I4-GREEN

I4-GREEN
(Report Benchmarking & clustering)
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General information

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Description of the related task and the deliverable. Extract from DoA	T6.3 Clustering within clusters: a regional perspective for a benchmarking strategy towards cluster development in (M18-M30) Lead Beneficiary: ACPMR, Contributors: ISMC A series of clustering workshops between I4-GREEN clusters and other relevant regional clusters will be aimed to the identification of joint cluster collaboration actions. We will build upon the European Strategic Cluster Partnerships for Smart Specialisation Investments (ESCP-S3) and identify key clustering topics to promote fruitful discussions and result-oriented activities, such as 1/ cluster innovation and international deployment 2/ Strategic analysis 3/ Regional Ecosystem Benchmarking 4/ Cluster partnerships in Europe and beyond. A report on Benchmarking and clustering activities (D6.3) will include an action plan that shall be driven by quadruple helix and SME involvement. I4-GREEN will also prepare a "Priority Sector Report" for the raw materials sector in the regions covered by I4-GREEN, thus contributing to the Regional Ecosystem Scoreboard (D6.4).
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Glossary	
Acronym	Meaning
ACPMR	Associação Cluster Portugal Mineral Resources
CRMA	Critical Raw Materials Act
DIHs	Digital European Innovation Hubs
EDP	Entrepreneurial Discovery Process
ECCP	European Cluster Collaboration Platform
EFSI	European Fund for Strategic Investments
EIC	European Innovation Council
EISMEA	Innovation Council and SMEs Executive Agency
E-LIX	Atalaya/Lain Tech Pilot Project for hydrometallurgical leaching
ERDF	European Regional Development Fund
ESG	Environmental, Social and Governance
ESIF	European Structural and Investment Funds
IHO	Iron Holm Oak (Pilot Project)
ERMA	European Raw Materials Alliance
ESG	Environmental, Social and Governance

REE	Rare Earth Elements
SLO	Social Licence to Operate
S3P	Smart Specialisation Platforms
TSSPs	Thematic Smart Specialisation Partnerships
IFRM-SEISA	Investing Forum in Raw Materials – Sustainable Ecosystems of Innovation and Strategic Alliances
INNOSUP01	Innovation in SMEs – INNOSUP H2020 Programme
IPB	Iberian Pyrite Belt
ISMC	Iberian Sustainable Mining Cluster
KPI	Key Performance Indicator
LIFE	EU's Programme for Environment and Climate Action
PGM	Platinum Group Metals
REE	Rare Earth Elements
RIS3	Research and Innovation Strategies for Smart Specialisation
RTO	Research and Technology Organisation
S3P	Smart Specialisation Platform
SME	Small and Medium Enterprise
SLO	Small and Medium Enterprise
SRMIS	Spring Raw Materials Innovation Summit
TSSP	Thematic Smart Specialisation Partnership
VHMS	Volcanic-Hosted Massive Sulphides

EXECUTIVE SUMMARY

This report consolidates the findings and outcomes of the benchmarking and clustering activities undertaken as part of the I4-GREEN project. Building on the European Strategic Cluster Partnerships for Smart Specialisation Investments (ESCP-S3), this report identifies and develops key clustering topics aimed at fostering cross-sectoral synergies and impactful, result-oriented actions. It covers four central thematic axes: (1) regional ecosystem benchmarking (2) cluster innovation and international deployment, (3) strategic analysis, , and (4) cluster partnerships within and beyond Europe. A structured action plan is presented at the end, shaped by the quadruple helix model and centred on SME involvement.

1. OBJECTIVES

- Compare Regional Ecosystem Capabilities
  Compare regional innovation ecosystems related to sustainable raw materials and mining value chains.
- Facilitate Cluster-Driven Innovation and Collaboration
  To stimulate synergies between industry, academia, SMEs, and public authorities for the deployment of green and circular innovations.
- Design a Quadruple Helix-driven Action Plan
  To develop a roadmap of the main priorities.
- Strengthen the European Raw Materials Value Chain
  To contribute to Europe's strategic autonomy and alignment with Green Deal objectives through sustainable ecosystem development.

2. BENCHMARKING METHODOLOGY

The benchmarking and clustering methodology used a qualitative approach based on the ECCP leveraging established European frameworks and adapting them to the raw materials context of I4-GREEN.

2.1. FRAMEWORK DESIGN

The analysis is based on four strategic dimensions inspired by the European Cluster Collaboration Platform (ECCP) and Smart Specialisation (S3) principles:

- Innovation Capacity: Level of collaboration in R&D, participation in EU projects, innovation maturity.
- Cluster Ecosystem Maturity: Strength of cluster governance, support infrastructures, inter-regional coordination.
- SME Engagement & Adoption: Involvement of SMEs in sustainable innovation, access to support mechanisms.
- Circular Economy Implementation: Integration of circular practices, policy support for resource efficiency.
- Alignment with smart specialisation strategies: Ensure the projects rooted in local capacities, which boosts economic relevance and impact.

Each region or ecosystem was assessed using these dimensions to identify performance profiles and strategic positioning.

2.2. DATA COLLECTION TOOLS

Desk research: Reviewed ECCP profiles, regional innovation strategies, regional innovation scoboards and participation in EU-funded projects (Horizon, Interreg, EIT RawMaterials).

Event-based mapping: Leveraged Pan-EU emulation sessions as real-life data collection opportunities, where 100+ stakeholders interacted:

- Spring Raw Materials Innovation Summit – Industry and Innovation in Raw Materials, organized by the Iberian Sustainable Mining Cluster (ISMC) and the International Center for Advanced Materials and Raw Materials of Castilla y León (ICAMCyL) Foundation, was carried out on March 29th, 2023, in the Technology Park of León (Spain), in collaboration with Clusters Meet Regions, the MINE.THE.GAP Project and other Europea Projects as participants;
- The Autumn Raw Materials Innovation Summit (ARMIS), organized by the Iberian Sustainable Mining Cluster (ISMC), was carried out on October 25th, 2023, in the Hotel Rafael Pirámides in Madrid (Spain), in collaboration with other European Projects;
- The Investing Forum in Raw Materials - Sustainable Ecosystems of Innovation and Strategic Alliances (IFRM-SEISA), organized by the Iberian Sustainable Mining Cluster (ISMC) with the support of ICAMCyL Foundation, took place on June 17th at the Hotel Meliá Sevilla in Seville, Spain;
- Clustering in European Innovation for Sustainable Practices was organized by ISMC. It took place on October 14th, 2024, in the Hotel Occidental Sevilla Viapol in Seville, Spain.

