High-level Strategic Breakfast on securing access to critical raw materials on 14 April 2025 in Madrid).

4. Lessons learnt & the road ahead

Drawing on the I4-GREEN experience, several elements stand out when reflecting on lessons learnt for the future I3 projects implementation. First, it is the alignment and seeking of synergies with other EU-funded projects. Second, the difficulties and the value of engaging industry and SMES. Finally, it is the intentional stirring of project pilots towards investments post-I3 project, along with the scalability of the solution proposed.

4.1. Building on the “travelled distance”: leveraging partnerships, aligning strategic objectives and buiding synergies

A key lesson emerging from the I4-GREEN experience is the **importance of building progressively on prior collaboration** rather than starting from scratch. The project demonstrates how **long-term interregional cooperation, grounded in trust and shared objectives**, can evolve from policy dialogue to industrial deployment.

The cumulative experience gained through earlier initiatives — such as MIREU, REMIX, and MINE.THE.GAP — provided not only the **technical and policy foundations** but also the **institutional relationships and mutual confidence** required to undertake investment-oriented actions.

The **continuity of actors and networks** across successive EU programmes (Horizon 2020, Interreg Europe, INNOSUP, and I3) proved essential for aligning regional, national, and European strategies in the raw materials domain. This “travelled distance” fostered a common language among policymakers, researchers, and industry partners, allowing them to jointly identify investment priorities and design mechanisms for scaling up innovation.

Another key insight is that **synergies among initiatives**—such as links with other S3 partnerships on Advanced Materials for Batteries, Efficient Manufacturing, and SMEs to Industry 4.0—enhance the transformative potential of each individual project. By embedding mining innovation within broader industrial modernisation efforts, I4-GREEN demonstrated how cross-sectoral collaboration can accelerate the green and digital transitions.

Ultimately, the I4-GREEN case shows that success in **interregional innovation depends not only on funding or technology but on the strategic alignment and continuity** of partnerships. Building on accumulated knowledge, fostering trust, and maintaining institutional bridges between projects enables regions to move from experimentation to implementation and to sustain collective impact over time.

4.2. Engaging industry and SMEs: intensive communication, enhanced coordination and adopting the “same language”

Among the main challenges I4-GREEN project encountered when engaging with SMEs and industry was the **difference of the mindset** (industry VS innovation project funded by EU) and lack of **understanding of how the EU projects operate**. In fact, companies struggled to understand the logic of the European projects, especially when the project timelines faced the reality of industrial processes (e.g., delays in receipt of materials, etc.). In addition, the EU project reporting requirements and confidentiality rules were difficult for companies to navigate.

To address these challenges, the I4-GREEN project adopted several mitigation strategies:

- **Alignment of project deliverables/components with business strategy:** Projects were most successful when the pilot aligned with the company’s strategic objectives.
- **Ensuring clarity and flexibility:** SMEs required clear explanations of project timelines and functioning, as well as adaptations of project components to their specific goals.
- **Establishing intensive communication:** Frequent bilateral and informal meetings were held to help build trust and mutual understanding, i.e., “speak the same language”.
- **Leveraging organisational leadership and reputation:** The coordinator’s credibility, long track record of cooperation within the ecosystem encouraged companies to stay engaged and communicate openly.
- **Securing necessary legal and IP support:** Bring in IP lawyers and experts helped address intellectual property and confidentiality concerns companies had.
- **Providing tailored coaching to companies:** Dedicated time was allocated to coaching of companies’ project managers to facilitate their participation in the project.

4.3. for the future from the start: investing in “projects bankability” and enabling scale-up effects

One of the main challenges the I4-GREEN project faced in ensuring the replicability of results and scalability of innovative solutions was the **variation in geological conditions and innovation capabilities across the mining**

regions involved (Andalucia, Alentejo, Castilla y Leon, and Extremadura). To address this, the project conducted an **in-depth analysis of the replicability potential**, which included:

- a stakeholder database and enabler mapping to identify ecosystems where I4-GREEN pilot replication projects can be promoted[9]
- studies on regional geology and ecosystems maturity[10] for the adoption of sustainable mining technologies, incl. the I4-GREEN pilots replicability.[11]

These efforts provided a solid evidence base for assessing the potential to scale up the technologies in other regions, although the results differ depending on the factor considered. For example, based on geology, Andalusia and Alentejo are the regions with higher potential for E-LIX replicability, and Alentejo and Extremadura stand out for IHO; Alentejo and Andalusia clearly stand out if RIS3 policies are taken as criteria; and Andalusia, Castile & Leon (and to a lesser extent Alentejo) have the strongest enablers' ecosystem. On the other hand, according to the Portfolio of Investment Leads (see the description above), the I4-GREEN project helped to lay the groundwork for private investments in scaling up existing technologies or developing new ones in the field of sustainable mining.

Finally, the **choice of pilots** was critical for the success and the sustainability of the project. The I4-GREEN coordinator, ICAMCyL, drawing on the previous partnerships and knowledge of the ecosystem, selected for the proposal the plants whose industrial development objectives matched the objectives of the project. In other words, ATALAYA/LAIN TECH and IRON HOLM OAK were already on the path of investing into the innovative technologies for raw materials extraction and mining waste valorisation.

[9] https://i3-i4green.eu/wp-content/uploads/2025/09/D6.1-Mirroring-Strategy.pdf

[10] https://i3-i4green.eu/wp-content/uploads/2025/09/D6.3-Report-Benchmarking-clustering.pdf

[11] https://i3-i4green.eu/wp-content/uploads/2025/09/D6.4-Priority-Sector-Report.pdf

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