3. REGIONAL BENCHMARKING

A comprehensive review of the I4-GREEN regions)Castilla y León, Andalucía, Alentejo, and Extremadura) hasa been carried out with a focus on their innovation capacity, cluster ecosystem maturity, SME engagement and adoption and circular economy implementation. Each region has been analyzed individually to assess current strengths, challenges, and opportunities, offering valuable insights to support sustainable growth and green innovation across Southwestern Europe.
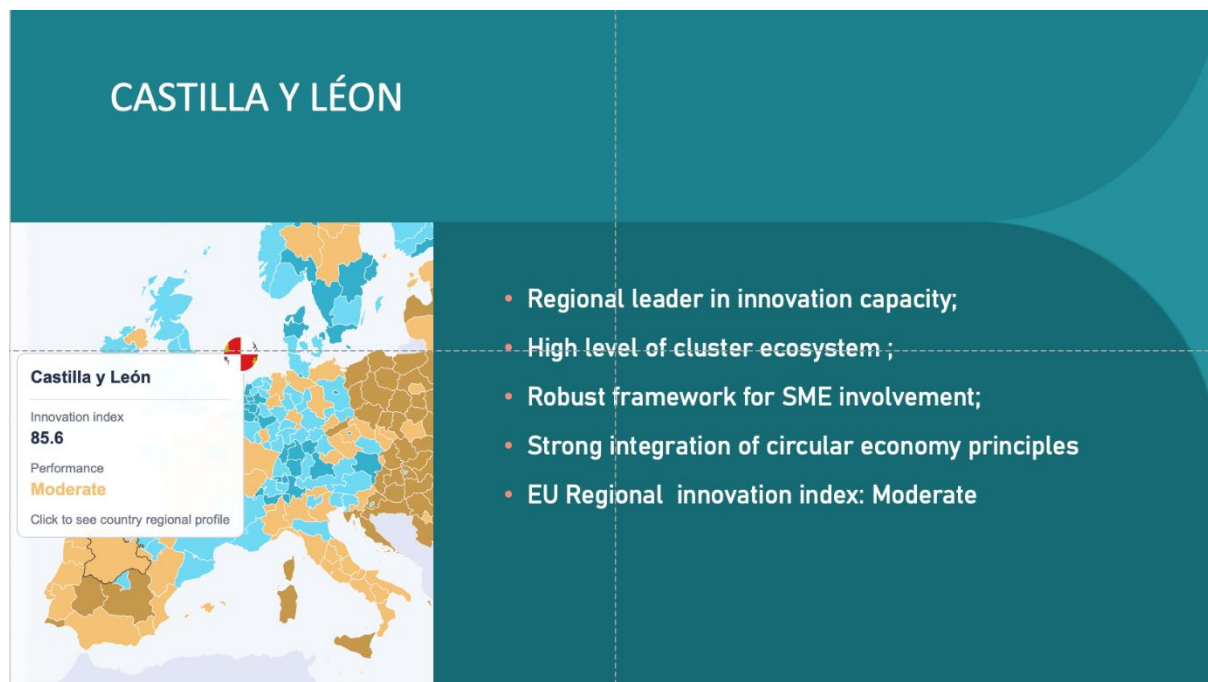
3.1. CASTILLA Y LEÓN

FIGURE 1: CASTILLA Y LÉON SNAPCHOT– SNAPSHOT DEVELOPED USING INFORMATION FROM THE RESULTS OF I4GREEN, THE REGIONAL INNOVATION INDEX AND RIS3 CASTILLA Y LÉON

Innovation Capacity

The region benefits from the presence of multiple research centers, SMEs, and universities actively engaged in applied research and technology transfer. ICAMCyL (I4-GREEN coordinator) in particular plays a critical coordinating role in fostering collaborations across the quadruple helix and positioning the region as a testbed for circular economy and raw materials innovation.

Castilla y León combines historical mining expertise with a growing commitment to sustainable transformation. The region is home to one of Europe's key tungsten operations (Barruecopardo), extensive slate and feldspar resources, and legacy mining sites with valorisation potential. Although its mining innovation ecosystem is still developing, the region co-leads the S3P Mining and Advanced Materials platform, and actively contributes to EU-level smart specialisation and circular economy agendas

Cluster Ecosystem Maturity

Castilla y León exhibits a high level of cluster ecosystem maturity due to the strong governance models and institutional synergies established between ICAMCyL and other regional and national stakeholders. The region has implemented effective inter-cluster coordination mechanisms that promote cross-sectoral and cross-regional dialogue, including through its leadership in organizing high-impact events.

The ecosystem is also supported by an established infrastructure of technology parks (e.g., Parque Tecnológico de León), research centers, and academic institutions, which work

together to integrate R&D outputs into industrial practices. Castilla y León actively participates in the Entrepreneurial Discovery Process (EDP) under the S3 framework, reinforcing strategic alignment and ensuring regional policies support innovation and sustainability objectives.

These elements are further complemented by digital matchmaking and knowledge-sharing tools such as MINE.THE.GAP, which enable continuous collaboration among clusters across Europe and beyond. This has positioned Castilla y León not only as a strong regional actor but as a strategic partner in the European sustainable raw materials innovation ecosystem.

SME Engagement and Adoption

SMEs play a pivotal role in the innovation landscape of Castilla y León, particularly in the raw materials and mining sectors. The region has developed a robust framework for SME involvement through the coordination of ICAMCyL, which ensure access to pilot projects, open calls, and capacity-building mechanisms. Events such as the SRMIS facilitated direct engagement with SMEs via matchmaking sessions and innovation galleries.

Projects like MINE.THE.GAP have been instrumental in bridging SMEs with technology providers, end-users, and funding instruments. SMEs have benefited from support in technology transfer, business development, and sustainability assessments, enhancing their ability to scale green solutions. Specific examples include SMEs involved in geophysical services, environmental remediation, and low-impact mining engineering, all of which participated in I4-GREEN networking and knowledge-sharing activities.

Moreover, Castilla y León promotes SME access to EU programs through targeted workshops and advisory sessions on Horizon Europe, EIT RawMaterials, and Interreg funding, simplifying complex application processes and reinforcing SME innovation adoption.

Circular Economy Implementation

Castilla y León demonstrates strong integration of circular economy principles within its regional innovation framework. Through projects like ReSilex and I4-GREEN, the region emphasizes the use of circular strategies such as raw material recovery, recycling of photovoltaic components, and closed-loop industrial processes. The active role of ICAMCyL in piloting new technologies for waste valorisation and material reprocessing illustrates a deep commitment to reducing environmental impact and optimizing resource use.

Policy support is also evident through the alignment of regional development plans with national and EU circular economy objectives, backed by funding from Horizon Europe and Interreg. The Entrepreneurial Discovery Process (EDP) and local S3 strategies reflect a prioritization of resource efficiency and green industrial transformation.
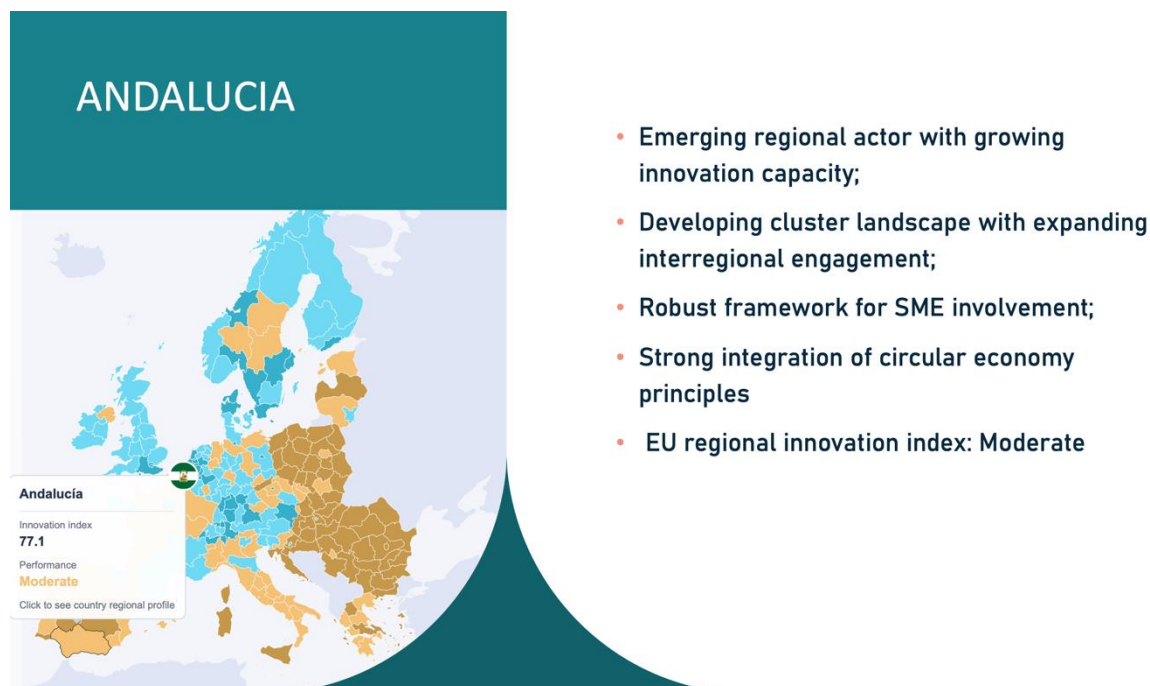
3.2. ANDALUCÍA

FIGURE 2: ANDALUCÍA SNAPCHOT– SNAPSHOT DEVELOPED USING INFORMATION FROM THE RESULTS OF I4GREEN, THE REGIONAL INNOVATION INDEX AND RIS3 ANDALUCIA

Innovation Capacity:

Andalucía demonstrates growing innovation potential, supported by a strong mining tradition and a regional commitment to sustainability and digitalisation. The presence of key innovation players such as AMINER (Asociación de Empresas Investigadoras, Extractoras, Transformadoras Minero-Metalúrgicas y de Servicios) and the support of the Junta de Andalucía (Associated Partner of I4-GREEN) have helped catalyse interest in green and digital transition projects. The region has hosted major events, such as the Investing Forum in Raw Materials – Sustainable Ecosystems of Innovation and Strategic Alliances (IFRM-SEISA), reinforcing its visibility in EU innovation circles.

Andalucía is increasingly engaged in EU-level discussions on sustainable raw materials through clusters and associations. Continued alignment with European priorities could further strengthen its innovation profile.

The E-LIX technology, piloted in the Riotinto site, represents a globally unique innovation capable of overcoming passivation in the leaching of complex sulphides—an industrial bottleneck in conventional hydrometallurgy. Through its integration of solvent extraction, electrowinning, and modular design, the E-LIX system has successfully validated the recovery of copper and zinc cathodes at industrial scale, while exploring recovery routes for other critical raw materials such as silver, lead, and platinum group metals. The innovation process is supported by the use of Life Cycle Assessment (LCA) methodologies, carbon footprint analysis, and water footprint optimization, all aligned with international environmental standards (e.g., ISO 14040).

The region has created a favorable environment for cross sectoral colaboration, involving technology developers (e.g., Nanofaber, partner of the project), EPCM contractors, universities (e.g., Universidad de Huelva), and public authorities (e.g., Junta de Andalucía), along with SMEs participating through open calls. This multistakeholder involvement enables not only co-creation of technological solutions but also their replication across similar geological contexts, especially within Alentejo region.

Cluster Ecosystem maturity:

The presence of ISMC contributes significantly to the maturity of the regional mining ecosystem. Maturity in this context refers to the degree of integration between mining stakeholders (industry, academia, public authorities, and civil society), the availability of innovation infrastructure, the adoption of sustainable technologies, and the capacity to generate cross-sector value. While regions like Andalucía and Extremadura demonstrate a higher level of maturity due to active pilot deployment and institutional alignment, Alentejo and Castilla y León show emerging maturity, with growing involvement in EU platforms and

ISMC's contribution strengthens the foundation for a more coordinated, innovation-led, and socially accepted mining industry. By aligning regional priorities with EU strategic objectives—such as reducing dependence on imported raw materials and promoting green industrial value chains—ISMC positions these regions as key players in Europe's sustainable transition.

SME Engagement and Adoption:

Andalucía demonstrates SME engagement and technology adoption within the raw materials and mining sectors, particularly through the mechanisms established by the I4-GREEN project and other projects and initiatives such as MINE.THE.GAP or MIREU. The regional ecosystem, coordinated by the Iberian Sustainable Mining Cluster (ISMC), has effectively mobilised SMEs around sustainability and circular economy goals, fostering both awareness and practical participation in innovation activities.

A key factor in this engagement has been the use of the MINE.THE.GAP platform, which facilitated targeted matchmaking between SMEs, technology providers, and industrial players. Andalucían SMEs were not only recipients of technical knowledge but also active contributors to several project components—ranging from geophysics, environmental consulting, and water treatment, to advanced material recovery and process optimization. Notably, SMEs from this region participated in the open call under I4-GREEN, contributing directly to the pilot E-LIX, where some evolved from technical contributors to core technology suppliers.

Events hosted in Seville, including the Investing Forum in Raw Materials (IFRM-SEISA) and Clustering in European Innovation for Sustainable Practices (CEISP), offered SMEs direct access to funding opportunities, sustainability advisory services, and collaboration with large enterprises and public authorities. These sessions created spaces for dialogue and networking, which were tailored to SME needs—particularly in understanding European funding instruments (e.g., Horizon Europe, EIC Accelerator, LIFE) and aligning with sustainability business models. These events ensured that regional SMEs were central actors in shaping Andalucía's innovation and sustainability agenda.

From a policy perspective, Junta de Andalucía has provided dedicated funding lines and administrative support for SME for R&D and demonstration projects, further encouraging adoption of green technologies. The strategic recognition of sustainable mining projects, such as E-LIX, has created a mobilized effect, increasing SME interest in circular mining, waste valorisation, and critical raw material recovery.

Circular Economy Implementation:

Andalucía has taken concrete and ambitious steps toward implementing circular economy principles within the mining and raw materials sectors. The region's RIS3 strategy explicitly integrates sustainability and circularity as cross-cutting priorities, and this has been effectively operationalised through initiatives under the I4-GREEN project, particularly via the E-LIX pilot plant in Riotinto. This pilot embodies the circular economy approach by demonstrating how critical and strategic raw materials can be recovered more efficiently, while simultaneously reducing waste, energy use, and environmental impact.

The E-LIX process overcomes a significant technical barrier in sulphide processing—passivation—and enables the sustainable hydrometallurgical extraction of copper and zinc, with the ability to recover other metals such as silver, lead, and platinum group elements (PGMs). By valorising penalising elements like arsenic or bismuth—which are often discarded as waste—into marketable by-products, the E-LIX system transforms typical liabilities into assets. This not only supports the EU's objectives on waste reduction and resource efficiency but also extends the life of existing mines from 13 to 60 years, creating new circular business opportunities and reducing the need for new extractive operations

Regional policies increasingly prioritise circular economy goals, but broader industry alignment is still required. Collaboration with leading regions and uptake of European best practices would help mainstream circular solutions at the SME and cluster levels.

3.3. EXTREMADURA

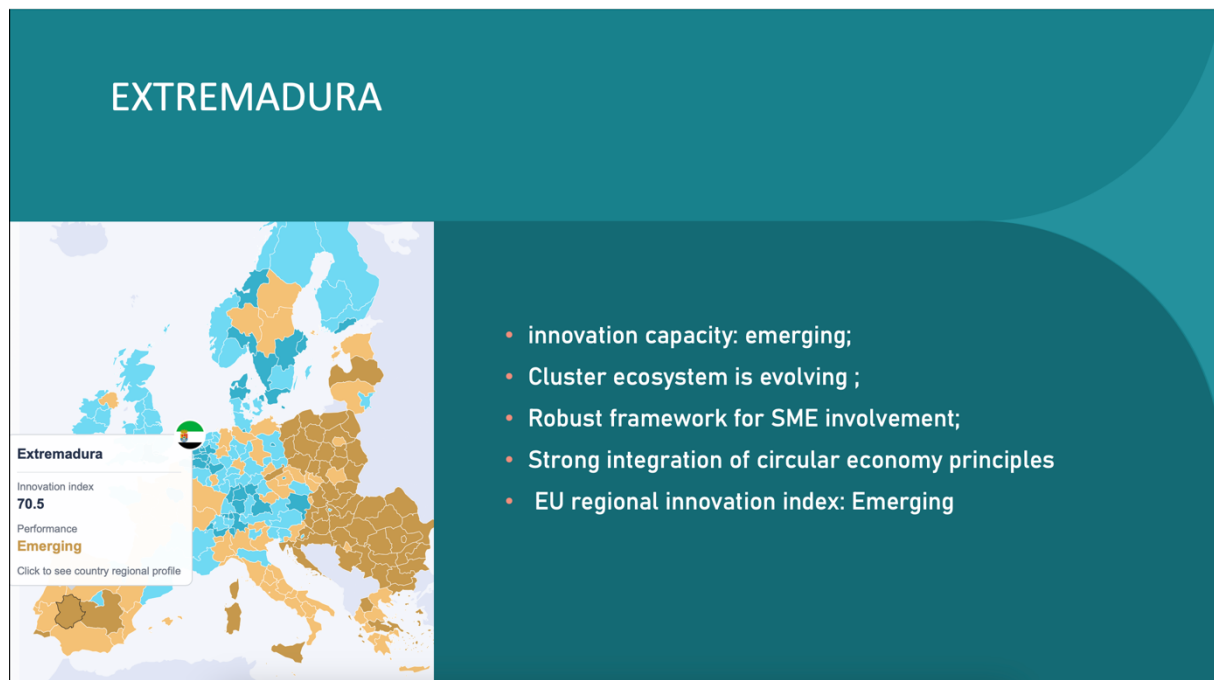

FIGURE 3: EXTREMADURA SNAPCHOT– SNAPSHOT DEVELOPED USING INFORMATION FROM THE RESULTS OF I4GREEN, THE REGIONAL INNOVATION INDEX AND RIS3 EXTREMADURA

Innovation Capacity

Extremadura is in the early stages of developing its innovation ecosystem in the raw materials and sustainability sectors. While the region possesses significant geological resources and mining potential, it lacks widespread participation in EU-level innovation projects compared to leading regions. Initial steps have been taken to integrate innovation goals through regional smart specialisation strategies (RIS3 Extremadura), which focus on natural resources and sustainability.

Academic institutions such as the University of Extremadura (I4—GREEN Associated Partner) are gradually increasing their involvement in applied research related to mining and environmental sustainability. However, limited innovation infrastructure and lower absorption of R&D funding remain challenges.

This capacity for innovation is supported by a favorable institutional and policy environment. The RIS3 Extremadura 2027 strategy explicitly prioritizes circular economy principles, green energy development, and the valorization of raw materials. These focus areas are embedded in the region's broader economic transformation agenda and reflect a strong alignment with EU sustainability and cohesion policies.

The innovation ecosystem in Extremadura includes several key actors. Organizations such as FUNDECYT-PCTEX and CICYTEX facilitate research-industry collaboration and support technology transfer. The University of Extremadura (UEx) and centers like CENTA contribute scientific expertise in environmental technology, clean energy, and biotechnology. Additionally, specialized infrastructures like the Centro de Cirugía de Mínima Invasión Jesús

Usón (CCMIJU) and the supercomputing facility CÉNITS-COMPUTAEX enhance the region's capacity for advanced technological development, including simulation, testing, and life cycle assessment.

Extremadura is also improving its capacity to access European funding through initiatives such as Horizon Europe, LIFE, and EIT RawMaterials. Mechanisms like cascade funding within the I4-GREEN project have been particularly effective in involving local SMEs in innovation processes related to sustainability and raw materials.

In the framework of the I4-GREEN project, Extremadura's innovation capacity in the raw materials and sustainability sectors can be described as emerging but increasingly strategic. The region has made notable progress by hosting one of the project's most significant pilot initiatives—the IHO pilot—which served as a testbed for circular processing technologies. Through this pilot, Extremadura demonstrated its ability to recover high-grade iron ore (71% Fe) and extract rare earth elements (REEs) from process tailings with concentrations reaching 17,000 ppm TREO. These achievements were integrated into a circular plant design that prioritized renewable energy use and a closed water cycle, aligning strongly with sustainability goals.

The regional innovation landscape lso suffers from fragmentation, with limited coordination between actors and relatively low integration of SMEs in advanced research and development efforts. Many smaller companies lack the internal resources needed to lead or scale technological innovations, especially in capital-intensive sectors like mining and materials processing.

Cluster Ecosystem Maturity

Cluster development in Extremadura is currently limited, with few formalised cluster organisations focused on raw materials or circular economy. Some regional initiatives are being supported by chambers of commerce and innovation agencies, but inter-cluster and inter-regional coordination mechanisms are still developing. There is potential for greater alignment with national innovation policies and for the formation of a dedicated sustainable mining or materials cluster.

The I4-GREEN facilitated this growth by integrating cluster organizations and networks into a structured process of knowledge exchange, capacity building, and matchmaking. This was particularly evident in the Emulation Sessions and the Sustainable Practice Exchange Platform, where clusters like ISMC, and ACPMR, acted as intermediaries between SMEs, technology providers, research centers, and end users.

SME Engagement and Adoption

SME engagement in sustainability innovation is still emerging. SMEs in Extremadura tend to operate in traditional sectors with low digitalisation and limited awareness of EU funding instruments. Nevertheless, pilot participation in regional calls and increased outreach by support agencies are improving conditions for SME engagement. Capacity-building programs and partnerships with technology providers could help enhance SME innovation adoption.

Extremadura's participation in I4-GREEN included hosting the IHO pilot, which served as a concrete example of how SMEs can be integrated into innovative, circular industrial

processes. This pilot, focused on the combined sustainable recovery of iron ore and rare earth elements (REEs), created a framework where regional SMEs were can be technology adopters.

<u>Circular Economy Implementation</u>

The integration of circular economy practices is currently minimal, though regional policies are beginning to incorporate resource efficiency targets. Pilot actions in industrial symbiosis and waste valorisation are in planning stages. Further efforts are needed to embed circularity into industrial and SME strategies. Strategic collaboration with regions like Castilla y León could provide a blueprint for implementing scalable circular economy initiatives.

In the Framework of I4-GREEN, the IHO pilot focused on the circular recovery of iron ore and rare earth elements (REEs) from both primary deposits and mining tailings. The process design included a closed-loop water system, the integration of renewable energy, and the reuse of tailings in construction materials and cement plants—effectively reducing final waste while generating new value streams. This approach demonstrated how former mining waste can become a secondary resource, reinforcing the EU's strategic goals for raw material self-sufficiency and industrial decarbonization.

3.4. ALENTEJO

FIGURE 4: ALENTEJO SNAPCHOTT- SNAPSHOT DEVELOPED USING INFORMATION FROM THE RESULTS OF I4GREEN, THE REGIONAL INNOVATION INDEX AND RIS3 ALENTEJO

Innovation Capacity

Alentejo is an emerging region in the area of sustainable raw materials innovation. While it has notable geological potential and ongoing mining activity, the region has yet to fully capitalize on EU research and innovation funding opportunities. Institutions such as the Cluster Portugal Minerral Resources (ACPMR), University of Évora and regional development agencies are beginning to develop initiatives tied to the green transition, including sustainability-focused research and innovation hubs.

There is growing alignment with the portuguese national Smart Specialisation Strategy (S3) and interest in participating in transregional projects, but regional coordination and visibility in European innovation platforms remain limited.

Includes platforms like PACT, VALORIZA, LITHOS, and CEGMA, promoting R&D, tech transfer, and business development.

The innovation capacity of the Alentejo region under the I4-GREEN project results from a strategic alignment between its regional smart specialisation strategy (EREI2030), its active participation in interregional cluster collaboration, and its potential to replicate sustainable technologies piloted in other regions of the project.

Alentejo's in I4-GREEN is represented through the Cluster Portugal Mineral Resources (ACPMR). The region has been actively engaged in cross-border initiatives such as CEISP (Clustering in European Innovation for Sustainable Practices) and IFRM-SEISA (Investing Forum in Raw Materials), strengthening collaboration with other European and Iberian regions. Through these activities, Alentejo is positioned as a strategic territory for deploying and replicating sustainable raw materials technologies validated in other parts of Europe.

One of the most significant outcomes of this positioning is the planned replication of the E-LIX pilot, initially developed in Andalucía, in mineral deposits located in Alentejo. The E-LIX technology is based on a green hydrometallurgical process for the recovery of metals such as copper, zinc, and cobalt. Its validation at industrial level has demonstrated a potential reduction of up to 90% in CO_2 emissions, circular valorisation of tailings, and improved resource efficiency. Replicating this technology in Portugal is expected to enable further environmental improvements and the expansion of a sustainable metallurgical value chain in Southern Europe.

Alentejo's specialization is structured around domains that include critical technologies, energy, and intelligent mobility, as well as agrifood and forest resources, cultural heritage and creative industries, and natural resources and environmental services. These domains reflect an integrated approach to sustainability, aligning with European objectives for decarbonization, circular economy, and responsible land use. The region has made sustainability a central principle of its strategic development, particularly relevant to the mining and industrial sectors.

Within the I4-GREEN project, Alentejo plays a role as one of the replication regions. While not as advanced in pilot deployment as other regions like Andalucía or Extremadura, it offers significant potential for scaling circular mining solutions. The region benefits from strategic mining sites such as Neves-Corvo and Aljustrel, which are considered ideal for demonstrating sustainable mining technologies. Alentejo's involvement in the Smart

Specialisation Platform (S3P) adds to its emerging innovation maturity and aligns it with broader European innovation networks.

However, Alentejo also faces several challenges that limit its innovation capacity. The regional innovation ecosystem remains fragmented, with limited integration of small and medium-sized enterprises (SMEs) into research and development activities. There is a need for greater infrastructure to support testing and deployment of new technologies, as well as more cohesive coordination among academic institutions, industry, and public actors.

Despite these gaps, Alentejo is well-positioned to benefit from cross-border collaboration with neighboring regions such as Andalucía and Extremadura. The I4-GREEN initiative provides an important opportunity for Alentejo to engage in joint research projects, technology transfer, and the development of co-financed innovation strategies. Through this collaboration, the region can contribute to and benefit from a pan-European innovation ecosystem for sustainable and circular mining, helping to position itself as a significant actor in the EU's green and digital transitions.

Cluster Ecosystem Maturity

Alentejo's cluster ecosystem maturity is best described as developing, with clear signs of structured growth but not yet fully consolidated. The region possesses several foundational elements necessary for a mature cluster environment—such as active research centers, strategic industrial assets like the Neves-Corvo and Aljustrel mining sites, and increasing engagement in European initiatives like I4-GREEN and the Smart Specialisation Platforms (S3P).

The Cluster Portugal Mineral Resources (ACPMR) plays an important role in supporting the emerging cluster ecosystem in Alentejo, particularly by acting as a national-level integrator and promoter of innovation, sustainability, and internationalization in the mineral resources sector.

In the context of Alentejo, ACPMR contributes by fostering connections between local mining operations (such as Neves-Corvo and Aljustrel), SMEs, and research institutions, helping to create a more cohesive innovation environment. It promotes circular economy practices, supports digital and green transition agendas, and facilitates participation in European initiatives like I4-GREEN, where Alentejo is a key replication region.

Through its network and technical platforms, the cluster also helps Alentejo stakeholders gain access to funding, international markets, and cross-border cooperation. Its involvement strengthens the regional ecosystem by introducing best practices, technological know-how, and structured governance models.

In the Framework of I4-GREEN, the cooperation between the Cluster Portugal Mineral Resources (ACPMR) and the Iberian Sustainable Mining Cluster (ISMC), have demonstrated advanced organisational structures, clear governance models, and robust engagement in regional RIS3 priorities. The participation in the European Strategic Cluster Partnerships (ESCP-S3) framework further underscores their maturity, allowing them to function as facilitators of innovation-driven investments and cross-border value chains.

SME Engagement and Adoption

SMEs in Alentejo are primarily active in traditional sectors, including quarrying, agriculture, and light manufacturing. While the awareness of sustainability goals is increasing, active participation in innovation projects is still limited. Some SMEs have begun participating in capacity-building activities and national innovation programs promoted by IAPMEI and ANI (Agência Nacional de Inovação).

A more systematic integration into EU-supported platforms like MINE.THE.GAP or Horizon Europe calls would allow these companies to upgrade processes and adopt circular economy practices. Regional support services should aim to simplify access to innovation funding and provide hands-on assistance with proposal development and technology scouting.

The engagement and adoption of innovation in Alentejo, particularly within the scope of the I4-GREEN project, remain areas of emerging development with both potential and structural challenges. Small and medium-sized enterprises in the region are crucial players in the raw materials and industrial value chains, but their integration into research and innovation activities is still relatively limited. Many SMEs face barriers such as lack of financial resources, limited internal R&D capacity, and a shortage of skilled personnel capable of implementing advanced technologies or sustainable practices.

Despite these limitations, there are encouraging signs of progress. Alentejo's participation in interregional initiatives like I4-GREEN and its involvement in Smart Specialisation Platforms (S3P) have opened new pathways for SMEs to access innovation ecosystems and collaborative networks. These initiatives promote knowledge transfer, encourage the uptake of circular economy practices, and create opportunities for SMEs to engage in technology demonstration projects, particularly in the context of sustainable mining and resource efficiency.

One of the key strategies for improving SME engagement has been the support for testbeds, demonstration sites, and open innovation calls that encourage companies to pilot and adopt sustainable solutions. This is evident in the structure of the I4-GREEN project, which actively involves SMEs in replication activities and cluster interactions. By participating in cross-border cooperation and cluster-driven actions, SMEs in Alentejo are gradually becoming more exposed to innovative practices and can better align with EU-wide green transition objectives.

To translate these efforts into widespread adoption, there is a need for stronger policy support, targeted funding instruments, and enhanced advisory services tailored to the specific needs of SMEs. This includes easier access to financing, incentives for innovation adoption, and training programs to build technological and digital capacities within small enterprises. Improving the coordination between universities, research centers, and the business sector is also essential to ensure that innovation is not only generated but also diffused effectively across the regional economy.

Circular Economy Implementation

Circular economy implementation in Alentejo is a strategic priority under the region's EREI2030 strategy and is closely aligned with the goals of the I4-GREEN project. The region views the circular economy not just as an environmental imperative, but as a transformative

opportunity to boost competitiveness, create value from waste and secondary resources, and foster industrial innovation—especially in sectors like mining, agriculture, and construction materials.

Alentejo has begun to adopt circular economy principles in its regional development planning, with specific emphasis on the valorization of natural resources, reduction of waste, and reuse of by-products. In the raw materials sector, this has translated into increasing interest in sustainable mining practices, including the recovery of critical raw materials from tailings, improved resource efficiency, and the potential use of mining waste in construction and other downstream applications.

Through its participation in the I4-GREEN project, Alentejo is exploring ways to replicate successful circular mining models demonstrated in other partner regions. Although it does not currently host one of the main industrial pilots, Alentejo's role as a replication territory means it benefits from shared knowledge, technical tools, and cross-regional collaboration. This includes opportunities to implement tested solutions in local sites such as Neves-Corvo or Aljustrel, which are key locations with active mining operations and potential for circular innovation.

The region also emphasizes cross-sectoral collaboration to implement circular principles. Institutions such as universities, research centers, and technology parks play a growing role in identifying synergies between sectors. Initiatives promoting bio-based innovations, digital transformation, and eco-design are increasingly being integrated into regional programs: the RISE and EMRIE projects, both interregional and involving the Cluster Portugal Mineral Resources, SMEs and public entities from the Alentejo region, as well as universities.

Nevertheless, there are barriers that need to be addressed. These include gaps in infrastructure for material sorting and recycling, limited awareness or technical capacity among smaller firms, and the absence of large-scale industrial symbiosis platforms. Policy support is critical in this regard, and Alentejo's smart specialization strategy outlines the need for investment in innovation infrastructure, regulatory incentives, and capacity building for circular business models.

3.5. REGIONAL BENCHMARKING FOR SUSTAINABLE RM – A COMPARATIVE ANALYSIS OF I4-GREEN TERRITORIES

Based on the previous analysis of the four regions involved in the I4-GREEN project, the following comparation can be drawn:

Category	Castilla y León	Andalucia	Extremadura	Alentejo
Innovation Capacity	Strong innovation ecosystem, EU project participation, circular mining pilots	Growing capacity, notable E-LIX pilot, increasing EU engagement	Emerging innovation, IHO pilot success, limited R&D absorption	Emerging region with replication potential, strategic alignment with EREI2030
Cluster Ecosystem Maturity	High maturity with strong governance and inter-cluster coordination	Maturing ecosystem, needs structured governance for circular mining	Early stage with few formal clusters, growing via I4-GREEN involvement	Developing ecosystem led by ACPMR, engaging in EU platforms
SME Engagement and Adoption	Robust SME engagement, supported by funding and innovation tools	High SME engagement through I4-GREEN and EU matchmaking platforms	Emerging SME engagement, catalyzed by cascade funding and pilot roles	Limited SME participation, but improving through EU and national instruments
Circular Economy Implementation	Advanced circular practices, policy alignment with EU goals	Operational circular economy via E-LIX, but industry-wide adoption is ongoing	Minimal but progressing through IHO pilot and policy frameworks	Strategic priority under EREI2030, leveraging replication of circular mining models
Alignment with RIS3	Directly supports RIS3 2025–2027 with decarbonisation and circularity priorities	Andalucia prioritizes sustainable mining and interregional cooperation	RIS3 2027 - raw materials in circular economy and green transition	EREI2030 - mineral resources in a cross-sectoral sustainability model

TABLE 1: TABLE SUMMARIZING THE BENCHMARKING INSIGHTS FOR THE FOUR I4-GREEN REGIONS—CASTILLA Y LEÓN, ANDALUCÍA, EXTREMADURA, AND ALENTEJO

The I4-GREEN project brings together four regions—Castilla y León, Andalucía, Extremadura, and Alentejo—that, while at different stages of development, present complementary strengths in fostering sustainable and circular mining practices.

Castilla y León emerges as the most mature region, with a strong innovation ecosystem anchored by entities like ICAMCyL. It has demonstrated leadership in EU-funded projects and advanced circular economy implementation, making it a reference point for sustainable raw materials innovation. The region's strategic alignment with its RIS3 2025–2027 strategy reinforces its role as a driver of green industrial transformation.

Andalucía is rapidly strengthening its innovation capacity, especially through the E-LIX pilot at Riotinto, which positions the region at the forefront of circular hydrometallurgy. Its active SME involvement and commitment to environmental sustainability are noteworthy, though its cluster governance could benefit from further formalization. Nonetheless, Andalucía's alignment with its RIS3 strategy and increasing EU-level engagement make it a key regional player.

Extremadura, while less developed in terms of innovation infrastructure and private R&D, is making important strides through the Iron Holm Oak (IHO) pilot. This initiative has helped demonstrate the region's capacity for circular processing and rare earth recovery. Extremadura's RIS3 2027 strategy supports this direction, embedding mining within broader themes like the circular economy and green transition.

Alentejo plays a vital role as a replication region, with promising sites like Neves-Corvo and Aljustrel and a regional strategy (EREI2030) that integrates sustainability and innovation. The region benefits from ACPMR's coordination but still faces challenges related to SME engagement, infrastructure, and visibility within EU innovation platforms. Despite this,

Alentejo is well-positioned to scale tested solutions and strengthen cross-border collaboration.

In summary, Castilla y León and Andalucía bring mature and tested innovation models, while Extremadura and Alentejo offer fertile ground for replication and the development of innovation ecosystems. Within the framework of I4-GREEN, supported by the Interregional Innovation Investments (I3) Instrument under EISMEA, these regions actively collaborate to foster interregional cooperation, enhance ecosystem maturity, and scale sustainable technologies. This coordinated effort reinforces the creation of a resilient and circular raw materials economy across Southern Europe, aligned with the EU's green and digital transition goals.

4. ACTION PLAN FOR CLUSTER DEVELOPMENT UNDER THE I4-GREEN PROJECT

The I4-GREEN action plan for cluster development outlines a strategic, interregional roadmap to foster sustainable raw materials value chains through enhanced cluster coordination, innovation, replication of green mining pilots, and deployment of smart specialization strategies. Grounded in the the Quadruple Helix model—industry, government, academia, and civil society—the plan target four key regions of the project: Andalucía, Extremadura, Castilla y León(Spain) and Alentejo (Portugal).

The strategic objectives are (aligned with the regional benchmarking carried out previously):

- **Strengthen regional clusters for raw materials innovation:** reinforce especialized regional clusters in the raw materials and mining sector that function as dynamic ecosystems of innovation, collaboration, and competitiveness. These clusters should bring together companies (particularly SMEs), research and technology organizations, universities, public authorities, and civil society actors to co-develop and implement sustainable solutions for mineral extraction, processing, recycling, and circular economy practices.
- **Promote replication of circular mining pilots across eu regions:** to extend the impact of the successful pilot projects developed under the I4-GREEN initiative—IHO Pilot and E-LIX Project—by replicating their circular and sustainable mining technologies in other regions across Europe.
- **Foster cross-border and intersectoral cooperation through the Quadruple Helix**: create strong, collaborative partnerships across borders and sectors to drive innovation and sustainable transformation in the raw materials sector. It is grounded in the Quadruple Helix model.
- **Align regional development with smart specialisation strategies (RIS3) and the EU Green Deal**: ensure that the development of regional raw materials ecosystems—through innovation, investment, and pilot replication—is fully aligned with each region's Smart Specialisation Strategy (RIS3) and contributes directly to the broader goals of the EU Green Deal.

- **Mobilize investment and funding for sustainable cluster Growth:** attract and unlock financial resources—from both public and private sources—to support the growth, scaling, and long-term sustainability of regional raw materials clusters.

These objectives are designed to transform regional strengths into interregional leadership in sustainable mining and raw materials supply, contributing to Europe's green and digital transition. It supports the development of a transnational cluster ecosystem for sustainable raw materials in the I4-GREEN regions—Andalucía, Extremadura, Castilla y León, and Alentejo—by scaling innovation, fostering replication, and aligning with EU and RIS3 strategies.

4.1. ACTIONS

4.1.1. Regional cluster structuring and innovation activation

I.   <u>Reinforce raw materials clusters in each I4-GREEN region:</u>

Reinforcing existing clusters, such as the Iberian Sustainable Mining Cluster (ISMC) in Spain and Cluster Portugal Mineral Resources (ACPMR) in Portugal, means building upon the institutional and organizational foundations that are already in place to expand their impact, improve coordination, and strengthen their strategic roles in the raw materials ecosystem.

In the case of Iberian Sustainable Mining Cluster (<u>ISMC</u>), which already brings together mining companies, technology developers, and innovation partners in Spain, the reinforcement involves deepening its alignment with regional RIS3 priorities, expanding its membership base to include more SMEs, and upgrading its services to support innovation, circular economy integration, and EU project participation. This may also include stronger connections with universities, local administrations, and civil society to operate as a full quadruple helix platform.

The Cluster Portugal Mineral Resources (ACPMR), plays a strategic part in the development of sustainable raw materials value chains in Portugal. ACPMR already is a national-level cluster that unites companies, research centers, universities, and public institutions in the mineral resources sector, covering both upstream and downstream activities—from extraction to processing, valorization, and recycling.

In the context of the I4-GREEN project, reinforcing ACPMR means integrating its expertise, partnerships, and innovation capacity into regional efforts in Alentejo, particularly in alignment with the goals of the EREI2030 strategy. As a recognized actor in European initiatives, ACPMR act as a bridge between local stakeholders, like those coordinated by ADRAL, and broader European platforms such as the European Cluster Collaboration Platform (ECCP), EIP European Innovation Partneship for Raw Materials, and Thematic Smart Specialisation Partnerships;

This reinforcement involve formal participation in Interregional Projects, co-leadership in EU project proposals, and support for SME engagement in innovation and sustainability actions.

By strengthening these clusters, I4-GREEN creates a coordinated network of raw materials clusters capable of driving both regional transformation and Europe-wide collaboration, advancing the goals of the EU Green Deal and the Critical Raw Materials Act.

II.   <u>Quadruple Helix stakeholder initiatives</u>

In practice, the Quadruple Helix Stakeholder initiatives means inviting regional stakeholders—such as SMEs, mining companies, universities, innovation agencies, local governments, NGOs, and environmental groups—to participate in regular workshops, roundtables, and collaborative design sessions.

Throughout the project, several high-impact events embodied the Quadruple Helix Stakeholder initiatives: The Spring and Autumn Raw Materials Innovation Summits (SRMIS and ARMIS); The Investing Forum on Raw Materials (IFRM-SEISA); Clustering in European Innovation for Sustainable Practices (CEISP).

Together, these activities form the operational backbone of the I4-GREEN Quadruple Helix Stakeholder They contribute to building trust, shaping innovation agendas, and guiding the deployment of sustainable mining technologies through a shared and coordinated approach across the I4-GREEN regions.

Expanding the scope of the Quadruple Helix Stakeholder Forum beyond national borders it is also important, include clusters and innovation actors from other European countries to n bring added value to regional cluster development and ensure the sustainability of project. supports the alignment of regional strategies with European priorities.

In the Alentejo region, the results will be disseminate in the PlaCaPRe, an innovative regional initiative designed to strengthen local production chains by leveraging the region's territorial assets and promoting sustainable development. PlaCaPRe is structured around working groups focused on four strategic areas that are highly relevant to the I4-GREEN project: sustainable bioeconomy, sustainable energy, and mobility and logistics. The initiative also incorporates important transversal themes such as digitalization and the circular economy, ensuring that innovation is both resilient and aligned with long-term sustainability goals.

By aligning with PlaCaPRe, the results of I4-GREEN will be able to benefit from an existing collaborative platform that already promotes knowledge sharing and the activation of regional value chains. This synergy will help identify and structure strategic projects that are aligned with the regional smart specialisation strategy, EREI2030. In doing so, it supports raw materials innovation that connects with key economic sectors such as energy and logistics, while contributing to broader goals of regional sustainability and economic transformation. ACPMR is co-coordinator entity of PlaCaPre platform in Alentejo region. The I4Green results will be used as a Best Practice for Mining and Regions under this platform.

4.1.2. Pilot Replication and Scaling:

I.   <u>Deploy validated sustainable mining Technologies:</u>

Deploying validated sustainable mining technologies refers to the process of taking innovative methods and systems that have already been tested and proven in pilot environments—those developed under the I4-GREEN project—and applying them in real-

world operational settings to enhance the sustainability and efficiency of raw materials extraction and processing.

This includes technologies like rare earth element (REE) recovery from mining waste and tailings, as demonstrated in the IHO (Iron Holm Oak) pilot, and hydrometallurgical processes, such as the E-LIX project, which enables the extraction of valuable metals like copper, zinc, and cobalt from low-grade ores using environmentally friendly chemical solutions. These technologies are considered "validated" because they have undergone feasibility testing, proven their technical and environmental benefits, and demonstrated economic potential at a pre-industrial scale. In addition, work has been done by the pilot leaders on an industrialisation plan to be implemented in the short-medium term.

The goal of deploying these solutions is to reduce the environmental footprint of mining operations, minimize waste, improve resource efficiency, and contribute to the circular economy. This also supports the EU's strategic goals of reducing dependence on critical raw materials imports and ensuring a more resilient and sustainable supply chain for green and digital transitions. In practical terms, deployment involves integrating these technologies into existing or new mining sites, supported by investment, local stakeholder engagement, and regulatory alignment.

II.   Prioritize replication at 24 pilot sites across I4-GREEN regions

The identification and prioritization of 24 replication-ready sites for the IHO and E-LIX pilot technologies across the I4-GREEN regions represents a strategic action aimed at scaling up sustainable mining practices and circular economy solutions in Southern Europe. These sites are distributed across the regions of Andalucía, Extremadura, Castilla y León (Spain), and Alentejo (Portugal), each of which holds significant geological and industrial potential for raw materials development aligned with the objectives of the EU Green Deal and the Critical Raw Materials Act.

The prioritization process considers socio-economic and environmental factors, including local employment needs, regional development strategies, and environmental rehabilitation goals. This ensures that the replication of the pilots contributes not only to innovation and raw materials supply, but also to regional transformation and sustainability.

III.   Support regions in submitting investment projects under I3, Horizon Europe, and Interreg

Supporting regions in submitting investment projects under I3, Horizon Europe, and Interreg involves helping regional stakeholders—such as public authorities, clusters, research institutions, and SMEs—prepare and submit strong, competitive proposals for European funding that align with their innovation priorities and the objectives of the I4-GREEN project.

This support includes a combination of strategic, technical, and organizational assistance to ensure that regional actors are not only aware of funding opportunities, but also capable of forming consortia, designing eligible projects, and navigating the often-complex application procedures.

By supporting regions, Clusters helps unlock significant investment for sustainable raw materials innovation, accelerates the replication of pilot technologies, and strengthens interregional cooperation through well-funded, well-managed projects.

Project as I4-GREEN and RISE (Raw materials Innovation for Sustainable Europe) under I3 instrument are good examples of how regional actors can effectively collaborate and access European funding to promote innovation in the raw materials sector. One of RISE's main achievements was supporting the alignment between regional innovation priorities and EU-level strategic objectives, such as the Green Deal and the Circular Economy Action Plan. Through structured exchange of experiences, peer learning workshops, and interregional policy dialogues, the project enabled participating regions to design more impactful public policies and investment frameworks for sustainable resource

4.1.3. Knowledge Exchange and Cross-Fertilisation

I.   <u>Promote best practices through the EU database and platforms:</u>

The main platforms alignement with the objectives of I4-GREEN are:

- S3 Platform (Smart Specialisation Platform): this platform supports regions in developing and implementing their RIS3 strategies. Sharing I4-GREEN outcomes here helps align project results with regional innovation policies and promotes interregional cooperation on shared specialisation areas.
- European Cluster Collaboration Platform (ECCP): This is the central hub for European clusters. By uploading I4-GREEN best practices related to cluster governance, SME engagement, or pilot scaling, the project contributes to strengthening Europe's cluster community and increasing visibility for participating regions.
- EREK (European Resource Efficiency Knowledge Centre): This platform focuses on circular economy and resource efficiency solutions. Documenting I4-GREEN's sustainable processing technologies, such as REE recovery or hydrometallurgy, provides actionable knowledge for other stakeholders working on similar challenges.
- CORDIS (Community Research and Development Information Service): For results that have strong research and innovation components, particularly under Horizon Europe or other EU-funded programmes, CORDIS offers a repository where technical reports, summaries, and outputs can be made publicly available.
- EIT: The platform of the European Institute of Innovation and Technology (EIT) operates through its Knowledge and Innovation Communities (KICs), which are partnerships uniting businesses, research institutions, and universities to collaboratively address major societal and technological challenges through innovation.

ICAMCYL, ISMC, and the ACPMR actively participate in both the European Cluster Collaboration Platform (ECCP) and the Smart Specialisation Platform (S3platform), reinforcing their commitment to interregional cooperation, sustainable innovation, and strategic development in the raw materials sector.

By promoting best practices through these platforms, I4-GREEN not only supports knowledge transfer and capacity building but also increases the project's policy relevance, enhances its impact at the EU level, and creates opportunities for new partnerships. It ensures that the innovations developed in the project do not remain isolated but are used to inform, inspire, and strengthen sustainable raw materials development across Europe.

II.   Promote best practices through networks:

By promoting best practices through networks such the Industrial Alliance for Circular Economy, EIT RawMaterials, European Innovation Partnership on Raw Materials, and the Circular Cities and Regions Initiative, among others, I4-GREEN ensures that its contributions go beyond project boundaries. This helps reinforce the role of regions like Andalucía, Extremadura, Castilla y León, and Alentejo as active contributors to Europe's green industrial transformation, while opening the door to future collaboration, policy alignment, and funding opportunities.

III.   Investment Mobilization:

EU tools like LIFE+, the European Regional Development Fund (ERDF), the ETS Innovation Fund, and the Just Transition Fund can be available European financial instruments to support the implementation, replication, and scaling of sustainable raw materials innovation—the technologies and strategies developed through the I4-GREEN project.

Each of these tools offers specific types of support that can directly contribute to the goals of I4-GREEN, especially in areas such as green technology deployment, environmental protection, circular economy practices, and regional economic transformation. (see D5.3)

Action plan summary:

The following table sumarizes the actions linked to the type of key performance indicator (KPI) that can be used to monitor progress. Each action is associated with a clear impact, showing how it contributes to the broader goals of the I4-GREEN Project.

Activity	Suggested KPIs	Impact
A1.1: Reinforce raw materials clusters in each I4-GREEN region	Number of members per cluster (including SMEs, RTOs, universities, public bodies) Number of governance structures created (e.g., steering committees, working groups) Number of staff trained in cluster management and coordination Number of stakeholder meetings or workshops held	Stronger regional innovation ecosystems and improved stakeholder coordination
A 1.2: Quadruple Helix Stakeholder Initiatives	Number of forums held, stakeholder participation rate	Enhanced stakeholder engagement, inclusiveness, and policy relevance
A2.1: Deploy validated sustainable mining Technologies	Technologies deployed, recovery rates, emissions reduced	Reduction of environmental footprint, increased resource efficiency
A2.2: Prioritize replication at 24 pilot sites across I4-GREEN regions	sites identified and replicated	Acceleration of pilot deployment and better investment targeting
A2.3: Support regions in submitting investment projects under I3, Horizon Europe, and Interreg	Proposals submitted, partners engaged	Improved regional access to EU funding and increased project quality
A.3.1: Promote best practices through theEU database and platforms:	best practices uploaded, platforms engaged	Wider dissemination of I4-GREEN results and influence on EU policy
A.3.2: Promote best practices through networks	Number of best practices shared through external networks or alliances Number of European networks or alliances formally engaged	Increased visibility of I4-GREEN regions and Clusters at the European level
4. Investment Mobilization	Funding leveraged	Expanded financial support for green transition and industrial innovation

TABLE 2: ACTION PLAN SUMMARY

5. CONCLUSIONS

This report began with the analysis of the regional innovation ecosystems within the I4-GREEN tregions, offering a comparative benchmarking of Castilla y León, Andalucía, Extremadura, and Alentejo. While each region is at a different stage of cluster development and innovation maturity, they collectively demonstrate strong potential to lead Europe's transition toward a more sustainable and circular raw materials economy.

Castilla y León stands out with a mature innovation ecosystem, advanced circular economy integration, and strategic leadership in EU-funded initiatives. Andalucía has demonstrated high technological readiness, particularly through the E-LIX pilot, and growing cross-sectoral collaboration, supported by policy and SME engagement. Extremadura, although still developing its innovation capacity, has made significant strides through the Iron Holm Oak pilot, showcasing its potential to contribute to critical raw materials recovery. Alentejo, as a replication region, has aligned its regional strategy (EREI2030) with EU sustainability goals and is positioned to adopt and scale circular mining technologies in collaboration with European partners.

The benchmarking insights are the base for I4-GREEN action plan for cluster development, which sets out clear strategic objectives and priority actions rooted in the quadruple helix model and smart specialisation. These include the reinforcement of regional clusters, deployment and replication of validated technologies, stakeholder engagement, cross-border partnerships, and alignment with European funding and policy frameworks.

By implementing this plan, the I4-GREEN regions will strengthen their roles as innovation hubs in the raw materials value chain. The actions are designed not only to generate measurable regional impacts—such as increased SME participation, improved governance, and pilot replication—but also to contribute to broader European goals, including the Green Deal, the Critical Raw Materials Act, and the development of strategic value chains.

Through platforms like the European Cluster Collaboration Platform, the S3 Smart Specialisation Platform, and networks such as the Industrial Alliance for Circular Economy, I4-GREEN will ensure that its results are disseminated, scaled, and integrated into wider EU innovation ecosystems.

In conclusion, I4-GREEN represents a forward-looking, regionally grounded, and strategically aligned initiative. Its action plan is a practical roadmap for building sustainable, resilient, and interconnected cluster ecosystems that will support Europe's transition toward climate neutrality, resource independence, and inclusive growth.

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